AN INVESTIGATION INTO THE ENGINEERING OF FABRIC PROPERTIES USING FABRIC OBJECTIVE MEASUREMENT TECHNIQUES

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ABSTRACT

Objective measurement techniques have been used since the 1930's to provide a more accurate method of gauging fabric quality than subjective hand evaluations. In addition to predicting subjective hand preferences, they also provide data on fabric development and ease of garment manufacture. The main techniques researched are the Kawabata Evaluation System and the Fabric Assurance by Simple Testing. The KES has been used to evaluate suiting, women's dresses, knitted fabrics and non-woven fabrics. Research with the FAST has been limited to mainly suiting with some shirting. This has left a large area of work to be explored; whether the FAST can be used to assess fabrics for a wider range of end-uses. In this thesis, the investigation focuses on women's dress fabrics, specifically weight reduced polyester fabrics.

The FAST system was modified in order to accurately differentiate between these fabrics. The Cusick drape tester was also used and further investigations focussed on other methods of testing drape, including the Aldrich method and one developed by the author. Although early indications were that this new test was repeatable, reproducible and correlated well with the Cusick method, it required more engineering work than was possible in the scope of this thesis and therefore was not used for the empirical work. The KES equipment for tensile and shear was also used and comparison made between the results of previous studies and with results found from the FAST. Statistical analysis was used throughout to establish both the effect of the weight reduction process on the fabric and its relationship to the problems of ease of manufacture, distortion of garment measurements and garment appearance.

The modifications made to the FAST procedure and apparatus proved valid during the analysis. The effect of the weight reduction process was to soften the fabric, reducing the drape coefficient and bending and shear rigidity results and increasing the weft extension results. The appearance data could not be statistically analysed but it seemed that for the garment silhouette chosen, low or no weight reduction was required. Equations were established that predicted ease of manufacture and correlation factors were found between actual and predicted grades ranging from 0.71 – 0.87. Interestingly, one of the most powerful combinations was the basis data of weight and number of warp ends. High correlation between predicted and actual grades was also found for the distortion problem (0.86).

DEDICATION

I would like to dedicate this thesis to my family.

Life has certainly been eventful during the time I have been working on this thesis; two births, a death and a marriage.

I would like to thank you all for the support I have had throughout my life as well as during this portion of it – you make all the difference.

To my mum; a special thank you for always having faith in me and helping me to have the same and for your love and support.

To my dad; for helping me make the right decision in the first place; for your boundless love and generosity of spirit.

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CHAPTER 1 – REVIEW OF LITERATURE

1.1 Objective Measurement

1.1.1 Introduction

In order to increase the control and reliability found during fabric evaluations, many researchers since the 1930's have been developing techniques so that the individual elements of previously subjective assessments (for example, stiffness, smoothness and fullness) can be measured objectively.

This section will aim to clarify the methods available for use by the industry; the subsequent sections (1.2-1.3) will focus on how these objective methods have been used to aid engineering in the areas of garment manufacture and fabric manufacture respectively.

A fabric objective measurement system (FOM) is one that assesses a number of mechanical properties and relates these to a fabric's intrinsic quality. The properties are generally assessed at low loads and are therefore distinct from performance tests that measure a property to rupture. For example, extension is a mechanical property that is sometimes measured at a load of 100 gf/cm width in objective measurement [1]. However, in performance testing, the loads would be increased until the fabric breaks or it surpasses the particular retailer requirements, which might be between 10-20 kg. The low loads used in FOM are designed to imitate the forces fabrics undergo when subjectively handled, during manufacture and to a certain extent during wear.

The properties that have been identified through research as important are: Bending, Shear, Tensile, Compression, Surface Properties, Formability, Dimensional Stability and Drape. The discussion in this section will be separated into these areas and will focus on both the histories of their development and how the parameters are measured today. This will take into account the two FOM systems of the KES (Kawabata Evaluation System), developed in conjunction with The Textile

Machinery Society of Japan and introduced in 1972, and the FAST (Fabric Assurance by Simple Testing) developed by CSIRO (Commonwealth Scientific Industrial Research Organisation) and introduced in 1989. The final section will investigate the methods in which the parameters required for testing are chosen.

1.1.2 Bending

There is a great variation in the methods and equipment that have been used to assess the bending properties of fabrics and these will be discussed briefly. Measurements are normally carried out on samples cut in both the warp and the weft direction rather than on samples cut on the bias. Peirce developed a formula that was claimed to predict the bending lengths of bias samples from the results of measurements on samples cut in the warp and weft direction [2]. However, Cooper has stated that bending measurements taken in the two principle directions are insufficient to fully define a fabric's bending properties, as different types of variation can exist in the other directions for fabrics with similar warp and weft bending rigidities [3]. Other researchers have also measured bending parameters in the bias directions [4, 5]. Given the current increase in the number of garments cut on the bias this technique becomes more important and was investigated during empirical testing for this thesis.

1.1.2.1 Flexometer

A flexometer operates on the cantilever principle and the fact that a stiff fabric will not bend to the same extent as a soft one. The fabric, in the form of a rectangular strip, has one of the short ends clamped while the other is allowed to hang without any restriction. In the original type, as used by Peirce in one of the earliest investigations of textile mechanical properties [2], a fixed length strip was used and the bending angle produced was measured. Parameters derived from the instrument were bending length, flexural rigidity and bending modulus. Modern flexometers, called fixed-angle flexometers operate differently to those used by Peirce; the length of samples required to allow the fabric to bend to an angle of 41.5° is measured. A number of researchers [5-9], have used the flexometer technique.

A further development is found in the FAST 2, which is a fixed-angle flexometer in which a light detector, rather than visual inspection, is used to establish when the fabric has bent to the correct angle. This reduces error by removing the human judgement factor. In the FAST 2 measurement, the test is performed in both the warp and weft directions. The bending rigidity can also be calculated from these measurements provided the weight of the fabric is known. Several researchers have used the FAST-2 instrument in their research into drape and sewability [10-12].

Fixed-angle flexometers are described in both the current British Standard (BS 3356 1990) and the American Society for Testing and Materials (ASTM D1388–64 1975) methods for measuring bending length. However, it is not universally agreed to be the best method to measure the bending parameters of fabrics. Other methods of measuring bending were suggested in Peirce's original article, these include the heart-shaped loop [2]: Gaucher notes that this method is better than the cantilever process for very limp fabrics [13]. Postle agrees with the use of the cantilever method but not with the angle used, he argues that measuring at a fixed angle of 41.5° underestimates the actual bending length by 1.3% and the bending rigidity by 4% [14]. He states that this is due to an oversimplification of the formula relating bending length to the angle produced when the fabric bends under its own weight and the correct angle is 40.5°.

1.1.2.2 Bending Hysteresis

Livesey and Owen developed an instrument that enabled them to produce bending hysteresis curves [15]. A fabric specimen is taken through a bending cycle under constant curvature conditions: first moving in an anti-clockwise direction until the sample is 90° from the starting point (equivalent to a curvature of 3 cm^{-1}), then moving 180° in a clockwise direction (90° clockwise from the starting position), and finally returning it to the starting position. Measurements were taken manually at 10° intervals and the bending hysteresis curve plotted and from this the flexural rigidity, residual curvature, percentage bending recovery and the coercive couple were be determined.

The technique was further developed, firstly, through automation [16] and then by attaching it to an Instron to produce the hysteresis curve using its chart recorder [8] thereby reducing the time required for testing. Since this development several researchers have used this technique to obtain these properties [17-19].

The properties most often used are the low curvature elastic flexural rigidity (G_o), which is the purely elastic component of fabric stiffness, and the coercive couple (C_o), which is the couple required to straighten a specimen after it has been bent to a curvature of 3 cm^{-1}. It is normally considered to represent the frictional forces that prevent complete recovery but Ly disagrees with this view, arguing that the coercive couple is not just frictional [18].

1.1.2.3 Instron Tensile Testing Machine

Although originally developed as an instrument to measure tensile properties, the Instron has also been utilised to measure bending-related properties. Eeg-Olofsson developed an instrument that was used in conjunction with an Instron to measure the buckling properties of a fabric and so create load-deflection curves. He found that the buckling length was dependent on the sample length but that it was not possible to calculate the flexural rigidity from buckling measurements [20]. Lindberg also used this apparatus to measure fabric buckling [21]. He claimed that the method differs from others used for bending measurements as it establishes bending in terms of the load the fabric can withstand before buckling. This is done in both flat fabric form (plate buckling) and with the fabric curved in a perpendicular direction to the compressive force (shield buckling), such as that of the bending of a sleeve. In contrast to the results of Eeg-Olofsson, a relationship between bending stiffness and plate buckling was established.

Pan used an Instron with a compression cell attachment to measure fabric bending properties [22]. He stated that the Instron could be adapted to assess bending properties very similar to those assessed by KES (see below), and it was therefore not necessary to buy a specific FOM system.

1.1.2.4 KES - FB2

The KES equipment measures pure bending from a bending hysteresis curve and establishes the properties of bending rigidity (B) and hysteresis of bending moment (the energy loss incurred during deformation, or a measure of the residual curvature left in the fabric after bending) (2HB) [23]. A large value of 2HB indicates greater fabric inelasticity and lower elastic recovery. The two bending properties correlate well as they are affected by similar factors in the fabric [24]. Another parameter that can be obtained from the test procedure is the ratio of the bending in the warp and weft directions [25].

$$\alpha B = \frac{B_2}{B_1} \qquad \ldots[1]$$

where:
αB = bending ratio
B_2 = weft direction bending
B_1 = warp direction bending

Many researchers that have used method of testing bending to compare different finishes, to predict wear, to evaluate interlinings, to predict the appearance of garments and to correlate with drape measurements [26-31].

1.1.2.5 Comparison of KES and FAST measurements of Bending

Yick found that the bending rigidity results obtained using the KES method were between 8-39% lower than those obtained using the FAST bending meter [32, 33]. This is probably due to the different methods of assessing fabric bending in the two systems. The cantilever principle is very sensitive to the measurement of bending length and the calibration of the instrument. The KES system uses a complete bending hysteresis curve to separate the bending properties of a fabric into elastic and frictional components. Hysteresis curves are considered very important to objective measurement because textiles do not generally recover completely and the hysteresis curve measures the different path that the sample takes during recovery. In effect, bending rigidity measures the elastic component of fabric bending and bending hysteresis measures the inelastic component. The hysteresis curves available from each of the four KES-FB instruments is perhaps the greatest difference between the two measurement techniques.

1.1.2.6 On-line Bending

Zhou investigated the possibility of measuring the bending properties of fabrics on the production line rather than having to take a sample of cloth off line and potentially delay production [34].

1.1.3 Shear

Shear may be defined as "the angle of distortion (shear angle) produced when a specified couple is applied in the plane of the fabric" [21]. Two main methods have been developed to assess the shear properties of a fabric. These are pure shear measured with constant length of sample sides and shear measured by extending a bias (45° to the warp direction) tensile strip. However, variations exist within each of these methods. Cusick states that the advantage of the former method is that in the latter the tensile strip is held out to its full width near the jaws and therefore slippage of the threads (which is necessary to assess the change of angle between the threads) is prevented [35].

1.1.3.1 Pure shear with constant length of sides

This was originally measured using an apparatus in which a square specimen of fabric is sheared under tension to a particular angle in each direction, with the lengths of the sides remaining constant while the area decreases [36]. The angle used in this test varies with different researchers, and includes 15° [35], 5° [8], while the KES instrument uses an angle of 8° [37].

The KES parameter of G (shear rigidity) is obtained from the slope between $\phi = 0.5^{\circ}$ and 5°. The parameters 2HG and 2HG5 are measures of energy loss during shear deformation arising mainly from yarn-to-yarn friction at cross-over points. A large hysteresis means that greater recovery forces are required to overcome fabric internal friction. The two parameters correlate strongly with each other [24]. Different opinions exist about whether the rigidity parameter is more important than the hysteresis parameter [38] or the converse [39]. This method of shear has been used by many researchers to assess the effects finishing and dry cleaning, to evaluate lightweight polyester fabrics, and to correlate with drape measurements [39-43].

1.1.3.2 Shear measured by extending a bias (45° to the warp direction) tensile strip

Shear rigidity is defined in the FAST system as a measure of the ease with which a fabric can be deformed in its own plane in a trellising motion [1]. It is calculated from the average of the extension results in the right and left bias directions (45° and 135° to the warp) at a load of 5 gf/cm width; the lower the value the easier it is to deform or shear the fabric. The FAST measurement of shear has been used by researchers in numerous ways, including to evaluate finishes and predict problems with patterns [44, 45].

The FAST procedure for measuring shear is fixed as the FAST-3 extension meter is only able to assess the extension at three loads (5, 20, 100 gf/cm). However, the technique of using a bias strip has also been used in conjunction with a standard tensile tester (for example, an Instron). This can produce load and hysteresis curves similar to those obtained from the KES and can therefore be used to calculate the shear hysteresis and other properties identified as important by Kawabata [22].

1.1.3.3 Directional symmetry of shear measurements

There is conflicting evidence on whether shear tests need to be performed in both directions or not. Cusick found different results when fabric is sheared to the same angle in the left and right directions [35] and the FAST methodology is to use the same number of samples from both bias directions, because the results they give are not the same. However, Mahar states that during trials using the KES instruments, the correlation between the shear to the left and the right was very high ($r>0.98$) [37]. Furthermore, Yick assessed both the KES (shear at constant length of sides) and FAST (45° tensile strip) and also found that there was good correlation using both techniques between the shear results in both directions [32, 33]. The measurements for the two directions had a correlation coefficient of 0.97 with a maximum difference between the samples of 13% (KES) and 0.93 with a maximum difference of 23% (FAST). Yick concluded that these results suggested that shear testing could be restricted to measurements in one principle direction. This theory was investigating during the empirical investigation for this thesis.

1.1.3.4 Comparison of measurement of pure shear and of a 45° tensile strip

Several researchers have compared the results gained from the KES and from tensile methods of determining shear [46] [47]; other workers have included results obtained using FAST and hence have been able to compare all three methods [32, 33]. Generally, these have shown good correlation, which is surprising considering the different methods of achieving the results.

If, as was found, that the two methods produce similar results, it can be concluded the bias tensile strip would probably be the more appropriate due to its simplicity [46]. Also, it is suggested that due to the high correlation between the parameters of shear rigidity and shear hysteresis, only one of them is required to explain fabric shear [46]. However, care must be taken because research has found that the majority of fabrics gave higher results when measured by the bias extension method than using the KES method [47].

1.1.4 Tensile

Many different methods exist for the measurement of tensile properties. Some researchers prefer to assess the load required to achieve a particular extension (Peirce chose 1%) [2], whilst others preferred to assess the extension obtained with a particular load (Waesterberg chose 20 g/cm) [7]. Variables that exist for tensile measurements are sample width, gauge length and rate of extension. Unfortunately, although information about these variables is important when comparing results from different researchers, it is often omitted.

1.1.4.1 KES-FB1

The KES system uses the same instrument that measures fabric shear to assess the tensile properties. A load and recovery cycle is used to establish the properties of fabric extension at 500 gf/cm width (EM), linearity of load extension curve (LT), energy in extending fabric to maximum load (WT) and tensile resilience (RT). The ratio is often used between the fabric extension (EM) of warp and weft directions (αT), in a similar manner to the bending ratio (equation 2) [25]. Researchers that have used the KES measurement for tensile include those investigating the effect of different finishes, evaluating interlinings and yarns [48-52].

1.1.4.2 FAST - 3

The FAST method calculates extension from the percentage elongation achieved under a load of 100 gf/cm width in both the warp and weft directions. This is a much simpler test than the KES as it measures one point on the load/extension curve rather than fully characterising it. It also uses a much smaller load than the KES for the measurement of suiting (the measurement of other end-uses will be discussed below: 1.1.10). Biglia found the FAST measurement of tensile properties important to predict appearance [53], other researchers used the method to assess finishing settings and evaluate non-woven fabrics [54, 55].

1.1.4.3 Comparison of KES & FAST methods

Correlation exercises have been performed between the FAST and KES and the correlation coefficient found was excellent (0.96) [32, 33]. Although these results indicate that the tests are interchangeable care must be taken because the results showed that for less extensible fabrics the FAST produced lower results than the KES, but for easily stretched fabrics the FAST produced higher results than KES. This could be due to the difference in the sample dimensions. The KES samples have a length of 5 cm and a width of 20 cm which gives an aspect ratio of 4, while the FAST samples have a length of 10 cm and a width of 5, which gives an aspect ratio of ½. The lower the ratio the more the distribution of stress becomes non-uniform due to a waisting effect on the samples.

1.1.4.4 Standard Tensile Instruments

The tensile equipment was used to test samples prepared at 22.5°, 45°, and 67.5° to the warp [56]. The samples were subjected to a single loading and unloading cycle, with a maximum load of 100 g at a constant rate of extension in order that other mechanical properties could be predicted from the resultant curves. Shear was predicted very accurately (0.807-0.941), and bending predictions had reasonable agreement (0.712-0.797). Surprisingly, however, the tensile parameters produced the lowest correlation factors with these three angled measurements. As the test was tensile in nature this was unexpected but the researchers explained this as due to the maximum load of 100 g being insufficient and stated that future experiments would be performed at a higher load.

Notwithstanding, this process differs from the conclusions of Leung that it is essential to measure all three mechanical properties (tensile, bending and shear deformation) to obtain a clear picture of the performance behaviour of woven fabrics [47]. In this case, the extension was tested using three different load ranges and it was found that the greatest range of results was obtained using the smallest loads. This suggests that differences between fabrics might be exhibited when extended with low loads, but not be apparent when extended with high loads.

1.1.5 Compression Parameters

1.1.5.1 Thickness

Early thickness measurements were obtained using a micrometer dial gauge with varying areas of measurement and loads. However, it was recognised that standard conditions of measurement were required [2]. Subsequent testing has yet to be standardised: Waesterberg measured thickness under a load of 5 g/cm^2, as did Hallos, Burnip & Weir [7] [19], the KES uses a pressure of 0.5 gf/cm^2 [23], and the FAST system records thickness at 2 gf/cm^2 (196 Pa) [1].

1.1.5.2 Hardness

Hardness is the relationship between thickness and pressure and is assessed by the curve produced when the former is plotted against the latter; this is a measure of the surface compressibility. There are many differences found in the literature with regard to the measurement of hardness. All relate to a difference in thickness when a fabric is subjected to different pressures, however the pressures used are not uniform. Peirce choose an arbitrary difference in pressure (80.14gms/cm^2) [2], Howorth & Oliver used the pressures of 0.01 lb and 1 lb/sq.in. [6], whereas Hallos et al. used the pressures of 250 and 125 gf [19].

1.1.5.3 Compression

Peirce identified the property of compression modulus as the difference in thickness divided by the original thickness. This produces a ratio that depends on the compactness of the fabric and its surface irregularities [2]. Other non-standard measures of compression have been developed; including compression recovery [19] and the resistance to compression [57].

Another method of compression, similar to that of Peirce, used by Elder, was to use an Instron tensile tester fitted with a compression load cell to measure the parameters of intrinsic thickness and compression [58]. Others have also used the Instron to measure the compression properties of fabrics in this manner [17] [9] [22].

1.1.5.4 KES – FB3

The KES uses a compression meter to find the parameters of linearity of compression-thickness curve (LC), energy in compressing fabric under a maximum pressure of 50gf/cm^2 (5 kPa) (WC) and compressional resilience (RC). The KES measurements of compression have been used by many researchers to assess fibre properties, the effect of finishing on cellulosics and wool fabrics, as well as the evaluation of silk and how to finish other fibres to become more silk-like [38, 59-61].

1.1.5.5 Surface Thickness

FAST defines Surface thickness (ST) as a measure of the amount of compressible fibre or 'pile' on the surface of the fabric. It is defined as the difference between the thickness of fabric at a pressure of 2 gf/cm^2 and at 100 gf/cm^2 (196 Pa and 9.81 kPa respectively), the measurement is taken before and after a steaming process and the difference in surface thickness is used to assess the stability of the fabric finish. . Subramaniam used a similar method, he calls it Surface Layer Thickness (SLT) [57]. He used the loads proposed by FAST and also added others. The original FAST parameters of thickness and compression have also been used by others [33, 62].

1.1.6 Surface Properties

Two main theories have been tried in order to develop a procedure to objectively measure surface properties, as well as several other methods which are included in the overview below; the FAST objective measurement system does not incorporate a test for surface properties.

1.1.6.1 Coefficient of Friction

Various methods have been investigated in order to determine the coefficient of friction including the inclined plane, an Instron (or other tensile tester), fabric replicas, grading against a standard, non-contact methods and the KES cloth friction tester.

The inclined plane method is one of the earliest methods used to calculate coefficient of friction. The parameter was recorded by placing a fabric-covered sled on a platform and tilting it, the angle is recorded when the sled moved. In various modifications it has been used to measure a test sample against self [17, 63], and both against self and a rubber standard [64]. If all other parameters are the same, a fabric with lower coefficient of friction is usually smoother.

Several researchers have used an Instron (or similar tensile testing machine) to establish the coefficient of friction of fabrics [7, 19, 22, 65-67]. The normal method is to use a sled covered with the fabric to be tested, which is drawn along a sample of the same fabric and the force required recorded on a chart recorded. A slight adaptation of this method was made by Virto & Naik who loaded the sled with weights to produce different compression loads [67].

1.1.6.2 KES – FB4

This KES instrument is one that was developed specifically for measurement of coefficient of Friction (MIU), mean deviation of MIU (MMD) and mean deviation of Surface Roughness (mean deviation of the thickness) (SMD). It does this by using a steel 'finger' to imitate the resistance against touch that the fabric possesses. As with any apparatus that tests against a standard great care is needed to decontaminate the metal between samples [23]. The KES surface parameters have been used by researchers to aid in the designing of silk fabrics, to evaluate fabric for ladies dresses, to evaluate interlinings and cotton fabrics [68-72].

1.1.6.3 Other methods

i) Fabric replicas

Fabric surface properties could also be measured using a system of rubber replicas to measure fabric surface properties [73]. He assessed the real area of contact of the replicas against a smooth, hard surface under a given pressure.

ii) Grading against standards

An alternative method of assessment was the use of glass ballotini [74]. This involved developing standards for smoothness from various sizes of the ballotini. Six standards were made; the smoothness of a fabric sample would be graded against the standards in an analogous manner to grading colour change or staining with a grey scale (ISO 105 A02 and A03 respectively).

iii) Non-contact method

A third process avoided any contact with the sample by utilising a laser to measure the distance between itself and the object using laser triangulation techniques [75]. This enables the calculation of fabric height and this is used as a measure of surface roughness.

1.1.7 Formability

1.1.7.1 Early Measures of Formability

Formability was defined by Lindberg as the longitudinal compression a fabric can accommodate before buckling [21].

$$\text{Formability} = kfc \qquad \ldots[2]$$

Where k = constant
fc = compressional formability = cb
c = compressibility
b = bending stiffness

Lindberg's original definition of formability was the product of bending rigidity and longitudinal compression. However, as the initial slope of the tensile load-extension curve was found to be very similar in magnitude to the load-compression curve, and furthermore, as it is simpler to measure extension, it has been substituted into the formability formula, [7]. Waesterberg calculated the warp and weft results, and the average of the two, and he also used the shear results to calculate the bias formability.

$$F_1 = \varepsilon b \qquad \ldots[3]$$
$$F_2 = \gamma b \qquad \ldots[4]$$

ε = extension @ 20 g/cm width (%)
b = bending stiffness (g – wt cm^2/cm)
γ = shearing (°).

1.1.7.2 Formulas using KES parameters

Waesterberg's formula was also used after the KES system was developed [76-78]. However, the parameter of extension at 20 gf/cm was not one of the KES parameters, it was found that the extension at low loads correlated well with the extension at 500 gf/cm, and thus the formula was modified [25].

$$F = \frac{EM}{F_{max} \times LT} \times B \times \frac{G}{2HG5} \qquad \ldots[5]$$

where, F_{max} is the maximum tensile load at which EM is measured

However, many other formulas have been found in the literature [79], [80]. [57]. There is a large variation in the equations, in the loads used for extension and in the inclusion or not of shear measurements; thus assumptions based on formability parameters must be viewed in relation to which formula is used.

1.1.7.3 The FAST measurement of Formability

The FAST method also derives formability from the bending rigidity and low load extension curves in both the warp and weft directions. The FAST formula (which can be found in the experimental methods chapter) uses the two extension results in order to eliminate the effect of zero loading, thus the effect of any handling error in the extension at 20 gf will be compensated for by the initial extension at 5 gf. This is important because as Mahar states the use of very low forces (20 gf/cm) is subject to experimental errors [38]. A correlation coefficient has been established between the KES & FAST measurements of formability of 0.92, when measured on shirting fabrics [32, 33].

1.1.8 Dimensional Stability

There are several measurements of dimensional stability, not least the current European standard (BS EN 26330) which measures the change in dimensions of a fabric or garment after a washing and drying cycle in an attempt to predict a consumer's home laundering. There is also the current British Standard for stability to steam (BS 4323). Although, the latter could be used as a measure to predict the change of dimensions due to steaming in garment manufacture, neither method is in common usage in current objective measurements tests.

Early methods that were used included a measure of settability [7, 21]. Lindberg defined settability as the ratio of dimensional strain retained after setting to the dimensional strain imposed before setting.

1.1.8.1 HESC: Stability Parameters

Although the KES objective measurement system does not included a test method for dimensional stability, one was developed by HESC to assess the shrinkage caused by pressing: HESC-FT-103A [81].

This is often used together with the KES mechanical parameters. Ito used this method to gain the parameters of equilibrium shrinkage after pressing (S_2) and humidity absorption rate after pressing (Q) to help programme the finishing conditions most suited to particular fabrics [52].

A more severe variation of the HESC 103 A was used by Nitta to assess the stability of the interlining material in suits [49]. This compressed the fabric until just before buckling prior to the initial steam pressing. In contrast the Melbo company used a less severe variation of the method of test that reduced the time taken to establish the properties from two days to under one [29].

1.1.8.2 Hygral Expansion and Relaxation Shrinkage

Hygral Expansion is a reversible change in fabric dimensions due to alteration in moisture content of the fabric. Early measurements of Hygral Expansion were often taken as a curve, for example Baird measured the change in dimensions between 0%

regain and 33% regain [82] and Mahar measured hygral expansion through the entire range of relative humidity, from 0% to 100% [76]. Køpke developed an apparatus for recording the weight and length changes during drying and steaming of fabrics in order to measure hygral expansion [83], this method was also used by Mahar [84].

Early measurements of relaxation shrinkage using the Wira steam apparatus [84], another method used was to soak the samples [85]. In principle, Relaxation Shrinkage is an irreversible change in fabric dimensions (expansion as well as shrinkage) associated with the release of strains within a fabric that were not completely set during finishing. FAST define the property as the percentage change in dry dimensions after release in water at room temperature [1].

Shaw developed a method of measuring both relaxation shrinkage and hygral expansion [86]. This method was used by Mazzuchetti [87] and was also the basis of the method adopted by FAST [1]. Both of the FAST dimensional stability parameters were used by researchers to classify the effects of finishing [88] and in investigating fabric sewability [12].

1.1.9 Drape

1.1.9.1 British Standard Method

The development of the drapemeter currently in use today as the British Standard (BS 5058: 1973) began by Chu 1950 [89]. Modifications were made by Cusick [4] [90] which simplified the equipment. This method of assessing drape by Gaucher, but he said that it was not accurate for fabrics below a drape coefficient result of 26% as the fabric folds under the plate and therefore is not taken into account in the measurement [13]. Drape coefficient was also used by other researchers [19] [11].

1.1.9.2 Methods using Image Analysis

Recognising that the drape coefficient is dependent of time; Vangheluwe and Kiekens stated that the shadow of the draping sample may have moved during the time taken for the operator to draw it [91]. They used image analysis to calculate the drape coefficient by positioning a camera above the drape meter and transferring the picture to a computer that calculated the area of shadow. They used a t-test to assess if there were differences between the image analysis and cut and weigh methods of assessing drape, but found no statistical differences.

This approach was further refined by Jeong and Phillips as their results obtained did not depend on the direction of the image [31, 92]. A result of 0.86 was found on a paired comparison t-test that showed good agreement with the traditional cut and weigh drape assessment. They suggested that drape distance ratio might also be used as a measure of drape and that the number of nodes was important.

1.1.9.3 Other direct methods of assessing drape

A variation of the drape tester was used by Iwasaki [93]. This involves draping a circular specimen in front of a glass plate with black lines on it and obtaining a moiré photograph. From this photograph, the shape factor and the area of the sample are calculated, when are then used as a measure of drape.

Collier developed an experimental drape tester that used a surface of photovoltaic cells to register the amount of light let through draped samples [43]. Fabrics with high degree of drape give high voltage readings, and those with low drapability yield low readings. This differs from the standard method which states for fabrics with different amounts of drape different sizes of test samples should be prepared; the Collier method different plates should be used over which the samples are draped using the same specimen size. Collier's voltage measurements correlated very highly with subjective appreciation of drape [43].

1.1.9.4 Indirect methods of assessing drape

There have been many attempts to derive the property of drape from other mechanical properties, some of these use bending and shear and some just use bending. Bending length has been found to be an accurate predictor of drape by many researchers [2, 4, 13, 94]. Several shear parameters (rigidity, modulus and hysteresis) have also be linked to drape by researchers [4, 13, 43, 95]. Two formulas were established by Marks and Spencer to predict draping properties. The bending factor (1000 x B_2/W) and the shear factor (1000 x G/W) [24].

Fabric thickness has also been linked to drape [43, 95] whereas a related parameter (compression) has been dismissed by others [39]. Some researchers have found that extension is an important parameter [39, 95] whereas others found contradictory evidence [13]. Surface parameters have also been linked with drape [39].

However, care must be taken when using these indirect measurements because of the contradictory findings as to whether certain parameters are important and also because the error inherent in the methods. For example, very small differences in bending length values (between 1.5 cm – 3 cm) relate to very large differences in drape coefficient results (20% - 80%), therefore the bending length results must be very accurate to be meaningful [94].

1.1.10 Selection of Properties

In order to fulfil the aims of FOM the selection of the parameters to measure are fundamentally important. Different opinions exist about the number of properties that should be measured and the manner in which they should be chosen. Howorth & Oliver state that

> "It is necessary to make use of any tests that might be related to the handling qualities, and to analyse the results in such a way that important tests may be identified and unimportant tests discarded" [6].

This suggests that as many tests as possible should be used and only after analysis should the number be reduced. Other researchers agree with this philosophy and have used statistical procedures such as principle component analysis to reduce the initial parameters [96] [22]. This statistical technique selects the variables that explain the most variation between the fabrics and dismisses ones that are not relevant. However, Raheel selected the tests for his experiment by analysing handling techniques, fabric responses and establishing the properties that would most reflect this and only measured those parameters [97].

A point to be taken into account is that fabric mechanical properties typically show non-linear behaviour and it is therefore very difficult to compare data measured by different techniques [98] and as this section illustrates there are a lot of different methods of assessing the same parameters. This shows the importance of the development of an industry wide objective measurement system. The two major attempts to this are the KES-FB, and the FAST.

1.1.10.1 KES-FB

These instruments do not use new principles (except KES-FB4) but are designed to allow the same test pieces to be used on all four instruments (if run in the correct order) and are therefore more convenient. However, some doubt the validity of the rates of deformation applied by the KES. They are intended to be similar to actual deformation used in the judgement of hand, however Bishop states they are extremely slow compared with typical handling movements. This may distort the measured hysteresis effect by allowing too much time for inelastic deformations [99].

The system is also complicated; Bishop states "A skilled technician, thoroughly conversed with the system, will take at least four hours per sample." [99]. However, the KES-FB has several advantages because of its complexity as the measurement conditions can be modified to improve the accuracy of results of different types of fabrics [100]. Examples of these modifications for tensile and shear can be seen the table below.

Table 1.1.1 Measurement conditions of the KES-FB equipment

	Standard	**Standard/ high**	**Knit**	**Knit/high**	**Non-woven**
Uses	Men's & Women's Suiting	Shirting, Women's thin dresses	Outerwear	Underwear	Apparel
Tensile					
Max load	500 gf/cm	50 gf/cm	250 gf/cm	50 gf/cm	50 gf/cm
Strain rate	0.4 %/sec	0.2 %/sec	0.4 %/sec	As knit	0.2 %/sec
Sample width	20 cm	As standard	20 cm	As knit	20 cm
Sample length	5 cm	As standard	2.5 cm	As knit	5 cm
Speed	0.2 mm/sec	0.1 mm/sec	0.1 mm/sec	As knit	0.1 mm/sec
Shearing					
Constant tension	10 gf/cm	As standard	10 gf/cm	5 gf/cm	10 gf/cm
Max shear angle	±8°	As standard	±8°	±4°	±8°
Rate of shear strain	0.00834/sec	As standard	0.00834/sec	As knit	0.00834/sec

Source: [100]

Many researchers have used these modified set-ups for the testing of women's dresses [101-104], for knitted fabrics [105, 106], and for non-woven fabrics [107].

Other researchers doubt the choice of loads that have been defined, Bishop stated that it seems unlikely that judges apply ten times the force to judge a woven fabric than a knitted one, just because the former is less extensible [99].

1.1.10.2 FAST

When FAST was developed the researchers assessed the properties provided by the KES-FB systems and established which ones were the most important in terms of fabric tailorability. FAST was developed to provide data on these properties and was not intended to predict hand properties. The order of the parameters listed in the data control sheet is the order of importance found by CSIRO for suiting fabrics with good tailorability properties [108].

The KES instruments are in many factories in Japan and are used regularly, however they have not had such a good reception in this country. Barndt has stated that he found the FAST system a better predictor of tailoring difficulties than the KES [109]. Shishoo reports that

"the FAST is much cheaper, simpler and more robust than the KES-F system, and hence perhaps more suited to an industrial environment" [110].

As can be seen above in the discussion on the individual parameters the correlation factors between the two systems are generally high.

1.1.10.3 Precision of Measurement

There have been two interlaboratory trial to assess the precision of measurement of the KES-F apparatus [111, 112] (now KES-FB) and one for the FAST [1], all have assessed the repeatability (within lab) and reproducibility (between lab). Extracts from the results have been given below, there is difficulty comparing the methods of KES-F and FAST as the results are often given in different units.

Table 1.1.2 Repeatability and Reproducibility for KES-F and FAST instruments

	Repeatability			Reproducibility		
	KES-F (1)	KES-F (2)	FAST	KES-F (1)	KES-F (2)	FAST
Tensile						
EM-1(%)	1.3			1.5		
EM-2 (%)	1.6			1.9		
EMT (%)		1.1			1.62	
E100 (%)			0.24			0.61
Bending						
B-1 (gf.cm^2.cm)	0.026			0.032		
B-1 (gf.cm^2.cm)	0.022			0.032		
B (gf.cm^2.cm)		0.009			0.019	
C (mm)			0.60			1.13
Compression						
T05 (mm)	0.10			0.13		
T20 (mm)	0.06			0.08		
T (mm)		0.076			0.130	
T2 (mm)			0.016			0.031
T100 (mm)			0.008			0.024
Shear						
G-1 (gf/(cm.deg))	0.24			0.33		
G-2 (gf/(cm.deg))	0.24			0.33		
G (gf/(cm.deg))		0.104			0.191	
EB5 (%)			0.27			0.84

Despite the difficulty in comparing the data, it can been seen that the simplicity of the FAST instruments does not appear to be reducing the precision of measurement. Indeed the complexity of the KES-F could have a negative effect on the reproducibility data; it was found that not all laboratories were using the same number of cycles for establishing bending and shear results [112].

1.2 The Relationships between Fabric Objective Measurement, Garment Manufacture and Appearance

FOM techniques provide a great deal of information about the quality of fabrics. One of the earliest ways that this was used was in the garment manufacturing process [7]. The techniques are useful in a number of areas. Firstly, in order to take preventative measures. For example, if one knows a fabric will have problems with puckering, one can take the appropriate steps to compensate by using different seams, needle sizes and threads. Information about the mechanical properties of a fabric can also help in the selection of fabrics for particular end uses. Secondly, it is possible to relate fabric performance during garment manufacturing to a fabric's mechanical properties if one takes note that in the manufacture of garments the fabric is subjected to bending, extension, longitudinal compression and shearing forces, and more importantly that all these properties can be measured objectively.

1.2.1 Fabric Selection

There are several examples of FOM techniques aiding in the selection of fabric. Melbo, a Japanese company, created a database of results from the KES-FB parameters of tensile, shear, bending and steam press properties over a four year period and related these to the fabrics that produced excellent suits [29]. They then used this as a reference to select new fabrics. They also related fabric bending properties (B_2 and 2HB/B) of below a certain amount to fabrics that exhibit long term appearance changes when made into a suit.

Fletcher Jones & Staff Pty Ltd have made it a policy not to purchase fabrics with extension results outside the range of 0.5-2.5% or with formability results below 35 mg.cm^{-1} [113].

A joint venture was carried out by Marks and Spencer and UMIST to establish a database of acceptable and unacceptable results [114]. Kawabata cites a presentation of Guruswamy, where the use of the fabric control chart is promoted for assessment of tailoring and wear for both suiting and women's thin dress fabrics [115]. Marks and Spencer initially recommended the KES-FB instruments to its suppliers but is now suggesting that the FAST is more suitable, due to the complexity of KES-FB [114].

For many end-uses, the fabric weight is critical for the selection as it is often seen as a guide to fabric quality [116]. Due to the differences in weight for the range of textile fabrics available, there are few standards regarding specific weights acceptable. However, within a particular range of fabrics, those of lower weights are generally considered to be those most difficult to manufacture [7] and more susceptible to wrinkling [117].

1.2.2 Total Appearance Value

Niwa developed an equation that relates sixteen of the KES mechanical properties to the Total Appearance Value (Tav) which predicts the appearance of the finished garments. Examples of the mechanical results that produce a profile from one to five for both winter and summer suiting are given below. It can be seen that the fabrics with good appearance (Tav 5) have much less variation in their results.

Figure 1.2.1 Examples of KES Control Charts

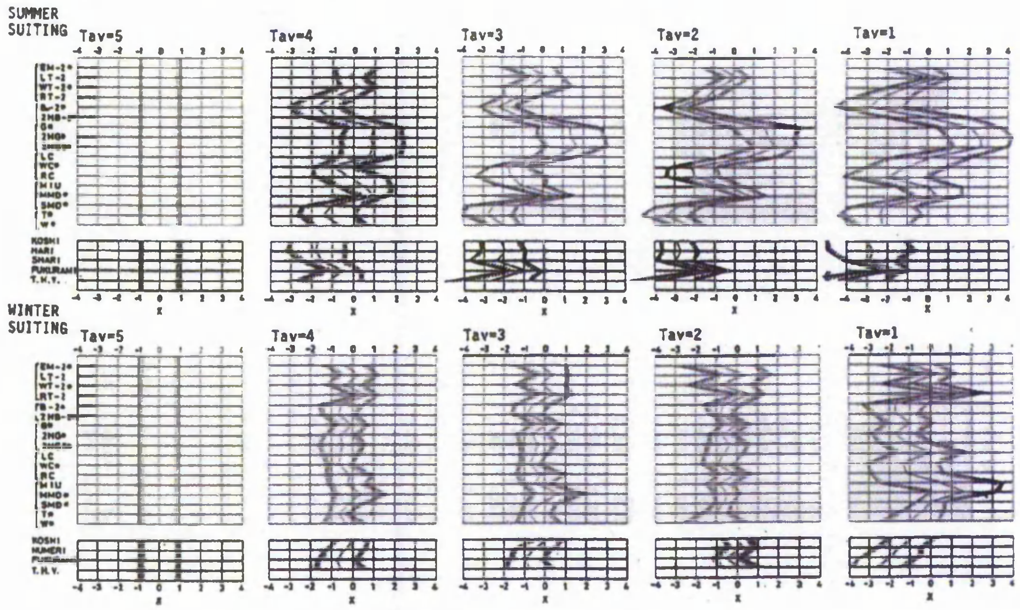


Fig. 4 Mechanical property ranges of samples of different Tav.

Source: [25]

Low extension, high shear rigidity, large shear hysteresis and lower compressibility are typical feature of low Tav fabrics [118]. There have been high correlation factors found between the predicted Tav values and the appearance assessed subjectively [118] [115]. Fabrics that present a high THV (Total Hand Value, which is another parameter identified by Kawabata related to the hand of fabrics) may not necessarily have a high Tav, as the table below shows.

Table 1.2.1 The Desirable Range of Mechanical Properties for High-quality Suit Production

Mechanical Parameter	Range for Good Appearance and Good Tailorability	Range for Especially Good Appearance
EM_1(%)	4-6	4-6
EM_2/EM_1 (%)	> 1	> 2
RT (%)	65 – 76	72 – 78
G (gf/cm deg)	0.5 – 0.7	0.5 – 0.7
2HG5 (g/cm)	0.8 – 1.7	0.6 – 1.5

Source: [115]

The mechanical parameters in the table have been given an optimum range as they have a non-linear relationship to quality; a result that is too low or too high can lead to problems.

Fabric extension and formability were correlated to suit appearance and it found that extensibility at 500 $gf.cm^{-1}$ was better than the formability parameter in order to discriminate between good and poor suit appearance [78]. Similar research has been done using the FAST parameters, where formability was found to have the largest correlation with garment appearance; weight and warp extensibility were also important [53].

Another factor that should be taken into account when discussing the appearance of garments is their dimensional stability. Large values of Relaxation Shrinkage and Hygral Expansion can be linked to poor appearance, but this is not always evident during manufacture. A humid atmosphere during wear, and even the effect of skin respiration or perspiration, can cause garments to loose their shape. Seamed areas and areas where the garment has been fused are particularly susceptible due to the mechanical action of sewing and repeated steam pressings [77] [50]. Measures to counter this have been suggested by Hori [119]. A variation on the steam press method (HESC 103 A method) was used by Nitta to assess the shrinkage of interlinings as this was argued to be critical for the appearance of the final garment, dimensional changes both at the time of manufacture and during wear were predicted [49]. The FAST parameters have also been used and those of Relaxation Shrinkage and Hygral Expansion were found to be the best indicators of poor appearance [1].

Many researchers use mechanical properties to predict information about suiting fabrics, however, some do try to relate the technique to other end uses. For example, Mamiya found that fabrics with higher shear properties ($G + 2HG_{0.5}$) were ranked higher when made into both dressy and sporty style dresses [69]. Larger properties of bending $(B/W)^{1/3}$ resulted in a lower ranking for the dressy style but an optimum amount of the parameter was found for the sporty style, illustrating the importance of end use for fabrics for women's dresses. Mamiya also found that for gathered skirts, the bending property of (2HB/W) was the most important parameter to predict consumer preference [30]. It was found that the property should be kept to a minimum to enhance gathered roundness and springiness. In a similar experiment Sudnik assessed the drape coefficient of various fabrics and provided broad categories that the results might fall into for different end uses, for example underwear 30-60% and suiting 65-80% [94].

1.2.3 Prediction of Problems

Waesterberg found that in order to predict difficulties in the easing-in operation, the mechanical parameter of formability produced the highest correlation coefficients. Information was also obtained on the sewing of long seams, which correlated with extension, and the ease of handling which was related to bending stiffness. The fabrics were evaluated during different production operations and inspected as finished garments. Formability was found to be the most important parameter overall. Thinner fabrics that were awkward to hand during manufacture were evaluated as suitable during the final garment inspection, indicating that problems during manufacture do not necessarily indicate a poor finished appearance [7].

For the Sanko Iryo Company, Ito also investigated problems in manufacture using data obtained from KES about fabrics' mechanical properties [50, 120, 121]. Shear, tensile and steam press shrinkage tests were used and linked to difficulties found in various manufacturing operations. If the fabric results suggested a potential problem, changes in manufacturing route were made in order to minimise the problems. They found a 10% reduction in their substandard products over a two-year period.

Specific problems have also been correlated against results from KES-FB instruments, for example dropping can be predicted by using the KES properties of shear hysteresis [24].

Table 1.2.2 Prediction of Dropping Problems

	Predicted when results are:
2hg5	< 3.8
100 x 2hg5/W	< 0.35

There have also been several investigations similar to the above using the FAST apparatus. Cheng, How & Yick correlated the properties measured by FAST with manufacturing problems in shirting fabrics, and found that different requirements were valid [122].

Table 1.2.3 Important Parameters in Predicting Problems in Manufacturing

Range of parameters	Difficulty predicted in	Instructions for workers who are concerned with this indication
Extensibility < 1.84%	Overfeed operations	Guide fabric carefully Confirm the length of seams being sewn
Extensibility in warp > 2.53% and/or in weft > 4.07%	Spreading Sewing operations	Avoid excess tension during spreading Spread fabric a bit longer than it requires Push fabric to avoid excess extension Confirm length of seams
Bending rigidity in warp < 7.67 μN.m and/or in weft < 4.06 μN.m	Cutting Handling	Use very sharp cutting knife Reduce cutting speed
Bending rigidity > 12.35 μN.m	Stiff Cutting operations	Reduce number of plies in a lay Guide fabric carefully during cutting Use very sharp cutting knife
Formability < 0.18 mm^2	Seam puckering Sleeve setting	Reduce needle size Reduce sewing thread tension Guide tope fabric ply carefully
Formability > 0.46 mm^2	Sewing operations	Increase needle size Change thread Reduce sewing thread tension
Shear rigidity < 33.9 N/m	Spreading Sewing operations Handling	Take care not to stretch fabric and repeat adjustment for each ply Reduce sewing thread tension Reduce machine speed Push fabric to avoid excess distortion
Shear rigidity > 55.3 N/m	Shaping and moulding operations	Pull fabric during sewing
Hygral expansion > 1.53 %	Garment appearance	Avoid excess steam press

Source: [122]

The company that manufactures the FAST apparatus (CSIRO) has also produced guidelines that states in which area of manufacture each of the mechanical parameters can be related to.

However not everyone agrees with the specifications FAST makes regarding tailorability. Ganssauge tested 43 fabrics using the FAST equipment and only three of them fell within FAST control limits, an example of the FAST control limits can be found in the Experimental Methods Section (figure 2.1.2). However he states "it must not be assumed that the vast majority of fabrics examined in the period in question would cause problems in making up" [62]. He suggested subdivision by weight class, end-use and fabric type in order to focus the results in a narrower range.

Table 1.2.4 Operations in Garment manufacture affected by Fabric Properties

Fabric Properties	Laying-up	Cutting	Fusing	Sewing	Pressing	Appearance
Relaxation Shrinkage			X		X	X
Hygral Expansion			X		X	X
Formability				X		X
Extensibility	X	X		X		X
Bending Rigidity		X		X		X
Shear Rigidity	X	X		X		X
Thickness	X					X

Source: [1]

Manich correlated the FAST parameters with sewability tests [12]. He found that three of the properties played a significant role: bending, shear rigidity (both positively correlated) and hygral expansion (negatively correlated).

1.2.4 Patterns

Objective measurement has also been used to assess how pattern cutters may adapt their patterns using the knowledge of the fabric characteristics. The FAST parameters were correlated with subjective assessments of completed ladies blouses. One pattern was found to present different problems depending on the weight of the fabric. Details of the fabric's inherent characteristics were correlated with problems exhibited on the finished garments; it was stated that these could be reduced or eliminated by several minor pattern alterations [45].

1.2.5 Overfeed

Overfeed is important because in order to give shape to garments, fullness is achieved by overfeeding one length of fabric relative to another. Formability can be related to how much overfeed a particular fabric can sustain without buckling (puckering).

The limit of overfeed of a particular fabric is very affected by which direction the seam is in. The bias directions can accommodate more overfeed than the principle thread directions of warp and weft. Problems with overfeed can be reduced by altering the design of patterns and settings on machines. As Harlock states "while this may be known to experienced pattern cutters it is only acquired after years of subjective assessment of fabrics" [118].

However there is a further element to consider: Ito and Kawabata designed an experiment to correlate the amounts of overfeed with the hand properties of fabrics [52]. They found that when machine overfeed was set at a constant (in this case 3.2), hard fabrics showed smaller values of actual overfeed than soft fabrics. Thus, the setting must be altered depending on the properties of each fabric in order to achieve the same overfeed results.

However, in contrast to the usual finding that formability is the most important parameter in predicting pucker; experiments using cotton fabrics were found to pucker less when they had high values of bending and shear hysteresis (2HB, 2HG and 2HG5). High values of bending and shear rigidity, together with formability (B, G and F) also correlated with puckering but were less important [72].

1.2.6 Steaming

Dimensional stability properties are important in order to assess the effect of steaming a fabric. This is particularly important to fabrics such as wool that absorb a lot of moisture, as they are highly susceptible to dimensional change. The results the tests provide can indicate the amount of time a fabric will require to stabilise to factory conditions, particularly after steam pressing. Processing systems that rely on large amounts of Work in Progress (WIP) generally allow enough time between operations for most fabrics to stabilise. However, systems with rapid throughput times such as Just in Time systems provide little time for the fabric to reach dimensional equilibrium and would therefore require the fabric to have small steam press shrinkage or expansion results and rapid recovery from shrinkage [123].

1.2.7 Interlinings

The dimensional stability property of Hygral Expansion is an important parameter for fabrics that have fusible interlinings. Once a fabric area has been fused it is then less able to change its dimensions. If the fabric has a high hygral expansion distortions will be evident between the fused areas (stable to dimensional change) and the unfused areas that will expand due to an increase in relative humidity. A comparison was made between shrinkage found on a fused sample (1.0%) and that found on an unfused sample (3.0%) to illustrate the point [1]. It has been found that fusibles should have stability properties of within 2% of the shell (outer) fabric or order to minimise problems [124].

Other mechanical parameters of interlinings have been investigated in order to assess their effect on quality. Their bending flexibility has little effect on the overall performance but shearing does as is causes difficulty in tailoring [49]. EMT and G were found by Nagano to be the most important mechanical parameters for interlinings [70].

1.3 The Relationship between Fabric Objective Measurement and Fabric Development

1.3.1 Introduction

In this section, the use of FOM in fabric manufacturing has been investigated. It is a logical progression from establishing limits for the fabric mechanical properties necessary for good quality garments to try to produce fabric within these limits. FOM can be used to assess the effects of individual processes, including fabric weave, finishing chemicals or the differences between two or more processing chemicals and finishing routes.

Holme reported on a course in which Prof. Kawabata stated his aims for FOM in terms of fabric processing:

> "The grey fabric parameters were also measured and fed into a computer in which the effects of all the finishing machines and combinations of finishing routines were already programmed. The computer then selected the finishing routes and conditions for finishing the fabric to attain the correct finishing for the customer" [125].

An analogy was drawn with FOM at that time (1984) and instrumental colour measurement twenty years previously. It was forecast that by 2000 the above aims would be realised. The main focus of the review was how fabric development procedure effect the mechanical parameters of fabric, also discussed is the effect on hand properties. The main focus was on the hand terms developed by Kawabata and the HESC such as Koshi (stiffness), Numeri (smoothness), Fukurami (fullness), Hari (anti-drape stiffness), Kishimi (scroopy feel) and Shinayakasa (flexibility with a soft feel) and Sofutosa (soft feeling) [23].

1.3.2 The importance of Communication between Industry Sectors

Saito stated that vertical processing methods can help develop expertise in fabric design and finishing that is necessary to relate fabric mechanical properties and physical characteristics [126].

In the horizontal method, each sector of the industry works independently solely for their immediate client. For example, a fibre manufacture only cares about what a yarn manufacturer wants and they do not work together to produce something that will in end be better for the garment manufacturer. The vertical system allows all sectors to be involved in fabric design and therefore increases effective communication and co-operation.

Kawabata & Niwa adopt a similar philosophy to help achieve excellent fabric quality, called a "trimming method" [127]. Although it starts with finishing, it also involves fabric and yarn design and ends with fibres. The intention is that finishing sector improves a fabric by varying the processes used, then the objective of improvement is given to the fabric supplier, the yarn supplier and eventually even the fibre supplier, in order that the quality can be improved at each stage.

Hearle and Porat state that engineering of fabric depends on theory and machine control [128]. In order that fabric manufacturing can be manipulated in an engineering sense, one must have accurate grasp of theory to predict the consequences of changes and sufficient control of the processes to ensure repeatability and reproducibility. It should be noted that it is not only the average of properties that are important but the variations as well, if one is to be able to control the consistency of a given process. Thus, the background research on the effects of different mechanical properties and finishing routes are essential.

1.3.3 Fabric Design

1.5.3.1 Fibre Properties

Many researchers investigate the mechanical differences obtained from fabrics using different fibres. This involves assessing the initial properties of fibres and in many instances how these properties can be manipulated.

An investigation into current knowledge on fibres clearly shows why the synthetic fibres of polyester and, to a lesser extent, nylon are often chosen for engineering experiments [129]. They have good durability properties such as tenacity, flexibility and abrasion resistance but are lacking in comfort properties such as moisture regain and content. Thus, it is desirable to improve the comfort parameters to a level commensurate with natural fibres, whilst maintaining their other strong characteristics; this been concentrated on in fibre engineering. Also, being synthetic, they are much more straightforward to modify than natural fibres; it is relatively easy to alter extrusion parameters compared with the genetic modification of plants or animals necessary to alter natural fibres.

i) Wool and Wool-like Fibres

Modifications to polyester have been carried out to make it more wool-like [130]. This was achieved by assessing the difference between wool and polyester using the KES-FB mechanical properties. Modifications to the fibre design included using fine denier fibres on the surface to imitate the smoothness of wool and coarse denier fibres in the centre to provide wool's stiffness and bulkiness. Medium denier fibres were arranged intra-layer to achieve a gradual distribution of denier.

The effect that fibre diameter and crimp have on the mechanical properties of wool fabrics has been assessed [59]. It was found that increasing the fibre diameter increased its stiffness and crispness. Winter fabrics were less affected by fibre diameter and were more dependent on crimp; this could be because higher crimp levels will increase a fabric's extension (EM) and the tensile energy (WT), whilst reducing the linearity of the load-extension curve (LT). These parameters are related to fabric flexibility, softness, smoothness and compactness. Madelay also found similar results, if the fibre diameter is constant lower crimp reduces stiffness and increases softness [131]. In contrast, Mahar found that an increase in fibre crimp increased the hygral expansion of the resultant fabric, which is generally thought to reduce fabric quality [84].

Fabric objective measurement was used by Carnaby to aid in the development of a pure wool worsted fabric having similar properties to crisp wool/mohair tropical suiting materials [132]. The desired properties of wool/mohair were assessed in terms of bending, tensile and compression, then variations of different types and blends of wool were compared against the standard. A blend of New Zealand crossbred wools and merino was found to provide the best mixture to imitate the mechanical results of wool/mohair blend.

ii) Silk and Silk-like fibres

A great deal of research has been carried out in the attempt to produce a fibre that is similar to silk and in order to do imitate it, the properties of silk must be understood. It has been stated that the mechanical properties are more important than the chemical nature of silk in order to explain its hand and characteristics [103]. Matsudaira assessed the differences in mechanical properties between silk and synthetics in order that synthetics could be made more silk-like [133]. It was found that silk fibres could not pack closely together because of their irregular shapes, distorted ridgelines and small crimps. As there is more space between the silk fibres this leads to yarns and fabrics that are softer than the polyester equivalent. The greatest difference was found to be in the primary hand value of Fukurami (fullness and softness) which silk had to a greater degree than polyester.

iii) Polyester Fibres

Polyester fibres have been used to produce fibres that are both silk-like and others that are wool-like. In contrast to these aims, Kawabata and Niwa stated that with the development of shingosen fabric the design of synthetics had moved from trying to imitate silk to the development of something completely new in terms of fabric hand [134].

Matsudaira, Tan & Kondo assessed the effect of various polyester fibre cross-sectional shapes on the resultant fabric mechanical properties [135]. They found that the space ratio (ratio of space to polymer in fibre cross-section) was important in terms of mechanical properties. The authors concluded that mechanical properties were predominately affected by fibre assembly structure rather than fibre cross-sectional shape.

The difference between micro-denier polyester and regular polyester was assessed by Behera [136]. Micro-denier filament fabrics were found to possess better drape properties and give better hand values. However, other research states that although having very fine denier yarns improved fabric hand, they caused problems in the weaving of the structure [136].

1.3.3.2 Yarn properties

Fibre properties can be significantly modified with changes in yarn parameters, hence it is important to know the effect of the basic yarn structures in order to understand the effect these have on the mechanical parameters.

Scardino investigated the effect that yarn structure has on fabric quality [137]. He found that spun yarns give fabrics a subtle surface roughness, softness, good bulk and low lustre. In contrast, filament yarns produce fabrics that have visual uniformity, high lustre, sheer and smoothness. Tactile properties are most affected by twist. An increase in the amount of twist increases bending rigidity and reduces compression, surface friction and softness; this is due to an increase in the fibre to fibre friction. However, filament yarns with twist have better stability properties than those yarns without twist. Twist was also investigated by Mori, who found that lower twist produces yarns with more fullness, bending rigidity THV and Tav [138].

Saito and Yamauchi also investigated the mechanical properties of yarns; in their research the difference between siro-spun, twisted and single yarns was investigated [51]. They found that the siro-spun was the best of the three because the fabrics produced from it had the low bending results (2HB and 2HB/B) that are desirable for good making up.

The crimp of fibres was assessed at various stages throughout the spinning process. It was found that both the crimp and crimp recoverability decreased as the fibres proceeded with the most marked reduction at the carding stage [139]. As there is a positive correlation between crimp and quality, it is important to know which processes have the most effect.

1.3.3.3 Fabric Construction

The construction of fabric is known to have a great importance on mechanical properties of the resultant fabric [129]. Any construction with many warp and weft interactions (for example plain weaves) stabilises the fabrics. However, constructions with long floats (few interactions) produce smoother, more lustrous fabrics.

The difference between plain and twill weaves has been investigated [140]. The mechanical property of shear was affected by construction; plain weaves had higher shear rigidity and hysteresis than twill weaves. Also, the shear rigidity of plain woven fabrics increased with pick density, but this was not repeated with the twill weaves. There was found to be more difference in compression in plain weaves than twill weaves; conversely, there was more variation in bending properties on twill rather than plain weaves. Other research agrees on the importance of the weave structure, as it was found to be the most important parameter in determining mechanical parameters and had a stronger effect than dyeing method, twist and warp density [138]

Another construction parameter along with the choice of weave is the length of weave float; Ganssauge stated that a longer weave float increased the weight, thickness and formability of a fabric and reduced its shear rigidity and recovery [62].

It also increased the coefficient of friction and reduced the deviation of the coefficient of friction. Longer weave floats generally increased the primary hand values of Numeri (smoothness), Fukurami (fullness and softness) and Sofutosa (soft feeling).

Construction parameters have also been linked to hygral expansion [141]. It was found that the property mainly depends on weave crimp but the fibre regain properties also have an effect.

1.3.4 The Effect of Finishing

This can be categorised by research into the effects on particular fibres (wool, silk and cellulosics) and investigations into specific mechanical properties.

1.3.4.1 Wool

There have been many investigations into the finishing treatments given to wool fabrics and how they effect the mechanical properties. Dreby compared the mechanical properties of fabrics that had been calendered with those that had a plain finish [63]. Reduction in flexibility, surface friction and compressibility were found when fabric was calendered.

The changes to mechanical properties as a result of applying shrink-resist polymers has been investigated [48]. An overall trend was that the fabric would have increased rigidity; however, it was difficult to predict the exact changes as it depended on a large number of factors (for example, construction of fabric and distribution of the polymer).

Fabric finishing has a major effect on the finished appearance on the garment. Fabrics that are too soft tend to look worse than harder fabrics, especially in conditions of high humidity. Therefore better appearance retention of seams is found when a hard elasomer (such as Sirolan BAP) is used rather than soft ones such as silicones [142]. This is because hard crosslinking agents increase a fabric's bending rigidity and therefore its formability.

The finishing process reduces rigidity and hysteresis in bending and shear [143]. The fabric becomes more supple and better able to recover more fully from deformation. Hygral expansion has a proven link the severity of set in finishing for example during dyeing; higher hygral expansion results are found from fabrics with higher degrees of set [38, 144], whereas hygral expansion is reduced by the presence of dye within the wool fabric [145].

Ito described a method in which the results of mechanical properties can predict what method of sponging was required to produce the desired end use fabric [52]. Optimum conditions in the finish procedure such as steam temperature, steam flow rate and speed of processing are decided upon based on the results of the mechanical data obtained from the data from KES-F1.

The differences in mechanical properties due to either wet or chemical setting of wool fabrics were assessed by Mazzuchetti and Dimichelis [87]. Chemical setting is purported to give greater dimensional stability and tailorability. It was found that successive finishing treatments brought the shear and bending properties of the two methods closer together and that pressure decatizing cancelled out differences between mechanical properties introduced during preceding finishing operations. The differences between the finishing fabrics in THV were less than 0.5, which would be imperceptible even to experts; therefore, the fabrics were considered identical and there was no advantage to chemical setting.

Table 1.3.1 Comparison of the THV & Tav of Different Finishing Treatments

	Wet	Chemical
THV	3.13	3.23
Tav	2.33	1.73

Source: [87]

The differing effects that batch and two different continuous decatizing processes had on wool fabrics has been investigated by De Boos and Wemyss [44]. They found that the batch method produced fabrics with better stability than the continuous methods and that a difference was evident between the two continuous processes. However, they note that although this type of information can be used they will not be the only factor for consideration:

> "the tests described will not make the decision about processes, routes or machinery easier for the finisher because commercial, as well as technical considerations are involved."

The stenter settings were found to be very important to the finishing of wool fabrics and the resultant mechanical properties [88]. The effects of overfeed and width were not independent, it was found that a 10% overfeed in warp and 7.5% in weft was required on the fabrics tested to prevent the fabric stretching during dyeing. This in turn, has an effect on the mechanical properties, for example, on average each 1% increase in fabric dimensions resulted in a corresponding 0.3% reduction in extension at 100 gf/cm. Pressure decatizing was found to produce fabrics with lower released surface thickness than atmospheric decatizing, thus indicating a higher level of permanent set.

Le et al assessed the variables of time, temperature, rotary pressing and pressure decatizing on the degree of set that was imparted to wool fabrics [54]. It was found that decatizing temperature reduced the frictional resistance to deformation, which increased extensibility and reduced bending rigidity. Using rotary pressing it is possible to offset this, as frictional resistance is increased. Further reductions in frictional resistance can be found when using one or all of the following: higher temperatures, un-dyed fabrics, plain weaves or highly compacted fabrics.

1.3.4.2 Silk

The finishing parameters of silk were investigated by Dreby. He noted that the coefficient of friction of an untreated silk stocking was 0.30 and that this could not be reduced to any great degree as softening agents did not have much effect with a coefficient ranging from 0.28-0.32 [63]. However, a delustering agent could increase the coefficient of friction to 0.50.

Eight processing variables were used by Nakata to predict the hand of silk fabrics. These variables were weave, fabric weight, yarn fineness, fabric tightness, twist multiplier, weight loss by scouring and extension cause by finishing in warp and weft directions [146]. He found that the fifteen mechanical properties and the hand values of Koshi, Tekasa (for crepe-like feel) and Koshi, Hari, Fukurami, Shinayakasa (flexibility and softness for dress weight fabrics) could be predicted with the eight processing variables.

Gong & Mukhapadhyay used silk as the reference and compared the mechanical properties of seven fabric types of polyester and cotton fabrics with different finishing treatments (caustic treated polyester and ammonia treated cotton) and constructions (satin, plain and twill weaves) [61]. A total of 172 fabrics were tested. They found that the caustic treated polyester was the most silk-like in tensile, shear and bending properties and the ammonia treated cotton was the most silk like in terms of surface properties. The total hand value of caustic-treated polyester was found to be the closest to silk; ammonia treated cotton was closer than standard cotton and twill weaves were closer than plain weaves. They found that the hand of caustic reduced polyester was closer to silk than that of microfibre polyester. In their experiment, they used satin weave on the caustic soda and plain weave of the microfibre, so there was also an effect of fabric parameters as well as finishing treatments.

1.3.4.3 Polyester

The mechanical properties of silk and polyester were compared by Matsudaira and Kawabata [147, 148]. They noted that the weight reduction process of polyester could be likened to the sericen removal process of silk, which provides the characteristic soft hand to silk fabrics. The distinctive hand of silk fabrics is due to their ability to easily deform and recover from shear strain in the small strain region. At larger strains, these distinctive properties disappear. Polyester fabrics in both weight reduced and standard states were compared to silk; the weight reduction process made the polyester more silk-like. The sericen removal of silk increased the weave crimp of the fabric and introduced an "effective gap" between the warp and weft threads at their crossover points.

Table 1.3.2 Comparison of Effective Gap of Fibres

	Silk	Polyester	Weight reduced Polyester
Effective gap	6.6	0.0	2.5

Although the weight reduction process introduces a small effective gap in the polyester fabric, it also destabilises the weave structure, which the sericen removal of silk does not do. Therefore, there is a limit of weight reduction that can be applied to polyester, although in Japan high amounts of weight reduction have been established (up to 30%) [40, 149].

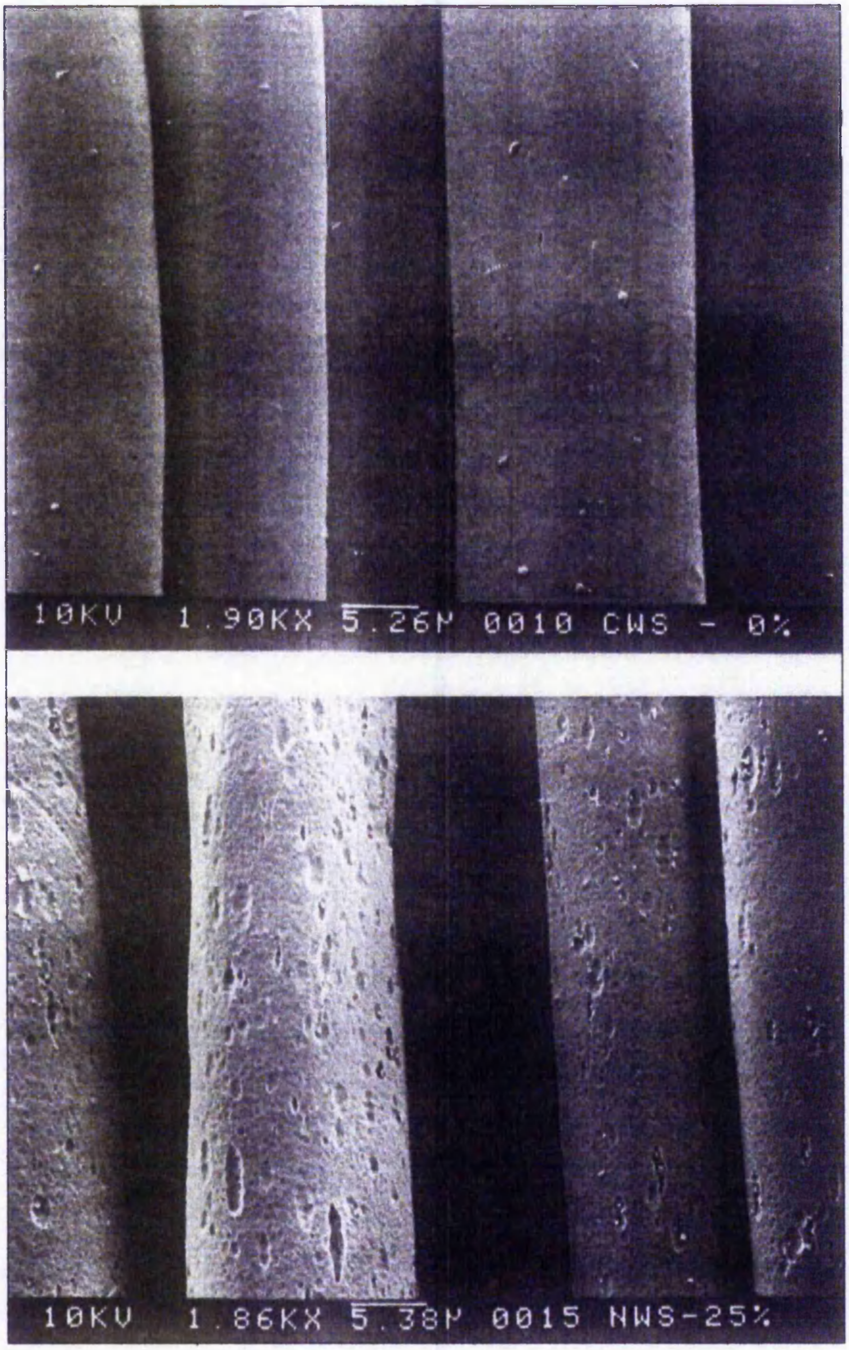
Matsudaira and Matsui assessed the changes in the mechanical properties of polyester fibre fabrics through the finishing stages, including weight reduction [102]. The processes reduced bending and shear rigidity, thickness and mass. The total hand value gradually increased as the fabric progressed through the finishing processes. The Koshi (stiffness) and Hari (anti-drape stiffness) were reduced and the Shinayakasa (flexibility with a soft feel) and Fukurami (fullness and softness) were increased. Discriminant analysis was used and it was found that the Hari and Shinayakasa of the polyester fabrics were similar to that of silk after the weight reduction stage.

Weight reduction can also have an effect on the hydrophilicy (ability to retain water, wicking height) of the fabric. This was investigated by several researchers. The technique, depending on the base and reaction conditions, can improve hand, drape and hydrophilicy, and the tendency for soiling, pilling and clinging is reduced. [150]. Treated fabrics also dry quicker than untreated fabrics [151]. It was found that temperature had a larger effect than the concentration of alkali, which in turn had a larger effect than the time of hydrolysis on the improvement in wettability [152, 153]. However, the changes have been found to be only effective on the surface, as no measured changes were found in the fibres' moisture regain [154, 155]. The strength of the fibre is also effected by the hydrolysis treatment; Dave found a linear correlation between strength and weight loss [155].

The different affects of hydrolysis on regular and micro-denier polyester were assessed by Hsieh [152]. It was found that the reduction in thickness was more pronounced in the regular polyester, whereas the microdenier polyester showed a greater degree of pore enlargement.

The effect of the treatment depends on the basic fibre characteristics of the fabric. Bright fibres with round cross-sections lose weight more slowly than delustred type with mulitlobal cross-sections. This could be due to the larger surface area or the presence of the delustrant or both. It was noted that a delustred sample is more heavily pitted (even though its weight loss was much less than a bright sample) and also that samples lose weight faster after texturing. The addition of a cationic surfactant increased the rate of weight loss [153].

Figure 1.3.1 Comparison of Treated and Untreated Polyester



Top: untreated
Bottom: after treatment with 10% aqueous NaOH at 60°C:
Weight loss = 25%. (For visual comparison only - scale not given in original paper)
Source: [150]

1.3.4.4 Cellulosics

Dreby investigated the effects that the concentration of four different softening agents had on the mechanical properties of cotton fabrics [63]. He noted that three out of the four chemicals had a slight stiffening effect at very low concentrations.

After this period, there was a very sharp increase in pliability with increased softener, before a reduction above a concentration of 1%. Dreby also assessed the effect of a crease resistant finish of a rayon fabric (regenerated cellulose) [63]. Results of compression tests on untreated and treated fabrics were analysed. It was found that the untreated sample was more compressible than the treated sample, although the treated fabric had a compressional resiliency (recovery) of 62%, whereas the untreated sample was only 43%.

The effect of cationic surfactants on cellulosics was investigated [60]. She found that the application of surfactants left residues on the fibres, which acted as lubricants for relative fibre motion, reducing bending and shear rigidities with only slight effects on the surface properties.

Taylor reported on a seminar in which Dr Cheng of Hong Kong Polytechnic related using FOM to change the hand properties of ramie to be more like the hand of cotton [156]. The finishing treatments were assessed and a self cross-linking silicone elastomer was found that reduced the undesirable stiff properties of ramie fabrics.

Hes et al stated that the problem with long processing routes (such as those intended to give an easy-care finish to cotton fabrics) is that there can be cross-effects of the processes that give end results which differ from those expected [72].

1.3.4.5 Mechanical Properties

The effect of chemical processing on drape results has been investigated [157]. It was found that mercerisation raised the drape coefficient by up to 10%, scouring and bleaching by 7-15%, starching up to 90% and carbonisation and heat-setting by 5-30%. Thus starching was found to have the largest effect on the drape coefficient.

Setting can be defined as any process that stabilizes the weave crimp. It was found by Baird that hygral expansion increases with the increased degree of set during finishing [82].

Hwo & Jong stated that any procedure that can effect the inter-yarn force and freedom of movement will alter the mechanical properties of fabrics [103]. Tarafdar stated that the FAST system's measure of surface layer thickness was a good predictor of the effectiveness of various operations like milling, raising and pressing [10].

However, Sundaraam noted that although FOM was a useful aid in fabric finishing it had limitations [158]. The system may help identify a problem but it would not be able to predict how it should be solved. It is extremely unlikely that one mechanical property could be altered in isolation, as they are not independent of each other. Some researchers assume independence of mechanical parameters, thereby raising questions about the validity of their conclusions [159, 160].

1.3.5 The Effect of End Use

The influence of repeated dry-cleaning was assessed by Okamoto, who found that for winter suits the hand showed an overall improvement but for summer suits dry-cleaning produced a deterioration in the hand [41]. He assessed wool and wool blends with polyester and cotton but found that there was no significant effect of fibre type on the changes.

A similar research was conducted by Dhingra, who assessed the mechanical properties before and after commercial dry cleaning and steam pressing, and also after steam pressing without the dry cleaning component [143]. Thickness, compressibility and compressional energy increased after dry cleaning and to a lesser extent after steam pressing. Dry cleaning and pressing caused stress relaxation within the fabric leading to a reduction in hysteresis and, albeit to a lesser degree, rigidity in shear and bending for fabrics finished with no chemical set. In contrast, where chemical had been used during finishing, the dry cleaning and pressing resulted in a marked increase in hysteresis and rigidity.

Mackay assessed the manner in which the sensory and mechanical properties of 1x1 rib knitwear fabrics change during domestic laundering [9, 106]. She found that acrylic fabrics changed due to loss of yarn bulking or texturing which resulted in a more flexible fabric; the cotton fabrics became stiffer, harsher and less extensible because of fibrillation damage; shrink resist wool incurred serious felting problems when washed at normal rather than low agitation.

1.4 The Aims and Objectives of the Research

There are two main systems for carrying out Fabric Objective Measurement studies, the KES-FB system developed by Kawabata and colleagues and the FAST (Fabric Assurance by Simple Testing) system developed by CSIRO. From the literature it can be seen that the FAST system has not been used as extensively as the KES-FB system in research on mechanical properties, garment engineering and fabric engineering. However, it can also be seen that where correlation work has been carried out, the FAST and KES-FB correlate well. Investigations on repeatability and reproducibility indicate that the FAST compares favourably with the KES-FB. It has also been said that the FAST is more suitable to an industrial environment because of its simplicity. However, until more research work is carried out on the application of FAST to fabric for different end uses than suiting and shirting, it is difficult for industry to recognise the suitability of the FAST system.

With these points as a reference, this thesis will investigate the application of the FAST technique to the totally new area of women's thin dress fabric. This has previously only been investigated using the KES-FB system. More specifically, weight reduced polyester fabrics will be considered. The aim of the research is to assess if FAST can be used in this uncharted area. Another aim of the research is to assess the effect of the weight reduction process on the fabrics' mechanical properties to determine if an optimum amount of weight reduction for different fabrics could be established. This is to be assessed by measuring fabrics with various percentage of weight reduction and analysing the difference in the results.

A further aim is to relate results of mechanical data with problem variables of ease of manufacture, distortion of garment measurements, and garment appearance. Although isolated information (such as fabric dropping which can be related to distortion of garment measurements) has been assessed using the KES-FB, a full investigation of this nature has not been carried out previously and thus is a new area of investigation. Appropriate statistical analysis methods will be used throughout to clarify relationships between problem variables and the mechanical property data.

Because the research is extending the use of FAST to a type of fabric having considerably different mechanical properties than have those fabrics for which FAST was originally developed, it is highly probable that some modifications to the equipment or test methods will be required. Information obtained from the review of literature a base to the investigation in any such developments and modifications of test methods and equipment will be based on a review of the literature, particularly any previous research using the KES-FB on similar fabrics, and the results from the modified procedure checked against current standard procedures.

CHAPTER 2 - EXPERIMENTAL METHODS

This chapter explains the standard test methods that were used throughout the research undertaken for this thesis. Guidelines are given where possible to the type of results that could be expected and where potential problems may be encountered. This information has been gained from the FAST user's manual [1], guidelines available on KES-FB [24] and from seven years personal experience working in textile testing, specialising in performing the FAST test for a commercial testing laboratory. This experience was invaluable for interpretation of the mechanical data produced by both the FAST and the KES-FB. A brief guide to the fabrics used is also given, as well as descriptions of the statistical techniques used.

2.1 SiroFAST

The basic principle of the FAST is to combine the results from three simple test instruments and a test method in order to establish a fabric profile that can act as a guide to quality. The results can be assessed against established guidelines to predict problems in manufacture. The system was developed for wool and wool blend fabrics but is applicable for most fibres that have a suiting end use [161].

2.1.1 Test Methods

The tests instruments measure compression (FAST-1), bending (FAST-2) and extension (FAST-3). A method for stability is also described (FAST-4). The instruments are connected to a computer with the FAST data acquisition and analysis software, and the results for the three tests are automatically entered into the FAST control chart as the samples are measured. The relaxation shrinkage, hygral expansion and weight per square meter results are inputted separately. Three samples are prepared in each of the warp, weft, right bias and left bias directions. The same samples can be used for the three tests provided they are used in the correct order: FAST 1 should be measured first, then the FAST 2 and finally the FAST 3. Separate samples are required for the stability, weight and compression after steaming measurements. The suffix of (1) represents measurement in the warp direction, (2) represents the weft direction and letters without suffixes relate to parameters that do not have a fabric direction (for example surface thickness - ST).

2.1.2 Measurements using FAST-1

The compression meter has a circular test area of 10cm^2, with an initial load of 2 gf/cm^2 providing the parameter T2. The same sample is then measured at a load of 100 gf/cm^2, which gives the results of T100. Surface thickness (ST) results are calculated by subtracting T2 from T100. The three thickness parameters are also measured after a pressing operation (the samples are subjected to 30 seconds steaming on an open press and 30 seconds vacuuming). The parameters are then denoted in the following way: released thickness at 2 gf/cm^2 (T2R); released thickness at 100 gf/cm^2 (T100R); and released surface thickness (STR). All the measurements are recorded in millimetres and the results are averages of five readings. The FAST control chart displays the parameters of T (referred to as T2 during the measurements), ST, and STR.

Both thickness and surface thickness are good indicators of fabric handle. They can also relate to the effectiveness of finishing treatments such as cropping or brushing. The measurements produced after steaming (released thickness and released surface thickness) indicate how much the handle and appearance of the fabric will change during manufacture when steamed during final pressing. The larger the difference between surface thickness and released surface thickness, the more un-stable the fabric will be, there are no specific requirements for these properties. The weight parameter (the measurement of which is described in 2.3.5) also has no requirements, but fabrics with lower weights usually present more problems in manufacture.

2.1.3 Measurement using FAST-2

The bending meter assesses the bending length of a 50 mm wide strip using a flexometer at a fixed angle of 41.5°. The instrument has a light beam inclined at 41.5° from the horizontal; the bending length (C) measurement is recorded when the fabric sample bends to the given angle and therefore disturbs the beam of light. The property is assessed in both warp and weft directions, referred to as C1 and C2 respectively. The average of three readings is used for the calculation of each parameter.

2.1.4 Measurement using FAST-3

The extension meter measures loads of 5, 20 and 100 gf/cm (E5, E20 and E100 respectively). Extension results are calculated by measuring the increase in length of the sample, from a 100 mm gauge length, when a 100 gf/cm load is applied. This is automatically calculated by the FAST programme and is displayed as a percentage. The average of three readings is used. The bias samples are extended under a load of 5 gf/cm (EB5), over an average of six reading (three each from the right and left bias directions). This average is used to calculate the shear rigidity parameter. The control chart displays the parameters of E100-1 and E100-2.

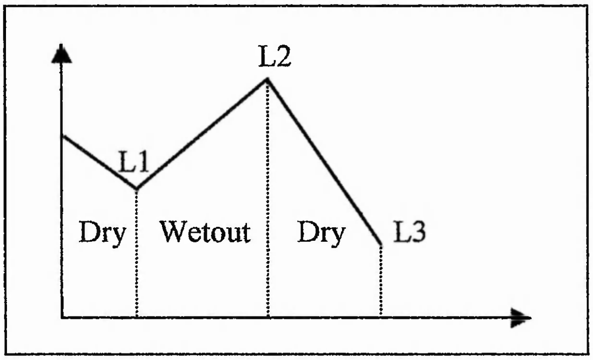
Problems can be experienced during manufacture if extensibility is too low (below 2%). However, problems are more usually found when the fabric is too extensible (more than 4% for the warp and 6% for the weft). This can cause problems in cutting and sewing because extra care is needed to control highly extensible fabrics.

In order to derive more information about the lighter weight fabrics tested, a new set of weights were developed. These allowed loads of 1 gf/cm intervals to be assessed up to 5 gf/cm and then intervals of 5 gf/cm up to 100 gf/cm; this will be described in detail in section 3.4.6.

2.1.5 FAST-4 Test Method

The FAST testing procedure also includes a description of how to test and calculate the parameters of relaxation shrinkage (RS) and hygral expansion (HE). These parameters are obtained from one stability procedure (figure 2.1.1) and the equations given below.

Figure 2.1.1 Visual description of FAST-4 procedure



The L1 dimensions are recorded after the stability sample has been placed in an oven at 105° for one hour. The results are recorded within 30 seconds of removing the sample from the oven, to minimise the re-absorption of moisture from the atmosphere. The sample is then soaked for at least 30 minutes in water at 25°-35° C containing approximately 0.1% non-ionic wetting agent, (the exact concentration and water temperature is not critical). After the soaking is complete, the L2 dimensions are recorded. The sample is then dried in an oven at 105° for an hour, before the L3 dimensions are recorded (again within 30 seconds from removing the sample from the oven). The parameters of Relaxation Shrinkage and Hygral Expansion can then be calculated.

$$\mathrm{RS} = \frac{(\mathrm{L1} - \mathrm{L3})}{\mathrm{L1}} \times 100 \ (\%) \qquad \ldots[6]$$

$$\mathrm{HE} = \frac{(\mathrm{L2} - \mathrm{L3})}{\mathrm{L3}} \times \mathit{100} \, (\%) \qquad \ldots[7]$$

In principle, relaxation shrinkage is an irreversible change in dimensions. It relates to the release of extensional or compressional strains within a fabric that are imposed (but not permanently set) during spinning, weaving or knitting and subsequent finishing. Results of above 3% shrinkage can cause problems with panel matching. Negative relaxation shrinkage (an extension) can cause problems during fusing. The garment areas that are stabilised with interlining will be unable to change dimensions to the same degree as the surrounding fabric, which causes puckering.

Hygral expansion is a reversible change in dimensions and is associated with the absorption and desorption of water. Values above 6% may cause puckering due to differential expansion of garment panels. This leads to garment distortion and generally poor appearance.

2.1.6 FAST Derived Parameters

The FAST data acquisition and analysis software also calculates several derived properties. These require no further measurement and are automatically generated as the necessary parameters are measured with the three instruments.

2.1.6.1 Bending Rigidity

The bending length (C) and mass per unit area (W) are used to calculate bending rigidity (B), assessed in both the warp (1) and weft (2) direction:

$$B = W \times c^3 \times 9.81 \times 10^{\ 6} \ (\text{in} \quad \text{N.m}) \qquad \ldots[8]$$

Bending Rigidity is the force needed to bend the fabric, it relates to the property of stiffness, as felt by the fingers, when evaluating the fabric's handle. It is also an important parameter during garment manufacture. Bending rigidity results that are too low (below 5 μNm) suggests the fabric will be difficult to handle, sew and cut. Bending rigidity is also a good indicator of how well the fabric will drape.

2.1.6.2 Formability

Formability (F) is calculated from the extension results at 5 and 20 gf/cm loads (E5 and E20 respectively) and the bending rigidity results (B). Formability is also assessed in both the warp and weft directions (1 and 2 respectively):

$$F = \frac{(E20 - E5) \times B}{14.7} (\text{in mm}^2) \qquad \ldots[9]$$

Fabric Formability predicts how smoothly a two-dimensional fabric will form into a three-dimensional garment. A low formability (below 0.25 mm^2) increases the likelihood of seam puckering.

2.1.6.3 Shear Rigidity

The property of shear rigidity (G) is calculated using the bias extension results (EB5):

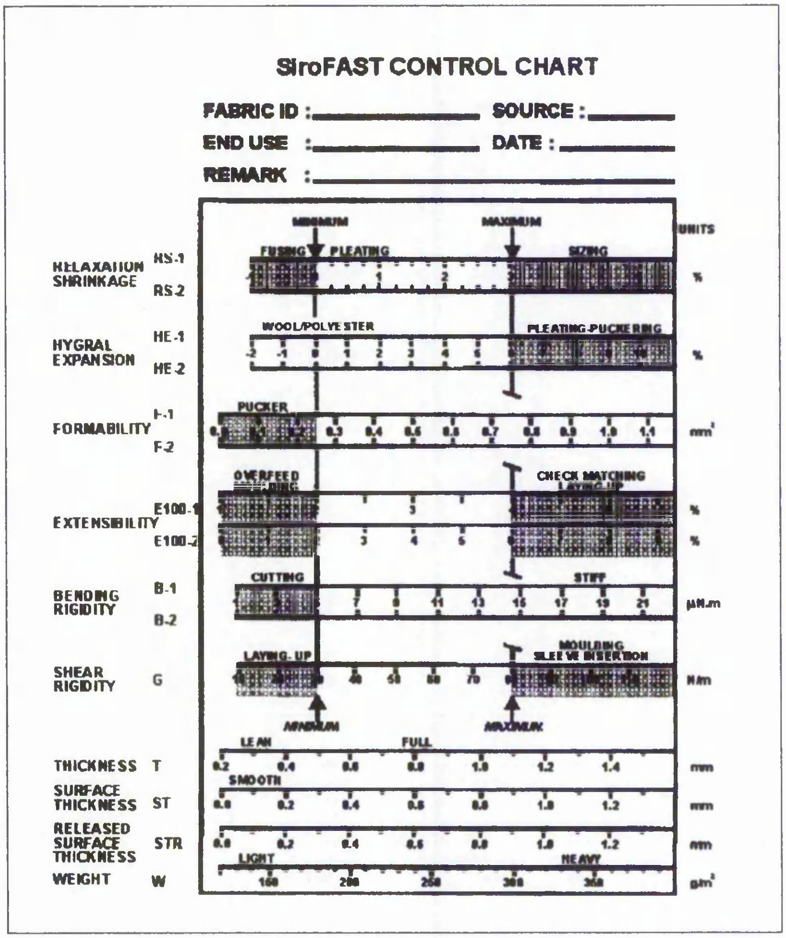
$$G = \frac{123}{BE5} \qquad \ldots[10]$$

The constant, 123, is obtained from the relationship between the load and the force of gravity. Shear Rigidity is a measure of the force required to shear the fabric. Values that are too low (below 30 N/m) indicate that the fabric deforms too easily and may cause problems in handling, cutting and sewing. Values above 80 N/m suggest problems with overfeed and moulding. Shear rigidity also relates to fabric drape, handle and creasing.

2.1.7 Control Chart

The parameters on which the FAST equipment provides results do not have pass and fail values in the same manner that some of the other tests have, but they do come with suggested guidelines that indicate possible problems if the results are outside maximum and minimum values. These limits can be seen on the FAST control chart. The majority of the tests have a non-linear nature: this means that increasing a property up to a certain point will result in a 'better' fabric and then further increases will detract from fabric quality. The chart is designed in such a way that the most important properties (in terms of garment manufacture) are at the top and then placed in descending order of importance [108].

Figure 2.1.2 Example of FAST control chart



2.2 Kawabata KES-FB

The principle of this measurement technique is fundamentally the same as that described for the FAST apparatus. Indeed, the KES is a forerunner to the FAST, which is often described as a simpler, cheaper version of the KES. There are four KES instruments, which measure tensile, shear, bending, compression and surface parameters. Measurement of tensile and shear parameters obtained for this thesis using the KES-FB1

There are a number of advantages the KES system has over the FAST. One is that it measures the recovery from deformation and so can establish the hysteresis (energy lost during deformation). This is important parameter related to inter-fibre friction and the viscoelastic behaviour of fibres, which can be an indicator of problems such as dropping [24]. The KES system also includes a measurement for surface properties which is very important in handle evaluation. Another advantage is that the conditions of measurement can be altered depending on the end-use of the fabric, for example in this thesis the KES-FB1 was used to measure very lightweight fabrics and thus the standard/high sensitivity set-up was used. This has been described in section 1.2.11 and allows lower weights and speeds to be used for fabrics that are easier to distort.

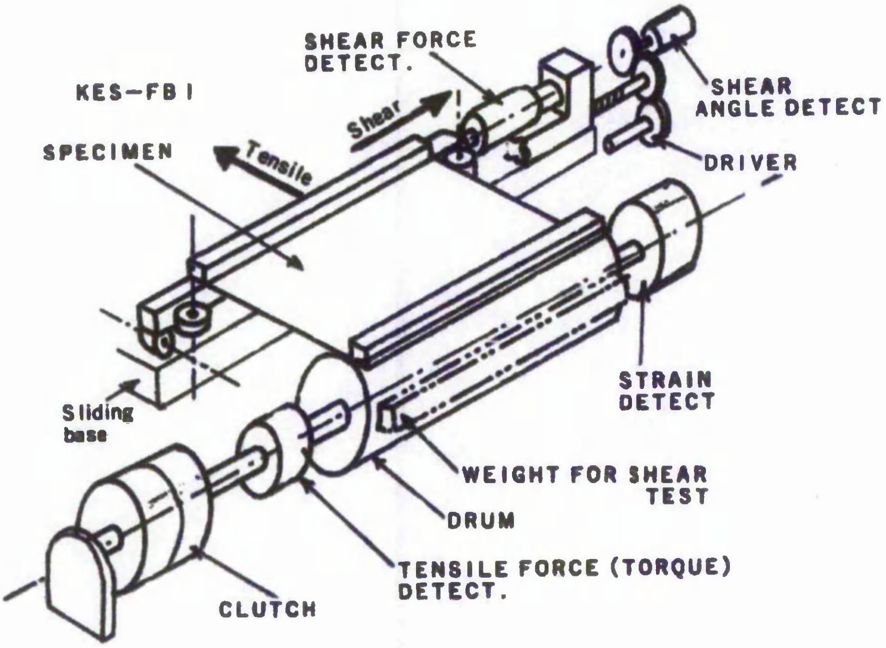
2.2.1 KES-FB1

(The results obtained from the KES-FB1 were obtained by Allison Admed At UMIST)

This instrument measures the tensile and shear parameters. The tensile parameter is measured in a different manner to the FAST as it has a larger width than length (20 x 5 cm). This is because samples with a narrower width than length (FAST samples are 5 x 15 cm) tend to 'waist' when extended. This results in uneven distribution of the force over the width of the samples and can lead to inaccuracies in the results. Thus, the KES system eliminates this source of error.

The measurement of the shear parameter also differs from that of the FAST as pure shear at constant length of sides is used rather than extension in the bias direction. The diagrams below show the equipment and explain the testing principles.

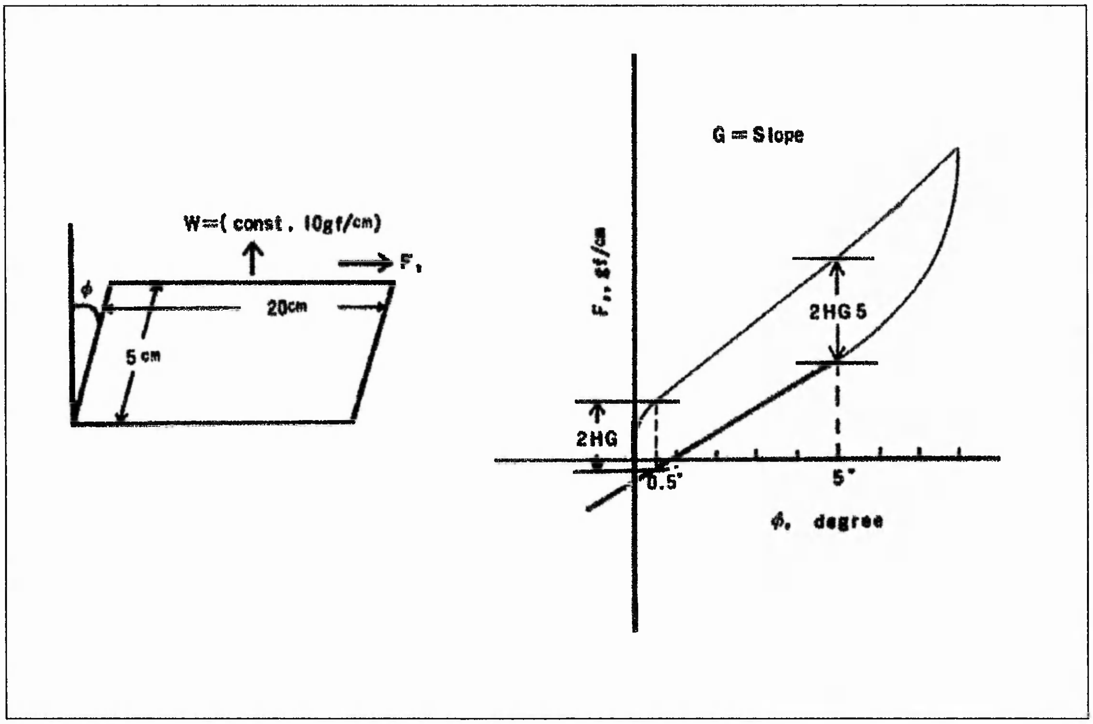
Figure 2.2.1 Kawabata Tensile and Shearing Testing Instrument



Principle of the tensile and shearing tester, KES-F1 and KES-FB1

Source: [23]

Figure 2.2.2 Kawabata Shear Graph



Source: [23]

G (shear stiffness) is obtained from the slope between ϕ = 0.5° and 5°. Typical values obtained for suits are between 0.6 and 0.9 g.cm/degree, whereas much lower values are expected for dress fabrics. 2HG and 2HG5 are measures of energy loss during shear deformation, where the loss of energy is mainly caused by the yarn-to-yarn friction at cross over points. A large hysteresis means greater recovery forces will be required to overcome fabric internal friction. 2HG5 is often used to predict fabric tailorability and garment appearance and 2HG is mostly used in hand value calculations. 2HG and 2HG5 correlate strongly with each other.

Figure 2.2.3 Kawabata Tensile Graph

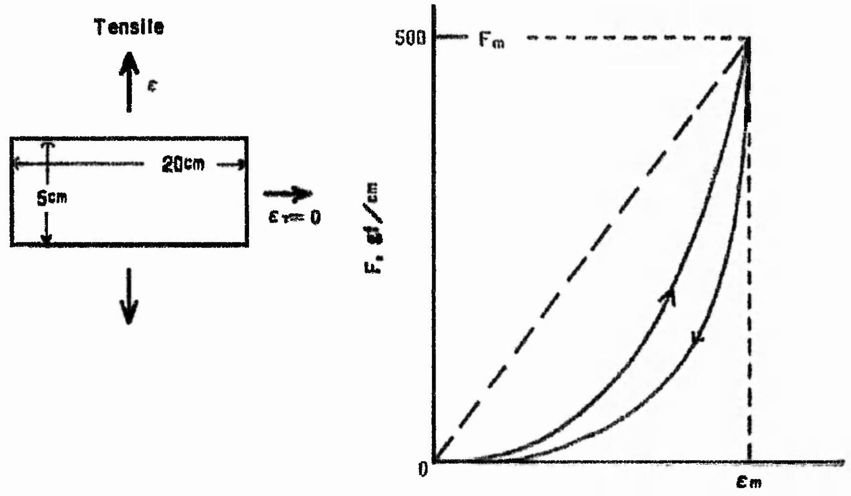


Fig. 4-1 Tensile property.

$$LT = WT/WOT$$

$$WT = \int_0^{\varepsilon m} F d\varepsilon$$

$$RT = (WT'/WT).100 \qquad \ldots[11]$$

where

$$WOT = Fm\varepsilon m/2$$

F: Tensile force per unit width (gf/cm)
ε: Tensile strain
Fm and εm are the maximum values of F and ε respectively.

$W' = \int_0^{\varepsilon m} F' d\varepsilon$ (recovering energy per unit area)

F': Tensile force in recovering process (gf/cm).
Source: [23]

EM is the fabric extension at the fixed maximum load (500g/cm is standard for woven fabrics), typical EM values found are between 3% and 10 %. The ratio of weft to warp extension (αT) is also important, as if there is too large difference between the extensions, the fabric might be difficult to manufacture into garments [115]. The linearity of load-extension curve (LT) measures the deviation of the load extension curve from a straight line. A value of 1 indicates a straight line; values between 0.55 and 0.70 are usually obtained. Tensile resilience (RT) values of between 55-70% are normal for suits, however shirting fabrics can have RT as low as 30% [24]. WT is the tensile energy, which represents the energy required to extend a sample to the prefixed maximum load; higher values of WT correspond to higher extensibilities, with typical values at around 10 g.cm/cm^2.

2.3 Other Tests

The tests described in this section are those that measure the performance or construction of fabrics. Further information about each test can be gained from the normalative reference, which is given and was current at the time of testing.

2.3.1 Analysis of Distortion Using a Non-Contact 3D Scanning Booth

(These measurements were obtained by Martin Bayley at the clothing research unit NTU)

The principle of this technique is that it project a series of moiré light patterns onto the object to be measured and uses this to produce x, y and z co-ordinates by assessing the distortion of the light patterns. The normal use of the booth is in the measurement of people rather than garments as it has been used to research sizing charts. Eight image files (known as clouds) are obtained as measurements are taken from separate areas of the object; (front upper right and left, front lower right and left and the corresponding areas for the back). These are then aligned together to form a single object from which measurements can be obtained.

2.3.2 Drape BS 5058 : 1973

The Cusick drape tester was used to assess fabric drape. The 30 cm diameter (medium) template was used for all the fabric samples. It was likely that some of the samples may have required the smaller 24 cm diameter template (if they were particularly limp) or the larger 36 cm diameter template (for very stiff fabrics). However, the results achieved with different templates are not directly comparable so it was decided one template would be used for all fabrics.

The principle of the drape tester is to place a circular sample of fabric in between two smaller circular disks to allow an annular ring of fabric to drape freely. A light is positioned in such a way as to cast a shadow over the draping section. The outline of the shadow is drawn onto a paper ring, which has the same dimensions as the draping section of fabric. The weight of the complete paper ring and of the shadowed area are measured and used to calculate the drape coefficient (DC).

$$DC = \frac{W_2}{W_1} \times 100 \qquad \ldots [12]$$

Where: W_1 = original weight of annular ring

W_2 = weight of shadowed area

A high drape coefficient indicates the fabric does not drape a great deal and a low drape coefficient indicates high drape. Two samples from each fabric are prepared, and then six measurements are recorded from each sample, (three with the face of the sample upwards (FU) and three with the face downwards (FD)). Averages of the six results for measurements taken for both samples face up and face down are obtained (DCFU and DCFD respectively). The number of nodes (waves of drape the sample forms) can also be used as measures of drape (NFU and NFD).

A fabric's stiffness, weight and shear resistance influences drape. It is important to know the amount a fabric drapes because it is one of the ways consumers judge fabric quality. It also affects the end use. Drape can be defined as its suitability for garment type, and the situation the garment is used for. Sudnik produced drape coefficient specifications for various end uses; underwear 30-60%, dresswear 40-70% and suiting 65-80% [94].

2.4 Drape and its measurement

2.4.1 Introduction

Two finishing experiments were undertaken prior to the work reported in this thesis. The aim of which was to assess the effect of cure time and concentration of resin on polyester cotton blends. During these studies, it was found that the parameter of drape was very important. Statistical analysis had indicated that drape was one of only four parameters that were affected during both finishing trials; it was significantly affected by more factors than any other dependent variable. An extract of the results can be found in the table below.

Table 2.4.1 The parameters effected by the two finishing trials

Variables	**Exercise 1**			**Exercise 2**		
	Resin	Cure Time		Resin	Cure Time	Interaction
Stab to Wash				**		
Stab to Steam	$*_1$			**	$*_1$	
HE	$*_2$	$*_2$				
RS				**	$*_1$	
Weight				*		
Tensile Strength					$*_1$	
Seam Strength				**	$*_2$	$*_1$
Seam Slippage		$*_1$		$*_1$	$*_2$	
Crease Recovery		$*_2$		$*_1$	$*_2$	
Drape		**		$*_{up}$	**	$*_{down}$
Formability		$*_2$				
Extension				$*_1$		
Bending Length					$*_2$	
Bending Rigidity		**				
Shear/ Bias Ext		*				
ST		*				
STR				*		
Parameters in bold – those affected by the finishing variables						

The other parameters affected by both experiments relate to fabric quality in terms of its durability and suitability to purpose. The drape coefficient is related to an intrinsic quality that can be considered added value and thus has a direct relationship to appearance and handle. Due to the importance of drape to both appearance and handle, and the difficulty and time-consuming manner of accurately differentiating between fabrics with similar drape coefficients, an exploration of the property was undertaken.

Research into the ways in which drape can be measured is found in brief in the mechanical properties section of this report. The current British Standard method describes the measurement of drape coefficient using Cusick drapemeter. However there have also been attempts using photo analysis [31, 91, 92] and of predicted drape from mechanical properties of shear and bending [4, 13, 94]. One method of testing drape that was not included in this section was that developed by Aldrich [162], which took an interesting approach in aiming to bridge the gap that exists between technologists and designers.

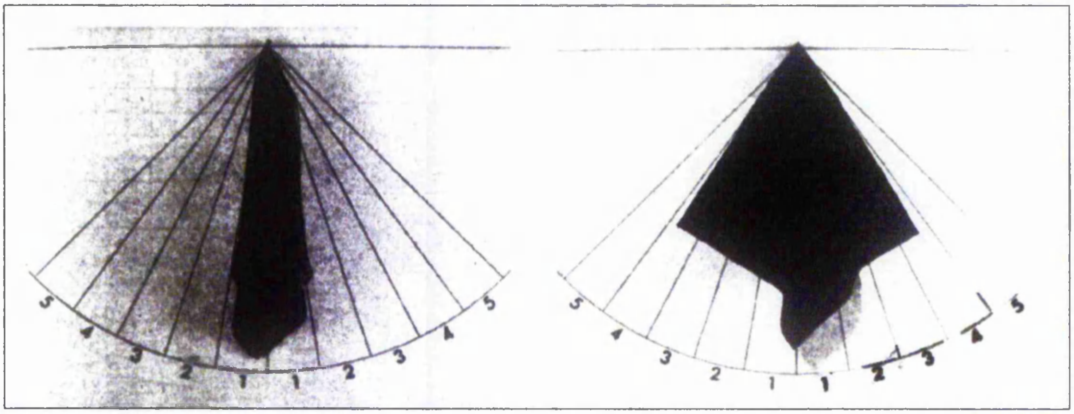
2.4.2 Aldrich Drape Test

This test was produced to fulfil the need for a portable method of assessing drape that could be quickly performed on a square sample of fabric. The drape tester was part of a test method that included extension, shear and weight to provide a profile of a fabric. The rationale behind this was that most buyers/designers are only given a 20 cm square sample of fabric from which to decide whether to purchase it. While they do not need to know the results as accurately as technologists do, it was argued that designers should be able to have a sense of visual and tactile order. It was stated that the tests were not designed to compete with other forms of technological measurement as a completely different approach and purpose was intended for the results [162].

This was a very interesting idea; firstly because a square sample was used, the samples for all other direct measures of drape are circular; it was therefore interesting to establish if a square specimen could be proved valid. The second reason for the interest was because the method is very quick and easy to perform. The basis of the test is to pin the specimen on one corner and establish how close the sides of the sample would fold towards the centre. This is measured by having a board is divided into ten sections, five either side of the pin. A reading is then taken where the positions of the sides of the sample fall in relation to the sections on the board. Low numbers indicated that the sample draped a great deal; high results indicated the sample had little drape, as can be seen from figure 2.4.1. The quick nature of the test is important as Vangheluwe & Kiekens showed, because drape coefficient is time dependent (results will differ over time). Results from the Cusick method are often inaccurate because the test is time consuming [91].

It was decided to investigate this method to establish how valid it was and if it could be altered to increase reproducibility and repeatability, in order to be of use to technologists.

Figure 2.4.1 The Aldrich Drape Tester



2.4.2.1 Modification One

When first observing the Aldrich Drape Tester, it was noticed immediately that the accuracy of the test could be improved by subdividing each section into four. The probability of the sample falling in a given section decreased from 1 in 5 to 1 in 20 (Aldrich: Mod # 1), which would help distinguish more comprehensively between fabrics.

There was no actual test method for the drape tester and there was no mention in the accompanying book of how the testing should be undertaken; for example, whether multiple samples should be used or the same sample should be measured several times. There was no mention of which corner to hang the sample on. Hence, these factors were investigated to assess if they had an effect on the results.

To assess these points, three fabrics were tested. There was a slight difference in the results for some fabrics, depending on whether the warp threads of the top edge of the sample were on the left or the right side of the pin (centre of board). This was given the notation warp/weft when the top edge of the sample was in the warp direction on the left of the pin and the weft direction on the right of the pin. Therefore moving from left to right: warp-pin-weft (and vice versa). Although the final averages were in the correct ranking order, the results had large ranges. The coefficient of variation (CV) was used as an indication of the variation of the results.

Table 2.4.2 Results from the Aldrich: Mod # 1- Fabric Group A

	Warp/Weft	Weft/Warp	Average
1A	24.8	23.0	23.9
Range	23-30	14-32	14-37
CV	**8.22**	**27.77**	**20.19**
2A	14.5	13.5	14.0
Range	11-17	10-24	10-24
CV	**11.23**	**29.12**	**21.78**
3A	27.3	28.9	28.1
Range	24-32	12-34	12-34
CV	**8.83**	**28.59**	**21.85**

There were clear differences between the results achieved when using the different corners. It was also noted that for all the three samples the warp/weft corner gave a narrower range and a smaller coefficient of variation. There was no obvious reason why this should be the case; the three fabric structures were different so it could not be due to them having similar non-isotropic natures. Further investigation was required to assess if this was a coincidence or a valid experimental finding.

2.4.2.2 Modification Two

During the initial testing of these fabrics, it was noted that some of the fabrics were touching the measuring board as they draped and that this tended to coincide with the occasions that produced results outside of the normal range. It was hypothesised that this inhibited the natural drape of the fabrics and therefore distorted the readings. Two methods were tried to alleviate this problem. Firstly, the test specimen was placed on the end of the pin - as far away from the board as possible. However, the length of the pin was not long enough to prevent the fabric from touching the board when it draped. The second possible solution was to position the board tilting forward. The tilting of the board enabled the fabric to drape without touching the board and was seen to be the best method (Aldrich: Mod # 2).

i) Comparison with Standard Drape Test

To establish whether the tilting board would produce a more consistent test it was decided to compare Aldrich: Mod # 2 with the British Standard Drape Tester. Four fabric samples were chosen and tested using the standard method. The ranking order was 3B; 4B; 2B; 1B. Sample 3B had the most drape and 1B had the least. The results indicated large differences in the amount of drape; therefore it should have been quite straightforward for the modified Aldrich equipment to distinguish between them.

Table 2.4.3 Comparison of the Cusick and the Aldrich # 2 Drape Tests (A-B)

A) Cusick Drape Tester- Fabric Group B

	Face Up	Face Down	Average
1B	78.0	76.4	77.2
CV	**2.47**	**2.50**	**2.70**
2B	56.4	55.8	56.1
CV	**9.57**	**5.92**	**7.99**
3B	21.4	21.7	21.5
CV	**2.43**	**1.90**	**2.33**
4B	22,8	22.4	22.6
CV	**4.68**	**3.37**	**4.18**
Total CV	**19.2**	**13.7**	**17.2**
Most Drape → Least Drape	3421	3421	3421

B) Aldrich: Mod # 2 - Fabric Group B

	Warp/Weft	Weft/Warp	Average
1B	13.4	38.7	26.1
CV	**5.97**	**2.84**	**48.70**
2B	12.9	11.9	12.4
CV	**4.18**	**4.53**	**5.93**
3B	15.2	10.5	12.9
CV	**6.65**	**14.29**	**23.48**
4B	11.0	11.2	11.1
CV	**13.48**	**5.36**	**10.23**
CV	**30.6**	**27.0**	**88.3**
Most Drape → Least Drape	4213	3421	4231

The results were an improvement over those of Aldrich: Mod # 1 as the majority of CV results were reduced. Further gains were seen in the lack of obvious difference in the coefficient of variation between the two corners in this experiment. However the large differences in the results obtained from fabric 1B when tested on the different corners indicated that the corner used did have an effect on the results and this would have contributed to the high CV for the overall average.

The ranking order of the results produced by Aldrich: Mod # 2 did not correspond to those produced by the Cusick Test. It was noted that the Cusick Test produced results that gave the same ranking order whether the samples were tested face up or face down and that the overall averages also corresponded to this ranking order.

This was the aim of the modifications to the Aldrich method in order to enable a reduction in testing that would not produce a reduction in accuracy, which was not the case at this stage of the modifications.

2.4.2.4 Modification Three

Further modifications were necessary to achieve consistent, unbiased results; the manner in which the grades were established was the next investigation. Each fabric was given the grade that corresponded to the sections of the top edges the specimen draped in line with. It was hypothesised to be more accurate to measure the shadow cast from a lamp positioned in front of the sample. This removed any differences in the results that could occur due to the operator sitting at different angles to the board.

The method of holding the sample on a pin was also thought to be unsuitable, as it was unrepresentative of how fabric drapes on the body. Furthermore, as the weave was actually pierced by the pin, this could have caused fabric distortion. Thus, the next modification consisted of clamping a corner of the sample to a bulldog clip (the same area of the fabric was always clamped). The clip was then attached to a rod positioned above the board. It was positioned a standard distance away from the board, as was the lamp. (Aldrich: Mod # 3). Four samples were tested using the new modification.

Table 2.4.4 Results from the Aldrich: Mod #3 - Fabric Group D

	FACE		BACK		AVERAGE
	Warp/Weft	Weft/Warp	Warp/Weft	Weft/Warp	
1D	19.0	14.8	14.2	18.6	16.7
CV	**20.0**	**9.9**	**10.4**	**12.5**	**19.7**
2D	13.2	12.8	12.8	14.0	13.2
CV	**7.4**	**5.8**	**7.7**	**9.0**	**8.5**
3D	16.4	17.2	18.4	15.0	16.8
CV	**3.0**	**28.6**	**10.1**	**0**	**17.4**
4D	15.4	14.8	13.6	13.6	14.4
CV	**19.1**	**21.1**	**8.8**	**5.9**	**16.7**
Total CV	**49.5**	**65.4**	**37.0**	**27.4**	**62.4**
Rankings	2431	2143*	2413	4231	2413

*It was decided to rank sample 1 before sample 4 because although they both had the same average result, sample 4 had the largest individual result.

The results did not show the improvement expected. The CV results were still very large for some of the fabric samples. However, it was felt that the test method was much improved, as a great deal of possible operator error had been removed.

i) Comparison with Standard Drape Test

The four fabrics from group D were tested on the Cusick Drape Tester. This would establish if the coefficients of variations were significantly less than for the standard test. In addition, it would establish whether the rankings would be the same.

Table 2.4.5 Results obtained using Cusick Drape Test - Fabric Group D

	Face Up	Face Down	Average
1D	58.1	56.8	57.4
CV	**4.3**	**2.7**	**3.8**
2D	39.4	43.3	41.3
CV	**0.1**	**2.1**	**5.0**
3D	59.5	54.4	56.9
CV	**0.8**	**1.4**	**4.6**
4D	51.9	51.7	51.8
CV	**2.2**	**1.0**	**1.7**
Total CV	**7.4**	**7.2**	**15.1**
Rankings	2413	2431	2431

The Aldrich test was still not as consistent as the Cusick test, however the coefficients of variations were improved from those for Aldrich: Mod # 3, especially for the averages. The ranking order of these fabrics was obviously harder to distinguish as the Cusick test also produced different ranking for face up and face down samples. In contrast to previous experiment, the warp/weft corner was more in line with the standard.

ii) Comparison with Subjective Drape Test

It was decided to test the same fabrics for drape in a subjective manner. This involved asking people to rank the fabrics from those with the least to those with the most drape. Four points were awarded to the sample considered to have the least drape, three points to the next fabrics in the scale and so on, until one point was give to the fabric with the most drape. The results were then averaged. It was necessary to take great care when conducting the subjective tests to present the fabric samples to each assessor in a completely random manner. The ranking of samples was chosen rather than grading due to the problems grading presents when averages are required [163]. Twenty people were asked for their opinions and the following results were obtained:

Table 2.4.6 Results using Subjective Drape Test - Fabric Group D

Most Drape →	2D (1.2)	1D (2.6)	4D (2.8)	3D (3.5)	→ Least Drape

It was thought logical that the overall average of the directions for the Aldrich and the average of the faces for the Cusick should be used as the results of the drape test. However when this result was used neither Aldrich's or Cusick's test correlated with the subjective analysis. The Aldrich test did correlate with the subjective assessment when the weft/warp corner of the face was used. Unfortunately, this corner was the one that produced the largest CVs and was therefore the most unreliable.

The weft/warp corner on the back produced the most consistent results. However, the ranking obtained from its results did not correspond to either the subjective ranking or the Cusick method. Thus, it was not clear which results should be used and whether the apparatus, even after the modifications, was suitable to be standard testing equipment.

iii) Testing Samples on Different Days

There were no further modifications that could be made in order to improve the test, without completely changing it and reducing its all-important simplicity. It was therefore decided to continue with the Aldrich: Mod # 3. Four different fabric samples were obtained and tested on the equipment. The same samples were then re-tested the next day. This was to assess whether the test method produced repeatable results.

Table 2.4.7 Results using Aldrich: Mod # 3 - Fabric Group E (Different days)

A) Day 1

	FACE		BACK		AVERAGE
	Warp/Weft	Weft/Warp	Warp/Weft	Weft/Warp	
1E	18.4	26.4	23.6	17.0	21.4
CV	**7.4**	**1.9**	**11.2**	**0**	**19.2**
2E	21.2	17.0	18.8	18.2	18.8
CV	**16.7**	**16.2**	**9.8**	**20.0**	**18.1**
3E	12.4	12.0	12.6	13.0	12.5
CV	**4.0**	**0**	**6.3**	**4.9**	**5.4**
4E	13.2	13.0	13.6	12.6	13.1
CV	**3.0**	**0**	**3.6**	**6.3**	**4.8**
Total CV	**31.1**	**18.1**	**30.9**	**31.2**	**47.5**
Rankings	3412	3421	3421	4312	4321

B) Day 2

	FACE		BACK		AVERAGE
	Warp/Weft	Weft/Warp	Warp/Weft	Weft/Warp	
1E	17.0	25.6	21.0	21.0	21.2
CV	**7.4**	**5.3**	**3.0**	**3.0**	**15.2**
2E	19.0	19.2	20.2	17.0	18.1
CV	**20.2**	**9.5**	**8.5**	**20.0**	**16.4**
3E	12.4	11.4	11.8	12.2	12.0
CV	**4.0**	**4.3**	**6.3**	**6.1**	**6.2**
4E	12.2	12.2	12.4	12.2	12.3
CV	**3.3**	**3.3**	**4.0**	**6.1**	**4.4**
Total CV	**34.9**	**22.4**	**21.8**	**35.2**	**42.2**
Rankings	4312	3421	3421	(34)21*	3421

* It was decided not to differentiate between these samples, as the ranges of their results were exactly the same.

There was a difference in some of the results obtained depending on which corner and face were used. The weft/warp corner when tested in the face provided the lowest coefficient of variation; thus the results were the most consistent with each other. The weft/warp corner on the face corresponded with the warp/weft corner on the back in this experiment. These two corners were the only ones that gave the same ranking as the Cusick test (3421), except for the overall average. These results were much improved compared to those from the Aldrich: Mod #2 and from the previous batch of tests (D), however, some of the CVs were still too large.

A paired t-test was used to analyse the results further. The critical value for the number of results within the test was 2.093. A t-value of less than this would indicate that there was no real difference between the means. A greater t-value would be evidence to suggest that the averages were different; thereby indicating that they were sets of results obtained on the different days were not from the same overall population of results and hence the test was not repeatable.

Table 2.4.8 Results from a t-Test using Paired Samples - Fabric Group E

	t-Value	
1E	0.281	Accept (H0)
2E	-0.432	Accept (H0)
3E	2.604	Reject (H0)
4E	4.073	Reject (H0)

The results of this statistical analysis indicated that the results obtained from Aldrich: Mod # 3 could not be relied upon to be repeatable. There was a reduced amount of drape evident in samples 1 and 2 compared to samples 3 and 4 and it was therefore considered that perhaps the test was more suited for fabrics with a small amount of drape.

The Cusick test has a similar difficulty. The British Standard test method provides three different templates for use on fabrics with the extremes of drape. However, this solution was not applicable to the Aldrich test, as its idea was not to be destructive because the test specimens were used for other tests. Thus the sample size could not really be reduced.

2.4.2.4 Summary of Modifications

It was decided not to continue with research into this method of testing drape. Several methods had been tried in order to increase the test's accuracy and repeatability; Aldrich: Mod # 3 provided the more accurate results. The test method had been greatly improved, however the results still varied considerably. The original purpose that the test was designed for it was still a valid tool, however it was not considered suitable for use by technologists.

2.4.3 Kerrigan Drape Tester

2.4.3.1 Introduction

It was decided to create a new test in order to further explore the validity of assessing drape using a square sample of fabric, but using a technique similar to the Cusick test method. The test was thus; a square was draped over a cylinder of 3 cm diameter; a lamp is positioned above to cast a shadow of the draping specimen onto a piece of paper with squares of increasing size, these are to record the degree of drape of the sample. Sixteen lines divide the squares; these are where the drape of the sample would be assessed. The readings are taken from the size of square the shadow cast on each of the sixteen lines. The test utilises simple equipment and is very simple to set up. The method is intended to approximate the area of the shadow created by the draping sample; as it misses the drawing and paper cutting stage necessary in the standard method, it was hoped it might be suitable for a designer who wants an idea of drape rather than a precise value. It was anticipated that if the test method was proven valid photo-sensitive board could be adopted to measure the area shadow cast without any counting. However, this was not appropriate until initial analysis showed potential for the test.

Two new fabric samples were obtained. Thirty-two measurements were taken on each. Sixteen on front and back, with the warp being placed in all four directions at 90° to the operator, (↑↓←→). These were tested in different combinations to assess if they had any effect. The results obtained were as follows:

Table 2.4.9 Results using the Kerrigan Drape Test – Fabric Group F

	Face Up					Face Down				
	↑	↓	←	→	Ave	↑	↓	←	→	Ave
1F	66.75	68.50	65.00	64.75	66.25	67.25	67.75	65.00	64.75	66.19
CV	**6.28**	**3.48**	**2.18**	**1.94**	**4.22**	**6.80**	**4.06**	**2.18**	**1.94**	**4.35**
Total Average (Up & Down)				66.22						
CV				**4.21**						
2F	89.00	91.00	92.50	88.25	90.19	82.75	73.75	78.00	72.75	76.81
CV	**13.20**	**12.30**	**12.62**	**12.15**	**11.41**	**6.19**	**3.39**	**4.32**	**1.73**	**6.61**
Total Average (Up & Down)				83.50						
CV				**12.55**						

The coefficients of variation for these samples were very low and therefore the test showed potential. There were no obvious differences between the different directions the samples were positioned in. There were differences, however, due to whether the samples were tested face up or face down, thus both were required.

2.4.3.2 Modification One

There was a larger coefficient of variation for the sample 2F than 1F; this was hypothesised to be because fabric 2F was stiffer. The maximum point of the shadow did not always fall on one of the lines. Therefore, the larger area of shadow for this fabric was not always accounted for. Thus, the method of test was revised to read the maximum point of the shadow in between the lines. This method took into account the width of the node. The results were approximations of the area of the shadow (Kerrigan: Mod # 1).

This followed the reasoning that having a large the numbers of sections in a histogram approximates to the area under a curve. In a similar manner sixteen readings should approximate to the area of the shadow, and so be similar to the Cusick method without the cutting and weighing.

i) The Effect of Alternating Fabric Faces

A further attempt was made to discover why the coefficient of variation was larger for sample 2F than for sample 1F. It was decided to assess the effect of the order in which the samples were measured. In the previous test, because the four directions (↑↓←→) were tested, all of the face up reading were taken together prior to all of the face down readings. This was noted to deviate from the other standardised methods of assessing drape that alternate which surface is uppermost when testing. This is because the impact of gravity (which causes the fabric to 'creep' increasing its drape) is cumulative and thus if the same surface is uppermost constantly for any length of time the drape coefficient will gradually be reduced. Therefore alternating the surface uppermost when testing reduces this effect of gravity. Sample 2F was re-tested in both manners to establish if it was an important variable.

Table 2.4.10 Results using the Kerrigan Drape Tester: Mod # 1

	Face Up	Face Down	Average	
2F	102.24	107.92	105.17	
CV	**10.77**	**8.76**	**9.92**	All face up and then all face down
2F	107.50	113.50	110.50	
CV	**4.63**	**10.25**	**8.36**	Alternating face up and down

Alternating the sample between the face up and face down readings produced more consistent results and was therefore incorporated into the test method. The fact that the results achieved when alternating the test specimens were larger than the originals did reinforce the theory that the previous results were reduced by fabric creep. Another alteration in the test method was to test the samples in one direction only (Kerrigan: Mod # 2). The cylinder used was round, as was the shadow and therefore it was hypothesised that turning the sample around only moved the shadowed area to different positions on the board. The previous results confirmed this. Therefore the samples were only tested with the warp perpendicular to the operator (↑), thus increasing the simplicity of the test.

2.4.3.3 Modification Two

i) Comparison with Other Methods of Testing Drape

At this stage, the previous work on fabric group D was re-examined. The Kerrigan: Mod # 2 was used to test fabrics 1D, 2D, 3D & 4D, the results were compared with the Aldrich, Cusick and subjective methods of assessing drape.

Table 2.4.11 Results using Various Methods of Testing Drape - Fabric Group D

	Rankings	**Total CV**
Aldrich: Mod # 3	2413	**62.4**
Cusick Drape Test	2431	**15.1**
Kerrigan: Mod # 1	2134	**27.1**
Subjective	2143	

The results indicated that although the Kerrigan: Mod # 1 test was not as consistent as the standard Cusick it was more consistent than the Aldrich: Mod # 3. Thus, further research was warranted.

ii) The Effect of the Size of Cylinder

It was resolved to refine the Kerrigan Drape Tester further by assessing the contribution that the size of cylinder supporting the fabric had on the drape assessment. The original cylinder used was only 3cm in diameter. The Cusick test had 60% of the fabric supported, with only 40% draping, whereas the original Kerrigan test supported approximately only 7% of the fabric area.

The Cusick test method also uses a 24 cm diameter template for limp fabrics, a 30 cm one for medium fabric and a 36 cm one for stiff fabrics. Altering the size of the sample alters the proportion of the fabric that is supported by the instrument. Using this logic, it was possible that the different variations for the two fabrics in the previous tests might have been due to one fabric being more suited to the smaller support than the other.

Three cylinders were tested, (A, B & C) with 7 cm, 8 cm and 10 cm diameter respectively. Three fabrics were chosen with varying degrees of drape. It was hoped that one cylinder could be used for all fabrics as this would further increase the simplicity of the test. Two samples of each fabric were tested on different days to analyse the repeatability of each of the cylinders.

Table 2.4.12 Results using the Kerrigan Drape Tester: Mod # 1 - Fabric Group G

	Day	1G		2G		3G	
		FU	FD	FU	FD	FU	FD
Cylinder A	i	142.4	138.3	109.0	110.0	105.9	104.2
CV		**4.64**	**4.54**	**4.13**	**2.50**	**2.53**	**3.54**
	ii	145.0	136.3	114.5	113.1	108.4	109.9
CV		**2.32**	**1.89**	**2.37**	**3.70**	**2.47**	**2.64**
Cylinder B	i	169.4	162.1	127.8	130.8	124.5	124.1
CV		**1.46**	**3.56**	**3.06**	**2.81**	**2.21**	**1.66**
	ii	174.0	171.9	130.6	131.6	121.6	121.5
CV		**1.80**	**5.13**	**2.08**	**2.18**	**4.43**	**2.80**
Cylinder C	i	193.3	192.6	157.3	157.0	149.8	149.4
CV		**0.67**	**1.78**	**1.39**	**1.90**	**1.73**	**1.63**
	ii	193.9	192.9	157.6	156.1	151.3	152.8
CV		**2.58**	**3.21**	**1.28**	**2.21**	**1.74**	**2.24**

Cylinder C provided the best results, as the averages of the two samples were consistently the most similar and the coefficient of variations were the lowest. Hence, cylinder C was chosen as the standard for Kerrigan Mod # 2.

2.4.3.4 Modification Three

A selection of a greater number of fabrics was required to establish how the test would perform. In order to test a larger variety of fabrics, it was necessary to assess if the number of readings performed during each test could be reduced without reducing the accuracy unacceptably. The previous tests had incorporated twelve readings for each surface of the sample, each having 16 values, and two samples were used for each fabric. This produced 768 values to collect and analyse.

An estimation of the error was calculated (as described in the experimental methods chapter) from these results and it was found that the error that was present in the results from twelve readings was less than one percent. Since the test was not required to be this accurate, the number of tests performed on each sample could be reduced. The error could be increased to 2% without severely damaging the accuracy of the tests. The results for the fabrics tested using the new cylinder were inputted into the error equation, using a required percentage accuracy of two in order to calculate how many readings were required. The results are given below.

Table 2.4.13 The accuracy of the Kerrigan Drape Tester Mod # 2

2% Accuracy	Number of Samples Required		
	Face Up	Face Down	Average
1G a	0.43	3.03	1.68
1G b	6.38	9.92	7.86
2G a	1.84	3.47	2.55
2G b	1.58	4.69	3.21
3G a	2.89	2.54	2.61
3G b	2.92	4.80	3.92
Average	**2.67**	**4.74**	**3.64**

Thus the number of tests for each sample could be reduced to five and the accuracy of the test was still acceptable. This would reduce the data to collect and analyse to 320 values, thereby more than halving the time necessary to complete the test. None the less, attention was paid to any fabric that produced inconsistent results for the two samples as this might indicate that the five readings were not enough.

i) Testing for Repeatability & Accuracy

Two samples of sixteen fabrics were utilised for this test. The results were analysed by two methods; firstly, a t-test was calculated. This was to establish if the two samples produced means that were taken from the same overall population. A paired t-test could not be used for this analysis as two different samples were tested. The results were therefore subject to actual differences inherent in the fabric samples as well as those that may have been caused by inaccurate testing; therefore a t-test assuming equal variances was appropriate.

Table 2.4.14 Results from a t-Test assuming Equal Variances - Kerrigan: Mod # 3 - Fabric Group H

	Face Up	t-Test	Face Down	t-Test
1H	167.00		170.80	
	169.60	-0.83	170.60	0.32
2H	157.00		154.00	
	154.80	0.87	155.8	-1.33
3H	184.40		183.20	
	182.60	1.05	184.40	-0.53
4H	169.80		170.00	
	169.40	0.23	168.60	0.66
5H	186.20		182.40	
	176.40	6.61	181.80	0.51
6H	180.60		184.20	
	180.40	0.24	178.80	3.58
7H	166.60		170.60	
	168.60	-1.02	169.60	0.59
8H	215.60		218.20	
	218.60	-3.54	218.60	-0.26
9H	176.60		173.00	
	177.00	-0.16	171.40	0.33
10H	193.00		197.20	
	188.60	3.14	195.20	2.02
11H	184.60		186.40	
	190.40	-4.19	184.00	0.79
12H	182.60		181.60	
	186.60	-1.11	186.20	-0.84
13H	160.60		162.60	
	162.20	-0.99	159.40	1.60
14H	192.60		196.20	
	194.80	-1.31	195.20	0.77
15H	184.20		181.40	
	188.80	0.26	183.20	0.00
16H	182.00		189.80	
	182.00	0.00	187.60	2.32

The critical t-value for the number of readings assessed was ±2.31. Therefore the majority of the results (80%) proved that there were no real differences between the means produced by the two samples, in turn confirming the repeatability of the test method. It was anticipated that the problems with the fabrics that did show a difference would be resolved when further modifications were made to the apparatus.

Confidence intervals (CI) were also used to assess the range of results. A test for drape should give approximately 5% of the average. As can be seen from the results, the CIs of this test were well within the expected range.

Table 2.4.15 Confidence Intervals - Kerrigan: Mod # 3 - Fabric Group H

	Face Up	CI	Face own	CI
Fabric 1	168.3	3.47	170.7	0.68
Fabric 2	155.9	2.83	154.9	1.60
Fabric 3	183.5	1.94	183.8	2.47
Fabric 4	169.6	1.85	169.3	2.34
Fabric 5	181.3	4.02	182.1	1.28
Fabric 6	180.5	0.91	181.5	2.60
Fabric 7	167.6	2.22	170.1	1.86
Fabric 8	217.1	1.45	218.4	1.66
Fabric 9	176.8	2.65	172.2	1.75
Fabric 10	190.8	2.23	196.2	1.30
Fabric 11	187.5	2.64	185.2	3.37
Fabric 12	181.6	2.06	185.4	2.11
Fabric 13	161.4	1.82	161.0	2.46
Fabric 14	193.7	1.97	195.7	3.51
Fabric 15	182.8	2.69	186.0	2.48
Fabric 16	185.9	1.22	184.8	1.31

Thus these two sets of analyses show that the Kerrigan test was both repeatable and accurate. Although improvements were still possible, the results to date were very encouraging.

2.4.3.5 Modification Four

The previous tests had been performed in a non-standard testing atmosphere because the test required a dark room. To progress further with the test it was necessary to construct a screen to create dark conditions in the room with the standard atmospheric conditions (20°C ± 2°, 65%RH ± 2%). This would make the results reproducible in different laboratories and was important for the development of the test.

The lamp that had been used in the previous tests also needed to be changed. It was replaced by a lamp that could be clamped at the desired height and had an adjustable aperture and current. This helped to focus the shadow and reduce the fuzziness that could lead to operator subjectivity when reading the results. After several trials an aperture of 8mm and the maximum current of 6 amps were selected as these gave the sharpest image. The testing board also had to be re-numbered, as the new cylinder had a larger diameter. Three points were removed from each of the sixteen sections, the change would effectively remove 48 points from all the drape values.

i) Comparison with Standard Drape Test - Independent Trial

The next stage was to establish how the results of the Kerrigan: Mod # 4 compared with the results of the Cusick Drape Tester. It was seen that the CI from the Kerrigan test was low, which was very encouraging. However, it also needed to be established if actual results were comparable; that is to assess if the Kerrigan test could distinguish between fabrics as well as the Cusick method.

The previous experiments had tested repeatability, whereas this one was designed to test reproducibility. Repeatability can be qualitatively defined as

> "the closeness of agreement between individual results obtained with the same method on identical test material, under the same conditions (same operator, same apparatus, same laboratory and short intervals of time)".

Reproducibility can be qualitatively defined as

> "the closeness of agreement between individual results obtained with the same method on identical test material but under different conditions (different operator, different apparatus, different laboratory and/or short intervals of time" [164].

Thus, it was decided to use an independent technician to perform the comparative tests. As all of the previous results had indicated that the Kerrigan method was both reliable and repeatable, it was decided to assess whether the results were reproducible when obtained by another operator. This would establish how easy the two methods were to follow for someone who had no experience of either. It would also alleviate all unintentional bias of the previous operator. A test method was written up and provided to the new operator, as well as the British Standard test method.

Three fabrics were selected from fabric group H for re-testing, (1H, 8H and 16 H). The fabrics represented the whole range of drape tested previously. These fabrics were re-tested by the same operator as previously (operator 1), in the conditioned atmosphere, with the modified equipment. The fabrics were also tested by the independent operator (operator 2) using both the Kerrigan: Mod # 4 equipment and the Cusick Drape Tester (British Standard Method).

A questionnaire was also developed to enable an accurate picture of how simple the methods were to follow, the amount of time it took for each method to prepare samples, to test them and to calculate the results.

Table 2.4.16 Results of Kerrigan: Mod # 4 and Standard Drape Test - Fabric Group H

	UP			DOWN		
	Kerrigan: Mod # 4		BS	Kerrigan: Mod # 4		BS
	Operator 1	Operator 2		Operator 1	Operator 2	
1H						
Sample 1	124	123	28.74	123	129	25.57
	120	125	25.97	126	128	25.17
	124	123	28.93	129	131	28.12
	126	122		125	124	
	123	123		122	128	
Sample 2	126	124	27.89	122	124	28.60
	122	126	29.89	125	124	29.60
	127	121	32.43	125	120	29.52
	125	128		119	121	
	125	124		124	124	
8H						
Sample 1	170	171	78.38	178	173	76.36
	172	176	79.06	174	173	79.19
	171	169	74.38	176	172	75.23
	176	173		175	169	
	173	164		180	169	
Sample 2	178	172	82.84	173	173	83.89
	174	177	80.32	175	174	84.38
	174	169	75.97	173	172	79.60
	173	172		173	166	
	177	168		175	170	
16H						
Sample 1	143	143	56.72	149	149	52.51
	147	144	55.86	149	145	53.27
	144	144	54.75	148	146	55.06
	141	145		148	143	
	146	145		150	148	
Sample 2	144	147	55.33	148	144	55.68
	142	142	55.00	145	145	56.22
	144	138	53.29	144	146	57.64
	144	145		148	144	
	143	139		146	144	

ii) Assessing Repeatability

The design of the experiment enabled several different analyses to be conducted. The first step was to assess how repeatable the results of the three fabrics were when tested by different operatives. This was performed using a t-Test assuming equal variances. The null hypothesis (H0) was that there were no differences between the averages of the samples and the alternative hypothesis (H1) was that the averages were different in some way.

Table 2.4.17 Results from a t-Test assuming Equal Variances - Kerrigan: Mod # 4 - Assessing Repeatability between Two Operatives

	Face Up		Face Down	
1H	0.325	Accept H0	-0.919	Accept H0
8H	1.846	Accept H0	3.805	Reject H0
16H	0.572	Accept H0	2.473	Reject H0

Critical value for 95% Level - ±2.101

The results, although not perfect, did illustrate a high degree of agreement for the samples assessed face up. The two rejections of the null hypothesis for the readings taken on the face down samples could point to the need for a third sample to be tested or that more than five readings should be taken per sample. It was decided that for subsequent trials the different operatives should test the same samples. This would allow the t-test for paired samples to be used and ensure that the only variations in the results were due to the apparatus and not to those inherent in the fabric.

iii) Assessing Accuracy

The confidence intervals (CI) of the test results were also calculated. A direct comparison of the Kerrigan and Cusick methods would not have been valid because there were differences in the number of results that were used in the calculation of the CIs. It was therefore decided to utilise the first three results of each of the two samples from the Kerrigan Test and to convert the data into percentages of the total area available from the board (240). This was actually a disadvantage to the Kerrigan method as more data would usually reduce the CI results. Only the results recorded by Operator Two were used so that the same operator performed both sets of tests.

Table 2.4.18 Confidence Intervals of 6 Samples - Kerrigan: Mod # 4 & Cusick Drape Tester - Operator Two

	Face Up		Face Down	
	Kerrigan	Cusick	Kerrigan	Cusick
1H	0.77	2.25	1.77	2.04
8H	1.51	3.18	0.33	3.95
16H	1.30	1.21	0.75	2.00

The results show that the Kerrigan method produced results that were more consistent than the standard Cusick Test. This applied to all samples apart from sample 16H face up. However the Kerrigan CI for this sample was still acceptable especially if one considers that not all the data available was used (a CI of 0.84 was calculated for the 16H face up results when all ten samples were included in the formula). This indicated that the modifications up to this point were successful and that the test was suitable to use for testing.

iv) Comparing Overall Results

The final step in the analysis was to compare the actual results produced by the Kerrigan and Cusick tests. As the Cusick results were given as percentages, the Kerrigan results were converted into this format. This was achieved by calculating the results as a percentage of 240, which was the shadow that would be produced if the fabric sample did not drape at all. The first three readings of each sample were used, as in the confidence intervals analysis.

Table 2.4.19 Results of 6 samples - Kerrigan: Mod # 4 & Cusick Drape Tester - Operator Two

	Face Up		Face Down	
	Kerrigan	Cusick	Kerrigan	Cusick
1H	51.53	28.90	52.50	27.76
8H	73.47	78.49	72.01	79.78
16H	59.58	55.16	60.76	55.06

The most noticeable difference between the two sets of data was that those produced on the British Standard had a wider range. This was a clear disadvantage of the Kerrigan Test, as it indicated that this test did not differentiate between fabric with different drape values as well as the Cusick method did. However, the Cusick method required different templates to be used if a drape coefficient of less than 30% or more than 85% was obtained using the standard template. Thus sample 1H should have been tested using a smaller template and sample 8H was very close to requiring the larger template. Results obtained from samples of different sizes cannot be compared with each other.

Therefore, it can be argued that although a narrower range was produced with the Kerrigan Test, this should not mean that the test was unusable as long as the confidence intervals indicated that the test was accurate. The fact that the confidence intervals were narrower for the Kerrigan test than the Cusick method indicated that the new test was accurate. The correlation between the results for the Kerrigan and Cusick method for the three fabrics were very high (0.98 for both face up and face down measurements) proving that the new test was valid.

The difference is the results can be explained thus, there was approximately a 50% range of results produced using the British Standard Test, which was quite evenly proportioned between the three samples (25% difference between both the low and medium, and the medium and high drape fabrics). The Kerrigan Test had approximately 20% range between these fabrics and the ratio was not un-similar to the standard method. It was therefore concluded that the Kerrigan Test did differentiate between fabric drapes to an acceptable level.

v) Opinions of the Independent Operator

As mentioned above, Operator Two completed a questionnaire during the experiments, the results it provided were very interesting. The total time taken to prepare samples, test and calculate the results was 200 minutes for the British Standard and 153 minutes for the Kerrigan Test. This corresponded to an average saving of 16 minutes per test. It was stressed, however, that the time taken to complete the Kerrigan test would have been reduced further if the test apparatus was steadier; as the test was in a development stage it was not constructed as well as possible. Also if there had been more space in the blacked out area, this would have eased the testing. These problems could be overcome with further modifications to the test equipment. In addition, it should be noted that if the British Standard method had been followed completely then sample 1H should have been re-tested using a smaller sample size. This would have taken approximately 67 minutes longer.

The total area of fabric used was nearly doubled using the British Standard method. It used 4242 cm^2 (5147 cm^2 if the extra samples were used), whereas the Kerrigan method only required 2400 cm^2. A comment was made by the technician that due to the larger sample size required for the British Standard there was more difficulty in avoiding creases in the fabric when preparing the samples; this reduced the accuracy of the British Standard test specimens.

The overall opinion of the independent operator was that the Kerrigan test method was easier to understand and generally required less time and was more convenient as there was no separate cutting and weighing stage. She did state that the Kerrigan Test would be more straight forward to use if the apparatus was improved, as she occasionally had to stop testing whilst it was stabilised. Also, the numbers on the board could have been clearer to reduce eye strain. These criticisms could be solved with subsequent modifications to the test.

2.4.4 Conclusions and Suggestions for Future Work

The measurement of drape was assessed and two methods that have not had exposure in the field of textile technology were explored. Both were unconventional in that they used less fabric than the Cusick test. The results were used to develop and or modify a quick and accurate test to measure fabric drape using a 20 cm square fabric sample. Although, through modification, the Aldrich method was improved, it was not found to be consistent or accurate for use by technologists, despite being suitable for the use it was developed for, namely aiding designers in the selection of fabrics.

The development of the Kerrigan Drape Test has produced a test that is both repeatable and reproducible, with good correlation factors between it and the Cusick drape test. Although further research work is necessary to refine the test and its apparatus, the indications with regard to the feasiblity of the test are encouraging. None the less, it was decided that as the test for drape would be critical to the measurement of the fabrics under investigation, the Kerrigan test would not be employed; it required further development work to be carried out on fabrics with a more stable structure and known physical parameters.

The research has highlighted several areas for future investigation. The British Standard method caters for fabrics with different drapes by using different sample sizes; it could be argued that in order to achieve the different ratios of supported and unsupported fabric, different size cylinders would simplify the test. A more permanent structure should also be constructed for the test, which would reduce the errors, whilst making use of engineering to retain portability. This could, for example, be achieved by constructing the casing for the test from hollow metal rods with elastic running through them (used as the support for lightweight tents), which would allow a lamp to be positioned centrally and would support fabric or paper to darken the area but would be light enough to ensure the test was portable.

Further investigation could compare the British Standard method to the Kerrigan method, which would involve assessing the amount of data that would be lost if the shadow created on the British Standard was assessed in the manner as the Kerrigan test (the sum of the maximum lines from sixteen areas) and also gauge how much better the Kerrigan test would be if its results were calculated by a series of weighings. This would identify any information lost when the Kerrigan method is used and also the different results obtained from round and square samples. If it was valid to use square samples, which the experimental data indicated was the case, further improvements could be explored by using image analysis equipment, which can assess the area of the shadow using photo-sensitive equipment [31, 43]. This would make the equipment more complex and thus might not fulfil the initial design requirements, although samples that use less fabric area would also be of use to technologists if the test proved sufficiently accurate. These further explorations were outside the scope of this thesis.

2.5 Materials

A summary of the fabric details can be seen in the table below. The fabrics used in the experimental work were partly finished, as they had been dyed. The effect of the subsequent operations of the finishing process were investigated.

All fabrics were finished in the same facility. All had 50 denier warp yarns that had 36 filaments.

Table 2.51 Properties of Fabrics used for the Finishing Experiments (A-B)

A)

Letter	Colour	Weight Reduction	Fabric Story	Woven Structure	Warp Ends	Weft Denier	Weft Type	Weft Picks	Weft Filaments	Twist
Q	Cream	0 %	Geisha	Satin	15000	75	Non-ionic	108	72	V low
Q_1	Black	0 %								
R	Chantilly	5 %								
R_1	Aqua	5 %								
A	Gold	10 %								
A_1	Teal	10 %								
S	Piedra	10 %								
T	Cream	15 %								
T_1	Pink	15 %								
M	White	0 %	Portia	Satin	15000	70.2	Non-ionic	110	36	No
N	Aqua	7 %								
O	Lt Pink	10 %								
O_1	White	10 %								
B	Lt Pink	12 %								
P	Cream	15 %								
P_1	Pink	15 %								

B)

L	Black	0 %	Juno	Satin	15000	75	Non-ionic	107	36	Med
X	Black	0 %								
Y	Chantilly	10 %								
Y_1	Navy	10 %								
C	Pink	17 %								
Z	Green	17%								
I	Moire	0 %	Venus	Satin	13000	75	Cat-ionic	109	36	High
I_1	White	0 %								
J	Moire	9 %								
J_1	Purple	9 %								
K	Moire	20 %								
U	Yellow	0 %	Electra	Satin	13000	75	Non-ionic	109	72	Low
U_1	White	0 %								
V	Angelica	5 %								
V_1	Yellow	5 %								
W	Peach	14 %								
D	Soft Blue	16 %	Carly*	Satin						
E	Chantilly	22 %								
H	Chantilly	16 %								
F	Apple	20 %	Victoria*	Plain						
G	Pale Blush	15 %								

*** These fabrics had different production parameters than the others and were therefore not used in the main investigation.**

2.6 Statistical Techniques

This section will briefly overview the statistical techniques used throughout the thesis. It is in no way intended to completely review the techniques and more information should be sought from the references given that are dedicated to statistics.

2.6.1 Design of Experiment

Each experiment in this thesis was subject to a design. This clarifies the aim of the experiment and enables decisions to be made regarding which research methods would be most suitable to achieve the desired result. The variables (both dependent and independent) that should be included in the experiment are also decided and the format of the experiment calculated (factorial or classical).

2.6.1.1 Dependent and Independent Variables

In any experiment there are dependent and independent variables. The dependent variables are those that change because of the experiment. For this thesis, dependent variables are the results of the test parameters that are described in sections 2.1 - 2.3. The independent variables are those that control the experiment. In this thesis, they are the finishing variables.

2.6.1.2 Factorial versus Classical Experiments

The manner in which the independent variables are arranged can be classified in two main experiments: factorial and classical. A classical experiment would to alter one variable whilst keeping other variables constant until the desired results are achieved; the value of the first variable is then held constant whilst individually altering the other independent variables, until all variables have been assessed. The number of alterations to a single variable under investigation are called levels. If each variable was tested at five levels, a classical experiment with two variables would result in ten tests. This method does not usually provide the maximum relationship between the variables, as it does not make allowances for interactions between the variables. In contrast, a factorial experiment would be one where each level of one independent variable was matched with each level of another independent variable. Using the above example of each variable having five levels, a factorial experiment would result in twenty-five tests. Although more work is involved when designing a factorial experiment, it can provide data concerning the interactions between variables.

2.6.1.3 Hypothesis Testing

Hypothesis Testing is any statistical technique where there is a theory to be tested about two or more sets of data. H0 is known as the null hypothesis (where it is assumed that there is no difference), H1 is known as the alternative hypothesis (where it is assumed that there is either a difference [2-tailed] or that one set of data is greater than the other [1-tailed]). In all the tests in this thesis, the objective was to prove that one set of results was larger than the other and thus the one-tailed test was used throughout.

2.6.1.4 Methods of Analysis

In the statistical techniques that are described below, there are outputs from the computer programme that can be analysed in two different ways, using either the reporting or decision approach. The reporting approach uses the P-Value; this indicates the probability of the results occurring by chance if the means were the same. Thus, a small probability would indicate that the results would not occur normally by chance unless there is a relationship between the dependent and independent variables. Using this approach, the difference between the data can be assessed as to how significant it is. Normally, the probability of 0.05 is used as guidance for accepting or rejecting the null hypothesis.

The decision approach uses the computed F statistics, which are calculated from the data and the critical values (which are established from the number of samples and the level of significance required). If the F statistic is greater than the critical value the means can be said to differ significantly [165]. This method uses a specific value to accept or reject the hypothesis. Both approaches are used in this thesis.

2.6.2 Coefficient of variation

The coefficient of variation is an important statistic used throughout this thesis. It relates to the standard deviation of the results to their average. A more significant result is found if a standard deviation of 1 is found from a mean of 10 than if the mean was 100.

$$CV = \frac{s}{\overline{x}} \times 100 \qquad \ldots[13]$$

This statistic allows a quick and easy comparison between the range of results of two or more sets of data. It can be linked to repeatability of the test method.

2.6.3 Percentage Error/Number of Test Samples

The percentage error statistic is important in the design of new tests as it is linked to the number of repeat tests in a test method. The coefficient of variation is used to calculate an estimation of the error that is present in the test results with a given number of repetitions. The formula can therefore be rearranged to calculate the number of tests required to obtain a certain percentage error. More repeat tests would be required for a test that had a large amount of variation.

$$N = \left(\frac{1.96 \times CV}{P}\right)^2 \qquad \ldots[14]$$

Where: N = the number of samples
CV = Coefficient of variation
P = Percentage accuracy [166]

2.6.4 Confidence Intervals

Confidence intervals (CI) are used to assess the range of results. This statistical technique utilises the standard deviation, and the number of samples, to assess how confident one can be in the mean of the data. The expected confidence intervals for textile tests vary considerably. This is due to the nature of fabrics, which are extremely variable. It also depends on the test; dimensional stability to washing, for example, has many variables and one can expect a CI of 10% of the mean (5% either side). This means that for any given sample results (for example: -10%) one can be 95% confident that the true result lies within plus or minus 5% (producing a confidence interval of between -9.5% and -10.5%). A test such as Percentage Composition, which is regulated by law, should only have a CI of 1% either side of the mean, which ensures that the result is within 2% of the true value.

$$CI = \overline{x} \pm 1.96 \frac{\sigma}{\sqrt{n}} \qquad \ldots[15]$$

where :
CI = confidence interval
$\overline{x}$ = average
σ = standard deviations
n = number of results
1.96 relates to a 95% accuracy

2.6.5 F-test

An F-test compares the variation present in two data sets. It works by comparing the variances of the two sets of data, and then dividing the variance of one set by the variance of the other. The results of the analysis are the probability that the two samples are not significantly different; thus a small probability indicates that the variation in the two samples is different [165]. It can be used to assess the differences between the repeatability of data and the spread of results.

2.6.6 t-Tests

The statistical analysis involving t-tests is used to compare the means from two sets of data. In order to use this technique, the data must be from normal populations. There are three forms of the t-test: those assuming equal variances, those with unequal variance and those with paired forms. The t-test assuming unequal variances was not used in this thesis.

2.6.6.1 t-tests assuming equal variance

Using the t-tests for equal variances assumes that the variances from the two sets of data are equal and also that they are independent of each other. For the majority of comparisons in this thesis, one can assume this. There is no reason to expect the results of mechanical properties that are obtained after the different finishes would also lead to a difference in the variation within those results.

2.6.6.2 paired

This form of the t-test does not require the sets of data to be independent; it is used when the same data set is observed twice. Thus, it cannot be used for destructive tests such as tensile strength, but for handle assessments or tests such as drape, this test can be applicable. It can be used to assess the difference between sets of testing equipment that measure the same parameter (providing the same samples are used) and it can also be used to assess the repeatability of measurements that are taken on different occasions or by different operatives.

2.6.7 ANOVA

This statistical technique is used to compare two or more sets of data. It compares the within group variation to the between group variation in order to assess if the population means are the same. It allows the interaction between the independent variables to be assessed.

2.6.7.1 Two factor without replication

The idea of this technique is that groups of data are split into subgroups that will have smaller variations. For example, when assessing the independent variable of temperature, the data could be divided up into the subgroups of the different temperatures used. The technique would be used to assess the effect of two variables where repeat data was not available.

2.6.7.2 Two factor with replication

This technique is similar to the above but instead of using the averages of the results the raw data is used instead. It is a more powerful statistical technique than without replication.

2.6.8 Kendall Coefficient of Concordance

(This analysis was performed by Nicola Tilt, statistical department, NTU)

This is a statistical technique that is used to assess the relationship between sets of ranking data. For example, the process would be used to assess the agreement within a set of data obtained about handle (or any subjective assessment) in order to ascertain whether all the judges should be used or whether one or more should be classed as an outlier(s). It is important when using subjective data from a number of people that it is not automatically assumed that they are in agreement. If the agreement is not established, the conclusions drawn from the data could be misleading.

The value of W will be between zero and one: zero indicates little agreement and one indicates total agreement between the assessors of the ranking of the subjective data.

$$W = \frac{S}{\frac{1}{12}k^2(N^3 - N)} \qquad \text{...[16]}$$

where:

$$S = \Sigma(R_j - \frac{\Sigma R_j}{N})$$

k = number of judges

N = number of objects ranked

$\frac{1}{12}k^2(N^3 - N)$ = maximum possible sum of the squared deviations,
i.e., the sum S which would occur with perfect agreeemnt among k rankings

W can then be assessed for significance by testing the null hypothesis that the rankings are independent. A significant value of W does not mean that the assessors are correct, but that they are:

> "applying essentially the same standard in ranking the N objects. Often their pooled ordering may serve as a 'standard' especially when there is no relevant external criterion for ordering the objects." [167]

2.6.9 Regression

Regression is a technique that in simple terms establishes a relationship between variables and calculates a formula for this relationship. When a graph is plotted of the results relating to two variables the act of establishing a pattern or trend from the data is the start of the regression procedure; drawing a line of best fit by eye is a regression technique because the formula for the line can be calculated. This is what the computer provides according to the rules in its programming. There are several different regression methods; the two described below are those used in this thesis.

A perfect regression between the variables would result in a R^2 value of one. The less the variables correlate, the lower the R^2 value will be. A R^2 value of zero indicates no relationship. The regression statistic is an indication of how much the variation of results in one variable can be predicted by a formula involving another variable. Thus the R^2 value can be used to assess to what degree a particular dependent variable rather than another can be used to predict an independent variable.

2.6.9.1 Linear

A linear regression is one where the relationship between two variables is a straight line. A simple pair wise plot would be the first step to a linear regression. If a relationship was established from the graph, an equation and R^2 could be calculated.

2.6.9.2 Multi-variate

The relationship that is established in a simple linear equation might not be enough to explain the independent variable. In that case, a multi-variate analysis could be performed. This would be to assess more of the problem than could be explained by using more than one of the dependent variables. The first step in performing this analysis would be to calculate simple linear regressions for all the test results (dependent variables) and the problem (independent variable). The parameters that have the highest R^2 results can then be used in a multi-variate analysis, providing they are independent of each other. This independence would be established by calculating the correlation between all the test results (dependent variables). When high correlation is found between two or more properties, they are likely to be explaining the same part of the problem (independent variable) and thus additions to the number of properties in the multiple regression would be unlikely to increase the effectiveness of the model.

2.6.9.3 Interpretation of Regression Results

The computer produces an output for each regression model that is tested; having several parameters enable the suitability of the model to be established. These include the R^2 value, which is the percentage of the variation in the independent variable (the problem) that is explained by the regression line, which in this case involves two or more test parameters. As the regression is a result from a model, another factor is available, that of the Adjusted R^2 which allows a direct comparison with other models and is a lower percentage than the R^2. High values from these parameters indicated improvements in the model. Also very important is the ANOVA significance factor or the probability that the results would be produced from a random sample where there is no relationship between the dependent and independent variables, for example a problem and various test parameters. As such, it is a measure of the regression model. The last important parameter is that of the P-value related to t-tests, which assesses how the dependent variables (test parameters) individually explain the independent variable, assessing the probability that there is no relationship between them. Both the ANOVA and t-test parameters should be low (less than 0.05) in order to indicate low probabilities.

CHAPTER 3 – RESULTS AND DISCUSSION

3.1 Introduction

Another exploration into testing equipment was made during finishing experiment 5 where modifications were made to the FAST equipment. This was in order to provide more information to differentiate between weight-reduced polyester fabrics whose characteristics were very different from the suiting fabrics the instrument was originally designed for. In this investigation, the most in-depth in the thesis, changes were made to the overall test procedure and to the FAST-3 extension meter equipment. Correlation experiments were undertaken between the results obtained from the 'modified FAST' and ease of manufacture, distortion of dress measurements and garment appearance. A further investigation was carried out between the 'modified FAST' and the KES-FB instruments, as the KES-FB can be adapted to test these types of low weight fabrics.

Table 3.1.1 Key to Test Parameters Used

T2	Thickness at 2 g
T100	Thickness at 100 g
ST	Surface Thickness
STR	Released Surface Thickness
B	Bending Rigidity
C	Bending Length
E100	Extension at 100 g
BE	Bias Extension
G	Shear Rigidity
RS	Relaxation Shrinkage
HE	Hygral Expansion
F	Formability
W	Weight (mass per unit area)
DC	Drape Coefficient FU = face up FD = face down
g	Shear rigidity (KES)
2hg	Shear hysteresis at 0.5°
2hg5	Shear Hysteresis at 5°
LT	Tensile Linearity
WT	Tensile Energy
RT	Tensile Resilience
EMT	Tensile Extension
In all cases, the notation of 1 denotes warp direction parameter, the notation of 2 denotes weft, the notation of 3 denotes right bias (45° angle from the warp) and the notation of 4 denotes left bias (135° angle from warp). Letters with no suffix relate to those parameters without direction or where the results in both/all directions have been averaged.	

3.2 Polyester Weight Reduction Experiment

3.2.1 Introduction

As stated previously (section 1.3.6), it was found that in the area of women's thin dress there had not been any research carried out using the FAST. To fill this void a calibration was made with Toray Textiles Europe Ltd. To research decided to find the weight reduction process of polyester. Weight reduction is a chemical process that erodes the surface of polyester fibres and is used as a finishing technique to reduce friction between the fibres and yarns, it also improves the fabric handle by increasing drape and reducing stiffness. As explained in section 1.3.4.3, the factors controlling the percentage weight reduction are the concentration of sodium hydroxide, the temperature, and the time of reaction. However, there is a limit to the amount of weight reduction a fabric can undergo without significantly affecting its ability to be easily converted to garments, because at high percentage weight reductions, the fabric becomes too soft. This creates difficulties when handling, cutting and sewing. The point at which advantages in terms of handle become disadvantages in terms of manufacture is established by the fabric manufacturer, using a combination of trial and error and their knowledge of the product. It was anticipated that the research would be able to provide a more scientific method for establishing the limits of the weight reduction process, perhaps by taking into account the properties of the base fabric.

The aim of the experiment was to build a database of fabric mechanical properties, together with the details of their production and whether they would be classified as problem fabrics during garment manufacturing. It was anticipated that the database would allow correlation factors to be determined between mechanical properties, production parameters and problems in manufacturing. In this way the fabric producer would be able to minimise or avoid the procedures that contribute to the fabrics being susceptible to problems in manufacture. The problems identified by the company were garment manufacture, fabric dropping, seam pucker, and pressing bubbles.

3.2.2 Experiment Parameters

Only fabrics that were commercially available could be tested, thus the direction of the research, although structured, would depend to a large extent on the results of the available fabrics. Seven initial fabrics were obtained for the research. The fabrics were separated into fabric 'stories', which reflected the base structure of the fabric. For example, the same base fabric (Carly) was used to create fabrics D and E, the only difference being the percentage weight reduction applied (16% and 22% respectively).

Table 3.2.1: Fabric Details 1

Letter	Colour	Quality No	Fabric Story	Weight Reduction	Weave Type	Problem
A	Gold	02584	Geisha	10 %	Satin	No
B	Light Pink	02871	Portia	12 %	Satin	No
C	Pink	01136	Juno	17 %	Satin	No
D	Soft Blue	02471	Carly	16%	Satin	No
E	Chantilly	01478	Carly	22%	Satin	Dropping
F	Apple	01129	Victoria	20 %	Plain	Pressing
G	Pale Blush	02060	Victoria	15 %	Plain	No

The fabric mill was aware that the weight reduction process was one of the production parameters that greatly influenced the degree to which the fabrics presented problems in manufacture; more specifically, that a higher weight reduction generally led to a greater number of problems. In simple terms, the higher the weight reduction percentage the more movement between the warp and weft yarns and therefore the less resistance the fabrics have to distortion.

However, the relationship is not so straightforward, as any fabric production parameters that affect the initial fabric's resistance to distortion also affects the percentage weight reduction that a particular fabric can accommodate before the fabric would be liable to problems with distortion. An example of such a production would be weave structure; at the same weight reduction levels, closer structures such as plain weaves exhibit fewer problems than open structures such as satin weaves. Other important factors include original weight, yarn type, degree of twist and warp and weft thread densities (section 1.3).

3.2.3 Fabric Mechanical Parameters

Research with similar types of fabrics (weight reduced and micro-filament polyester) has been carried out using the KES equipment, which can be adapted to be more suitable to test a large range of fabrics [102]. For this experiment, as there was no easy access to a Kawabata system, it was decided to use the FAST objective measurement system. The equipment was designed for suiting fabrics that are thicker and less liable to distortion than weight reduced polyester, and because the FAST was developed to be a quick and simple method of test there were more problems inherent in using it, rather than the KES, for the measurement of these fabrics. The initial task was therefore to establish if the FAST could be modified to overcome these difficulties and thus both accurately and effectively differentiate between the weight reduced percentage fabrics.

The first step in achieving this aim was to dismiss the established guidelines related to suiting fabrics, as a quality fabric for a suiting end use would require a different combination of mechanical properties than these weight reduced fabrics. It was also doubtful that the same range of tests using the same loads and specifications would provide the information required for the weight reduced polyester fabrics. This follows the idea that in the KES method of test there are different machine settings for different types of fabrics, as described in the mechanical properties section (section 1.1).

It was therefore decided that the initial set of tests would encompass more than the usual FAST parameters. Whilst it was expected that some of them could be omitted, all of the original FAST tests would be used initially, together with any modifications of these tests that were thought to be more suitable for these types of fabrics. Table 3.2.2 provides details of the tests carried out on the fabrics, whilst below is the theory for the modifications.

3.2.4 Initial Modifications

In order that there would be a high percentage of accuracy all the test results were averages of five rather than the three that the normal FAST procedure recommends. This was based on the assumption that the differences between fabrics that did and did not exhibit problems would be small and therefore the differentiation between the fabrics would be required to be very accurate.

The majority of the garments that presented problems were ones where the pattern pieces were cut in the bias direction. Thus the length and the width of these garments (usually warp and weft respectively) are the bias directions. It was therefore relevant to test all mechanical properties (normally tested solely in the warp and weft direction) in both bias directions. Previous researchers have tested formability [7] and bending rigidity [3] in bias directions.

3.2.4.1 Dimensional Stability: Relaxation Shrinkage and Hygral Expansion

The stability tests were carried out in accordance to the FAST testing methods. However this test was not likely to be suitable for these types of fabrics as the fabrics were all 100% polyester and therefore not as absorbent as wool blends. Polyester has a moisture regain of approximately 1.5% (the lowest regain of all the commonly used fibres) whereas wool has a regain of 18% [129]. Nevertheless, it was important not to omit the test before assessing the data and clarifying that it did not provide any information. Also, it was taken into account that the weight reduction process and fabric structure have an effect on moisture absorption properties because they modify the space between the yarns; thus it was valid to investigate the possibility of the percentage weight reduction causing differences in the dimensional stability results.

3.2.4.2 Bending: Bending Length and Bending Rigidity

Bending Rigidity is said to relate to the feel of a fabric between the fingers [2]. As one of the possible purposes of the weight reduction process is to increase the 'silk-like' handle, bending rigidity was considered an important parameter to differentiate between the fabrics. The bending length was tested in the warp, weft and both bias directions. Five results were obtained in each direction and averaged, in accordance to the modified test method. It was expected that the samples in the bias directions would have shorter bending lengths and therefore lower bending rigidity results, because it was hypothesised that there would be less resistance to distortion in the bias direction: the results would indicate whether this was a correct assumption. They would also help to establish the role that weight reduction and the other production parameters, such as fabric structure, have on bending. For example, the actual bending length results might not differ between fabrics but the bending rigidity results (which include the fabric weight) might. As a certain amount of bending rigidity is necessary for fabric to hold a garment shape, it was hypothesised that the problem fabrics would be those that had low results; further, that an increase in the percentage weight reduction would reduce the bending rigidity results.

3.2.4.3 Formability: Extension & Bending Rigidity

The formability parameter measures how easily the fabric will accommodate in-plane compressive strain without buckling [21]. Fabrics that have low formability results are likely to pucker; as this was one of the manufacturing problems, the formability parameter was also important for the characterisation of these fabrics. The modified test method included measuring the parameter in the bias directions as well as in the warp and weft.

3.2.4.4 Shear: Bias Extension

This parameter was thought to be one of the most important of the original set of FAST tests. It is a measure of how easily the fabric trellises; that is, how easily the warp and weft threads can be pulled out of the normal 90° - right angle relationship. As the problem garments are cut on the bias, gravity pulls the fabric out of its normal 90° alignment. The more resistance fabrics have to this force, the greater the shear rigidity they have and the less likely they are to 'drop', which was one of the fabric problems [24]. It was theorised that an increase in weight reduction percentage was likely to reduce shear rigidity.

3.2.4.5 Drape:

Drape is not normally associated with the FAST tests but an indication of drape can be obtained from the bending and shear results. However the various literature on this subject seem to disagree as to whether bending [13, 39] or shear [43] is the most important parameter to predict drape and the exact manner in which the result for drape should be calculated. As the decision to cut garments on the bias is usually taken to increase their draping properties, a measure of drape for these fabrics was important. It was likely that fabrics with a low drape coefficient (high tendency to drape) will also 'drop' when in garment form [24]. It was expected that the drape coefficient would decrease as the weight reduction increases.

3.2.4.6 Weight:

Five samples (using a calibrated circular cutter) were taken from each fabric in a diagonal positioning across the fabric width. It is generally found that fabrics of a lower weight are more difficult to handle [1]. This, together with the fact that the bending and formability are based on the weight results, make weight a very important parameter. The results were very important in order to distinguish between those fabrics that had the same base weave but differed in weight reduction process.

3.2.4.7 Compression:

Unfortunately, due to technical problems, the steam bed used to obtain the released compression properties was not working satisfactorily during this experiment, thus only the original compression measurements could be acquired. It was likely that these tests would prove to be unaffected by the process, as the fabrics are very thin prior to weight reduction treatment ($T < 0.29$, $ST < 0.07$). However, research suggests that the weight reduction process does effect fabric thickness [152]; thus it was interesting to note if the FAST equipment could detect any differences.

3.2.4.8 Extension:

This was the parameter that required the greatest amount of modification. The FAST test method for suiting fabrics utilises extension at 5, 20 & 100 gf/cm loads in the warp and weft directions using an average of three repeat tests, and at 5 gf/cm load in bias directions using an average of six (three in each bias direction). As stated above, to ensure accurate sampling, the averages were calculated from five results for warp, weft and each bias direction.

In addition to increasing the number of samples taken, it was also relevant to increase the number of loads tested in the extension procedure. The loads of 5, 20 and 100 gf/cm could provide the ideal information for suiting fabrics, but due to the fact that the fabrics being studied were of a much lower weight and generally of a less stable structure, lower loads may be more suitable. However, as it was not known which weights would be the most appropriate, a wide range of loads was used. It was anticipated that the analysis of the results would indicate the particular loads that explained the largest percentage of the problem. This follows the hypothesis used to define different conditions of usage of the KES equipment [100]; these weight reduced fabrics would fit into the category to be tested using the high sensitivity set-up (if measured with the KES). This set-up enables the KES equipment to use lower loads than those defined for standard conditions (for fabrics with a suiting end-use), specifically because it has been identified that more information is obtained at different loads [100]. It was considered likely that the results in the bias directions would be the most informative and also that the problem fabrics would be those with too much extension rather than too little.

The extension meter had to be adapted for the new range of loads to be used. The apparatus works on a reverse pivot principle, where the weights are gradually removed from one side of the apparatus thereby imposing greater forces on the fabric sample clamped in the jaws at the other side of the instrument. The machine has a maximum load of 100 gf/cm (500 g over a 5 cm sample width) that can be applied to the test specimen. For the purposes of this experiment, this maximum extension was not seen as a drawback, as loads up to and including this maximum load were used. There was a slight disadvantage when comparing the results to those produced by the Kawabata equipment, as its maximum load is 500 gf/cm, (50 gf/cm for high sensitivity set-up). However, other researchers have done this comparison (on shirting fabrics) with success [32, 33].

The FAST extension apparatus is also limited by a maximum extension that can be recorded (21.4%). It has a fixed upper jaw and the lower jaw is constricted by the instrument dimensions. There is no disadvantage to this for samples tested in the warp and weft directions as generally they do not extend by greater than 21.4% (unless elastomeric fabrics are used); however, the bias direction samples were more extensible those the warp and weft samples and thus presented a problem at high loads.

Another factor considered was the manual nature of the instrument. The rate of force applied to each sample is governed by the speed at which the dial that controls the lower jaw is turned by the operator. Although every effort was made to standardise this speed, it was not as reproducible as the KES or other tensile testing equipment that are automatic and as such have a standard rate of extension.

Kawabata and Niwa established that for these types of fabrics a slower speed was necessary; using standard conditions the rate of extension of KES F1 is 0.2 mm/sec, but that the speed is reduced to 0.1 mm/sec when high sensitivity conditions are used [100]. This is perhaps to limit over-stretching the fabric so that it would not recover. The author was aware of these disadvantages and that more care was necessary when testing these fabrics than suiting fabrics.

Table 3.2.2: Initial Set of Testing Parameters

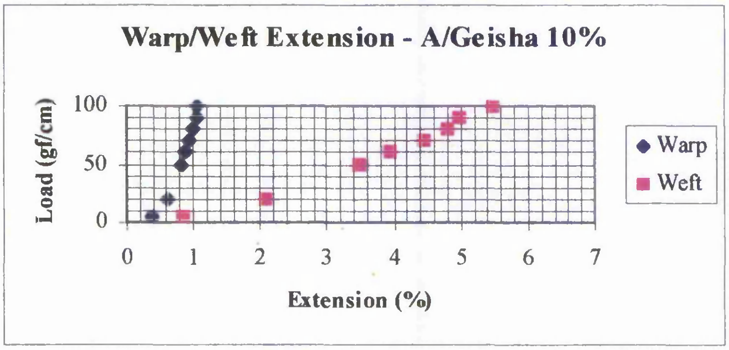
Fabric:						
Stability				Extension		
RS 1*	(L1-L3)/L1%			E5 1*	average of 5	
RS 2*	(L1-L3)/L1%			E5 2*	average of 5	
				E5 3*	average of 5	
HE 1*	(L2-L3)/L3%			E5 4*	average of 5	
HE 2*	(L2-L3)/L3%					
				E20 1*	average of 5	
Bending				E20 2*	average of 5	
C 1*	average of 5			E20 3#	average of 5	
C 2*	average of 5			E20 4#	average of 5	
C 3#	average of 5					
C 4#	average of 5			*E30 3#*	average of 5	
				E30 4#	average of 5	
B 1*	weight x $C1^3$ x 9.81 x 10^{-6}					
B 2*	weight x $C1^3$ x 9.81 x 10^{-6}			*E40 3#*	average of 5	
B 3#	weight x $C1^3$ x 9.81 x 10^{-6}			*E40 4#*	average of 5	
B 4#	weight x $C1^3$ x 9.81 x 10^{-6}					
				E50 1#	average of 5	
Formability				E50 2#	average of 5	
F 1*	((E20-E5)*B)/14.7			E50 3#	average of 5	
F 2*	((E20-E5)*B)/14.7			E50 4#	average of 5	
F 3#	((E20-E5)*B)/14.7					
F 4#	((E20-E5)*B)/14.7			E60 1#	average of 5	
				E60 2#	average of 5	
Shear				E60 3#	average of 5	
G*	123/(AVERAGE(E5 3 & E5 4))			E60 4#	average of 5	
Compression				E70 1#	average of 5	
T2*	average of 5			E70 2#	average of 5	
T100*	average of 5			E70 3#	average of 5	
ST*	average of 5			E70 4#	average of 5	
Weight*	average of 5			E80 1#	average of 5	
				E80 2#	average of 5	
Drape				E80 3#	average of 5	
DC FU#	cut out / original %			E80 4#	average of 5	
DC FD#	cut out / original %					
Nodes FU#	average of 6			E90 1#	average of 5	
Nodes FD#	average of 6			E90 2#	average of 5	
				E90 3#	average of 5	
Normal FAST = *				E90 4#	average of 5	
Modified FAST = #						
1 = Warp				E100 1*	average of 5	
2 = Weft				E100 2*	average of 5	
3 = 45 °				E100 3#	average of 5	
4 = 135 °				E100 4#	average of 5	

3.2.5 Discussion and Second Set of Modifications

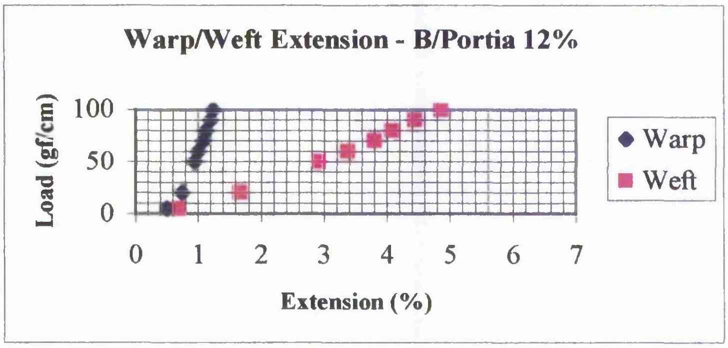
The results for the seven fabrics tested using the initial modifications produced a range of interesting outcomes. In particular, the tests on the extension parameters warranted further investigation. The results for these tests showed that fabric structure was an important factor; the satin weave fabrics (A-E) produced weft extension results that were much higher than the warp results, whilst the reverse was seen for the results of the plain woven fabrics (F&G). In order that a more detailed emphasis on their properties could be undertaken, it was decided that further testing should be only performed on satin weaves.

Figure 3.2.1 Comparison of Warp and Weft Extension Results (Fabrics A-G)

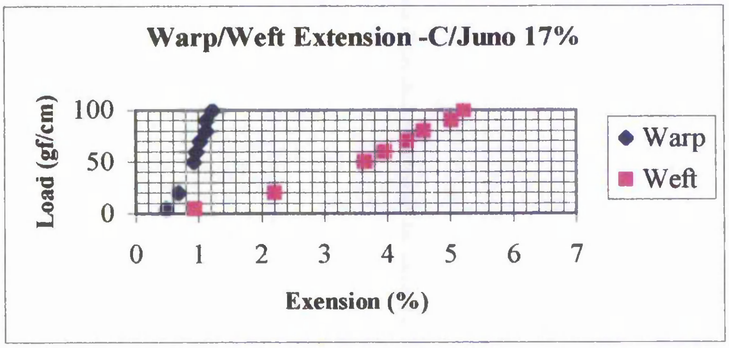
A) Warp and Weft Extension Results for Geisha 10%



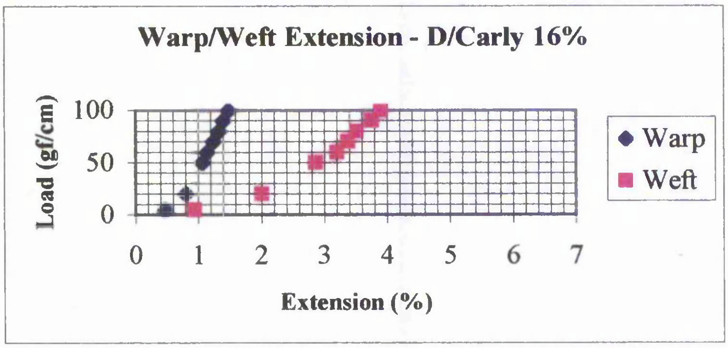
B) Warp and Weft Extension Results for Portia 12%



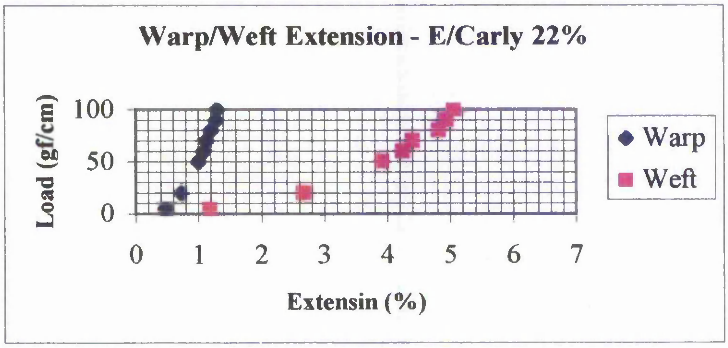
C) Warp and Weft Extension Results for Juno 17%



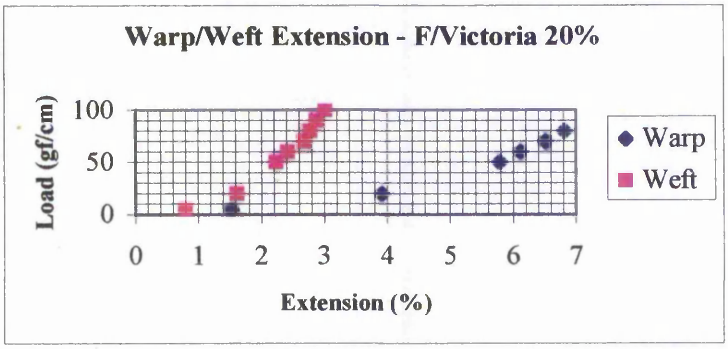
D) Warp and Weft Extension Results for Carry 16%



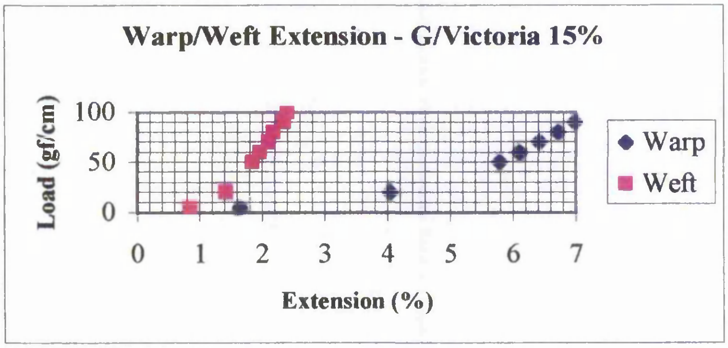
E) Warp and Weft Extension Results for Carry 22%



F) Warp and Weft Extension Results for Victoria 20%



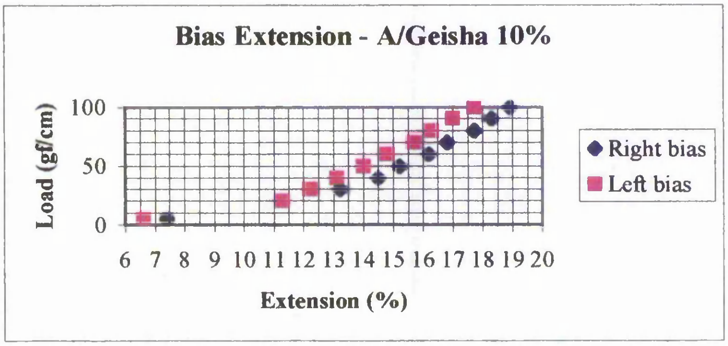
G) Warp and Weft Extension Results for Victoria 15%



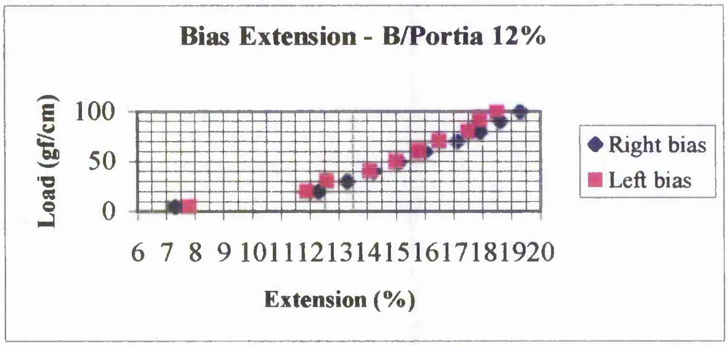
Furthermore, it was noted that it was possible to obtain more information from the bias extension results. The choice of the loads with which to test the bias extensions samples was made to correspond with the warp and weft extension tests, although it was obvious from the graphs that the results of the lower loads should be given more emphasis as the results above the load of 50 gf/cm were quite linear in nature. This follows the theory of Leung who found that the greatest range of results was found by using small loads [47].

Figure 3.2.2 Bias Extension Results (Fabrics A-G)

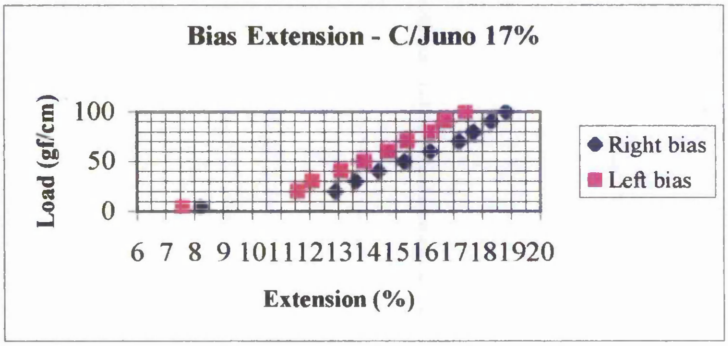
A) Bias Extension Results for Geisha 10%



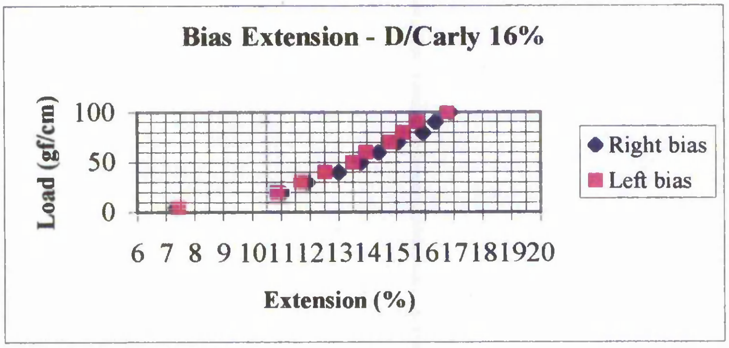
B) Bias Extension Results for Portia 12%



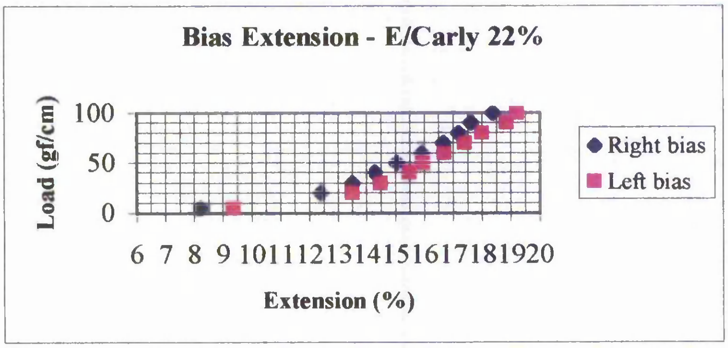
C) Bias Extension Results for Juno 17%



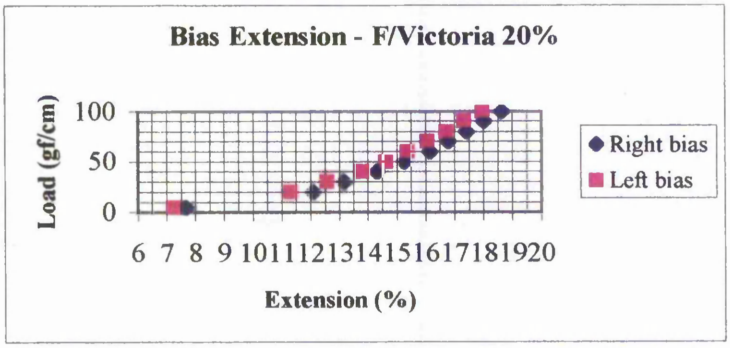
D) Bias Extension Results for Carry 16%



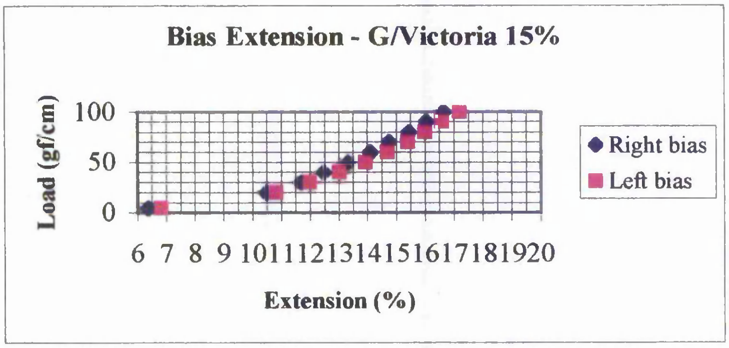
E) Bias Extension Results for Carry 22%



F) Bias Extension Results for Victoria 20%



G) Bias Extension Results for Victoria 15%



Thus, it was decided to continue with the loads used during the initial testing for the warp and weft directions, but to modify the range tested in the bias directions to have a maximum of 50 gf/cm and smaller intervals between successive loads. Below the 5 gf/cm load the intervals between the loads would be 1 gf/cm, whilst above 5 gf/cm and up to 50 gf/cm the interval would be every 5 gf/cm; these details can be found on table 3.2.4 below.

As bias extension is directly related to the shear parameter, this modification would also allow the loads below five grams to be used as additional measures of shear rigidity. The shear parameter is normally only calculated from the extension at 5 gf/cm results, however for the purposes of this investigation the parameter was also calculated at smaller forces to assess their effect. This was because these fabrics distorted very easily and thus it was theorised that forces lower than those necessary to distort suiting fabrics could be relevant.

The relationship between shear rigidity and bias extension can be defined as below:

$$G = \frac{k}{B} \qquad \ldots[17]$$

where:
G = Shear
B = Bias extension result at Load
k = coefficient (related to Load)

$$k = \frac{\text{Load} \times 100}{4}$$

Thus the coefficient for the new loads of 1 to 4 grams were 24.5, 49.1, 73.6 and 98.1 respectively [161].

A further alteration to the shear test method was to include the separate shear results obtained from the bias sample at 45° and those obtained from the bias sample at 135°. This was because it was noted that if the results of satin weaves were considered separately from the plain weaves, all the non-problem fabrics (A-D) produced results with left bias being less extensible than the right bias, but that this was reversed for the problem fabric (E). This effect could be because the satin weave used for the fabrics was a 5 end satin; this refers to the weft threads going over four warp threads and under one. This produces a weave that is not symmetrical and has slightly different angles of twill on the face and back. Thus, as the individual results were easily available, it was decided to calculate the shear parameters for the two directions separately to assess if this had an effect. The average could be calculated subsequently if there was proved to be no difference between the results from the bias directions. These modifications can be summarised in the Table 3.2.3.

Table 3.2.3: Second Set of Testing Parameters

Stability				Extension				
RS 1*	(L1-L3)/L3%			E5 1*	average of 5		E1 3#	average of 5
RS 2*	(L1-L3)/L3%			E5 2*	average of 5		E1 4#	average of 5
HE 1*	(L2-L3)/L2%			E20 1*	average of 5		E2 3#	average of 5
HE 2*	(L2-L3)/L2%			E20 2*	average of 5		E2 4#	average of 5
Bending				E50 1#	average of 5		E3 3#	average of 5
C 1*	Average of 5			E50 2#	average of 5		E3 4#	average of 5
C 2*	Average of 5							
C 3#	Average of 5			E60 1#	average of 5		E4 3#	average of 5
C 4#	Average of 5			E60 2#	average of 5		E4 4#	average of 5
B 1*	W x $C1^3$ x 9.81 x 10^{-6}			E70 1#	average of 5		E5 3*	average of 5
B 2*	W x $C2^3$ x 9.81 x 10^{-6}			E70 2#	average of 5		E5 4*	average of 5
B 3#	W x $C3^3$ x 9.81 x 10^{-6}							
B 4#	W x $C4^3$ x 9.81 x 10^{-6}			E80 1#	average of 5		E10 3#	average of 5
				E80 2#	average of 5		E10 4#	average of 5
Formability								
F 1*	((E20-E5)*B)/14.7			E90 1#	average of 5		E15 3#	average of 5
F 2*	((E20-E5)*B)/14.7			E90 2#	average of 5		E15 4#	average of 5
F 3#	((E20-E5)*B)/14.7							
F 4#	((E20-E5)*B)/14.7			E100 1*	average of 5		E20 3#	average of 5
				E100 2*	average of 5		E20 4#	average of 5
Shear								
G 1#	24.5/E1 3	24.5/E1 4					E25 3#	average of 5
G 2#	49.1/E2 3	49.1/E2 4					E25 4#	average of 5
G 3#	73.6/E3 3	73.6/E3 4						
G 4#	98.1/E4 3	98.1/E4 4					E30 3#	average of 5
G 5*	122.6/E5 3	122.6/E5 4					E30 4#	average of 5
Thickness							E35 3#	average of 5
T 2*	Average of 5						E35 4#	average of 5
T 100*	Average of 5							
ST*	Average of 5						E40 3#	average of 5
							E40 4#	average of 5
Weight								
W*	average of 5						E45 3#	average of 5
				Normal FAST = *			E45 4#	average of 5
Drape				Modified FAST = #				
DC FU#	average of 6			1 = Warp			E50 3#	average of 5
DC FD#	average of 6			2 = Weft			E50 4#	average of 5
Nodes FU#	average of 6			3 = 45 °				
Nodes FD#	average of 6			4 = 135 °				

Five extra samples were obtained, these together with the original five (the original seven after the two plain weave fabrics were removed) were tested using the second modification to the testing procedure. These fabric details can be seen below.

Table 3.2.4: Fabric Details 2

Letter	Colour	Quality No	Fabric Story	Weight Reduction	Problem
A	Gold	02584	Geisha	10 %	No
B	Light Pink	02871	Portia	12 %	No
C	Pink	01136	Juno	17 %	No
D	Soft Blue	02471	Carly	16 %	No
E	Chantilly	01478	Carly	22 %	Dropping
H	Chantilly	02471	Carly	16 %	No
I	Moire	02541	Venus	0 %	No
J	Moire	02541	Venus	9 %	No
K	Moire	01426	Venus	20 %	Pucker
L	Black	02500	Juno	0 %	No

Note: The initial fabrics (A-E) were re-tested using the new extension and shear methods, five more fabrics were obtained and also tested. Fabric H was a different colour but the same structure and treatment as fabric D. Fabric L was the base (0% weight reduced) of fabric C in a different colour. Fabrics I was the base for fabrics J and K.

3.2.6 Discussion and Third Set of Modifications

A large amount of data was gathered in the above testing, however only those that prompted further modification to the equipment or test method will be discussed. An anomaly was encountered when assessing the results from the second batch of fabrics. Fabric H, which should have produced the same results as fabric D, displayed very different drape coefficient results. The weights of the two fabrics were within tolerance for the weight reduction specified, however the drape results were 10% different. The fabrics were re-tested for drape, to investigate whether an error had been made during the test. However the same results were obtained. A t-test confirmed that the results were significantly different. A critical value of 1.7 was produced and t-statistics were calculated of 18.4 and 16.0 for the face up samples and face down samples respectively. Thus, it was established that fabrics within the Carly story were not as reproducible as required, probably because they were in the development stage and therefore the process had not been finalised. It was therefore decided not to include them in subsequent testing.

The results of the stability parameters were assessed at this stage, and because there was little difference between the results from the different fabrics the stability parameters of Hygral Expansion and Relaxation Shrinkage tests were omitted from further testing.

Eleven new fabrics were obtained; the details are given below. The twenty-one fabrics could then be separated into five fabric stories each having at least three levels of weight reduction percentage, this enabled a more detailed analysis of the results.

Table 3.2.5: Fabric Details 3

Letter	Colour	Quality No	Fabric Story	Weight Reduction	Weft Type		Problem
					Text	Twisted	
A	Gold	02584	Geisha	10 %	Yes	V low	No
B	Lt Pink	02871	Portia	12 %	Yes	No	No
C	Pink	01136	Juno	17 %	Yes	Med	Buttonhole
I	Moire	02608	Venus	0 %	No	High	No
J	Moire	02541	Venus	9 %	No	High	No
K	Moire	01426	Venus	20 %	No	High	Pucker
L	Black	02500	Juno	0 %	Yes	Med	No
M	White	01019	Portia	0 %	Yes	No	No
N	Aqua	02130	Portia	7 %	Yes	No	No
O	Lt Pink	02913	Portia	10 %	Yes	No	No
P	Cream	01256	Portia	15 %	Yes	No	Sewing
Q	Cream	02516	Geisha	0 %	Yes	V low	No
R	Chantilly	02131	Geisha	5 %	Yes	V low	No
S	Piedra	02926	Geisha	10 %	Yes	V low	No
T	Cream	00000	Geisha	15 %	Yes	V low	No Info
U	Yellow	00000	Electra	0 %	Yes	Low	No
V	Angelica	02926	Electra	5 %	Yes	Low	No
W	Peach	01134	Electra	14 %	Yes	Low	No
X	Black	02500	Juno	0 %	Yes	Med	No
Y	Chantily	01054	Juno	10 %	Yes	Med	No
Z	Green	01136	Juno	17%	Yes	Med	Buttonhole

Table 3.2.6: Fabric details 3 - in Story Breakdown

Letter	Colour	Quality No	Fabric Story	Weight Reduction	Weft Type		Problem
					Text	Twisted	
A	Gold	02584	Geisha	10 %	Yes	V low	No
Q	Cream	02516	Geisha	0 %	Yes	V low	No
R	Chantilly	02131	Geisha	5 %	Yes	V low	No
S	Piedra	02926	Geisha	10 %	Yes	V low	No
T	Cream	00000	Geisha	15 %	Yes	V low	No Info
B	Lt Pink	02871	Portia	12 %	Yes	No	No
M	White	01019	Portia	0 %	Yes	No	No
N	Aqua	02130	Portia	7 %	Yes	No	No
O	Lt Pink	02913	Portia	10 %	Yes	No	No
P	Cream	01256	Portia	15 %	Yes	No	Sewing
C	Pink	01136	Juno	17 %	Yes	Med	Buttonhole
L	Black	02500	Juno	0 %	Yes	Med	No
X	Black	02500	Juno	0 %	Yes	Med	No
Y	Chantily	01054	Juno	10 %	Yes	Med	No
Z	Green	01136	Juno	17%	Yes	Med	Buttonhole
I	Moire	02608	Venus	0 %	No	High	No
J	Moire	02541	Venus	9 %	No	High	No
K	Moire	01426	Venus	20 %	No	High	Pucker
U	Yellow	00000	Electra	0 %	Yes	Low	No
V	Angelica	02926	Electra	5 %	Yes	Low	No
W	Peach	01134	Electra	14 %	Yes	Low	No

Prior to the testing a separate investigation was carried out to establish the accuracy of the test methods and to make the final modifications necessary. The results of which are summarised in table 3.2.12 - the final testing details.

3.2.6.1 Accuracy of the Results

The results from the extension meter in both the bias and the primary thread directions were predicted to be of great importance in differentiating between problem and non-problem fabrics. However, the results obtained to date using the modified equipment produced variations (within the five repeat tests) that were larger than one would have liked. This fact, together with the knowledge that there would probably only be a narrow margin between problem and non-problem fabrics, indicated that all possible sources of error should be found and reduced.

3.2.6.2 Sample Preparation

The first possible source of error for the bias extension samples was in their preparation. Throughout the previous tests it was found to be quite difficult to accurately mark the specimen dimensions because the fabrics distorted so easily. As the extension load is defined per fabric width it was especially important to obtain samples with an accurate width measurement. This was not a problem when preparing samples in the warp and weft directions as they could be unravelled to correct dimensions, but it was a potential source of error for samples prepared in the bias directions.

The coefficient of variation and percentage accuracy using the five repeat specimens were obtained. All of the fabrics produced different results and these varied considerably (for example at 5 gf/cm load the range of coefficient of variation (CV) was 3.34-15.29 which produced a percent accuracy (%A) of 2.93-13.4). Thus, in order to simplify the comparison, the averages from all the fabrics in the first batch (Table 3.2.1 Fabric Detail 1) were calculated.

Table 3.2.7: Accuracy of Extension Results

Load	5	20	30	40	50	60	70	80	90	100
CV	8.0	7.2	6.9	6.2	6.0	5.9	5.7	5.8	5.5	5.3
% A	7.0	6.3	6.0	5.4	5.2	5.2	5.0	5.1	4.8	5.7

The results were not unacceptably inaccurate, however it was notable that the accuracy was higher at greater loads. One possible reason was that the results were only given to one decimal place. Thus at smaller loads the difference between a set of three results displayed on the computer as 0.2, 0.2 and 0.3, for example, could in fact have been much smaller, 0.22, 0.24 and 0.26, for example. The programming of the FAST equipment was not within the scope of this thesis, however other ideas were tried in order to assess if the accuracy could be improved. A stamp was developed that marked the test specimen dimensions on the fabric in a single operation; it was anticipated that this would eliminate errors in sample marking (especially important in the width) due to fabric distortion. Three fabrics were selected to have further tests undertaken on them; three repeat tests were prepared using a normal marker and the new stamp methods.

Although five repeats were used in the normal testing it was felt that three tests would allow the difference between marker and stamp produced samples to be identified without undertaking more testing than necessary. It was noted that as a greater number of repeat tests was linked to the percentage accuracy, this trial could not be compared to the actual test results, but that it could be used to compare the two methods of preparation.

Table 3.2.8: Coefficient of Variation – stamp and marker

	1	2	3	4	5	10	15	20	25	30	35	40	45	50
Fabric 1 Stamp (S)														
3	50.0	47.2	23.9	27.5	21.6	16.7	12.0	12.1	11.0	10.0	9.8	9.6	9.4	9.1
4	59.3	58.6	65.5	51.4	51.6	48.0	36.0	28.0	17.5	10.8	7.5	5.4	4.3	3.5
Fabric 1 Marker (M)														
3	12.2	5.2	1.6	4.4	2.2	2.9	2.2	1.7	2.6	2.9	2.3	2.1	2.4	2.0
4	17.3	13.0	8.36	2.7	5.3	4.5	1.9	1.8	2.4	2.3	2.9	2.8	3.4	2.8
Fabric 2 S														
3	29.4	23.5	31.1	32.6	23.4	13.8	14.8	12.3	10.7	9.9	9.6	9.6	8.8	8.4
4	17.1	13.0	14.1	9.0	16.6	9.5	10.5	10.7	10.4	9.5	10.6	9.3	9.5	9.5
Fabric 2 M														
3	16.8	13.5	14.5	14.8	18.1	10.7	10.7	10.6	11.5	9.9	10.7	10.8	10.	10.5
4	35.2	27.2	21.5	17.5	21.2	15.4	14.1	13.7	14.3	12.4	12.1	12.5	12.4	11.9
Fabric 3 S														
3	22.4	6.8	9.2	6.5	3.8	1.9	0.5	1.8	2.4	3.0	3.4	2.8	3.8	3.6
4	5.6	4.4	3.6	2.3	2.4	1.9	3.8	3.0	2.6	2.7	2.7	2.5	2.8	2.7
Fabric 3 M														
3	17.3	8.1	11.0	10.0	8.7	6.3	2.3	4.2	3.3	1.5	2.0	2.8	2.2	1.8
4	31.2	16.9	16.0	15.2	13.8	10.3	10.5	7.4	7.1	7.5	6.7	7.1	5.9	6.8
Overall Averages														
S	30.6	25.6	24.6	21.6	19.9	15.3	13.0	11.3	9.1	7.7	7.3	6.5	6.4	6.1
M	21.7	14.0	12.2	10.8	11.5	8.4	7.0	6.6	6.8	6.1	6.1	6.4	6.1	6.0

The overall averages suggested that the original marker technique produced more consistent results, however conflicting results were found for each of the individual fabrics. Fabric 1 produced results that had fewer variations in both directions when samples were prepared with the marker. The results for fabrics 2 and 3 were inconsistent, the load used affected the consistency of the right bias direction results. However, for both fabrics all the left bias results were more consistent with the stamp preparation.

This analysis did not clarify the situation and thus a more in-depth assessment was sought, with the six results for each load from each fabric compared using an F-Test to assess the diversity of the results using both methods of preparation. This was in order to clarify whether the differences in diversity suggested above were statistically significant.

Table 3.2.9: Probabilities Associated with Diversity – Stamp and Marker

	1	2	3	4	5	10	15	20	25	30	35	40	45	50
Fabric 1														
	0.24	0.19	0.19	0.08	0.01#	0.01#	0.02#	0.01#	0.05#	0.09	0.17	0.10	0.14	0.11
Fabric 2														
	0.48	0.44	0.27	0.24	0.44	0.49	0.44	0.49	0.36	0.39	0.41	0.34	0.32	0.31
Fabric 3														
	0.09	0.01*	0.02*	0.02*	0.00*	0.00*	0.01*	0.01*	0.01*	0.02*	0.03*	0.02*	0.06	0.04*
Averages														
	0.15	0.08	0.07	0.01#	0.01#	0.01#	0.01#	0.02#	0.07	0.08	0.10	0.17	0.16	0.21

Note:
Probability > 0.05 = no difference
Probability < 0.05 = difference in diversity
* marker method greater diversity
# stamp method great diversity

The majority of results (34/56) indicated that there was no significant difference between the results obtained with the different methods. They also indicated that some fabrics produce more consistent results when prepared with one method, whereas the reverse was also found with other fabrics. Thus as using the stamp was not seen as a major advantage further experiments were not undertaken, and the original method of preparation of the samples was used in subsequent testing.

3.2.6.3 Extension Loads

Another approach was examined in order to try to increase the accuracy of the extension technique. This was to manufacture weights designed specifically for the extension meter. The instrument works on a pivot principle, where the weight removed is actually the load imposed on the sample. As these experiments utilised extensions at a greater variety of loads than the machine was originally designed for, it had to be adapted. A base was constructed to fit over the current pole the FAST weights fitted on; ordinary balance weights were then used to achieve the loads necessary. Due to the nature of the device, the exact position of the weight on the arm was very important to the results. Although great care was taken with the positioning of the balance weights on the base, it was possible that this had produced variations. Thus special weights were designed using the dimensions of the machine and this completely eliminated this possible source of error. The weights were circular and up to 52 mm diameter, with a central hole of 20 mm diameter; the diameter and the depth could be varied to produce the desired load intervals.

The results obtained using the second modification (using a stand and various balance weights) were compared to those using the new apparatus, the summary of which can be seen in the table below.

Table 3.2.10: Average Coefficients of Variation – second and third modifications

	1	2	3	4	5	10	20	30	40	50	60	70	80	90	100
Warp															
2nd modification					16.78		22.68			11.46	10.23	10.95	10.87	11.88	11.70
3rd modification	22.5	4.1	5.5	12.0	11.6	7.9	8.4	6.7	8.0	6.5	8.3	7.3	5.7	7.1	6.7
Weft															
2nd modification					9.20		7.13			7.56	6.19	5.83	6.28	5.93	5.13
3rd modification	9.7	7.7	10.5	7.7	4.3	5.9	3.6	3.4	3.1	3.5	3.2	2.9	3.2	2.8	2.9

	1	2	3	4	5	10	15	20	25	30	35	40	45	50
Rbias														
2nd modification	15.08	10.33	8.64	8.34	8.42	6.26	6.33	6.11	6.57	6.20	5.56	5.61	5.65	5.52
3rd modification	11.4	7.4	6.3	6.0	5.9	5.1	5.0	4.8	4.6	4.5	4.5	4.3	4.3	4.3
Lbias														
2nd modification	11.76	10.74	9.15	8.19	8.54	7.05	6.18	5.58	6.39	6.01	6.02	6.07	9.89	5.09
3rd modification	14.0	9.8	7.4	6.8	6.2	5.0	4.7	4.6	4.5	4.5	4.4	4.3	4.2	4.2

The results indicated that although the reductions in coefficient of variation (and therefore diversity) were small, they were consistent. The results in the warp and weft directions showed a larger effect from this new equipment; this may have been because great care was taken with the testing of the bias direction samples due to the fact that the ease of distortion had been very noticeable in preparation. However, for the warp and weft samples this was not as prominent and therefore less care may have been taken with the mounting of the weights which was compensated for by this new method. Thus the modification was proven valid and included in further testing. It was also decided to increase the set of loads imposed on the warp and weft samples in order to include loads less than 5 gf/cm, in a similar manner to the bias samples.

3.2.6.4 Negate zero loading

Another method was tried in order to reduce the diversity in the results obtained from the repeat samples from each fabric, which was to subtract the initial extension result from the subsequent results in order to eliminate the effect of zero loading. The FAST formability parameter uses the extension at 20 gf/cm and subtracts the extension at 5 gf/cm, so that if there is a discrepancy in the method of loading the samples it will be negated by using the difference of the two loads. It was thought that this principle could be adapted to reduce variation for the modified test method. However, as can be seen from the table 3.2.11, there was no advantage to using this zero loading technique, thus the results from the individual loads were used.

3.2.6.5 Conclusion

Thus one out of the three methods proved to be useful to reduce variation. The final testing details can be found in table 3.2.12, which reflect all modification made.

Table 3.2.11: Average Coefficients of Variation – Result from each Loads and after Subtracting the Extension at 1gf/cm

	1	2	3	4	5	10	20	30	40	50	60	70	80	90	100
Warp															
Normal	22.5	4.1	5.5	12.0	11.6	7.9	8.4	6.7	8.0	6.5	8.3	7.3	5.7	7.1	6.7
Zero loading		105.3	113.3	101.5	55.1	27.9	19.2	17.0	14.3	12.9	12.7	11.6	10.7	10.8	9.5
Weft															
Normal	9.7	7.7	10.5	7.7	4.3	5.9	3.6	3.4	3.1	3.5	3.2	2.9	3.2	2.8	2.9
Zero loading		59.4	31.7	14.7	11.3	9.3	5.1	4.2	3.9	3.7	3.8	3.4	3.6	3.2	3.1

	1	2	3	4	5	10	15	20	25	30	35	40	45	50
Right bias														
Normal	11.4	7.4	6.3	6.0	5.9	5.1	5.0	4.8	4.6	4.5	4.5	4.3	4.3	4.3
Zero loading		7.7	6.9	6.9	6.1	5.4	5.1	5.0	4.9	4.8	4.7	4.6	4.6	4.5
Left bias														
Normal	14.0	9.8	7.4	6.8	6.2	5.0	4.7	4.6	4.5	4.5	4.4	4.3	4.2	4.2
Zero loading		10.8	8.2	7.8	7.2	5.7	5.3	5.2	5.1	5.1	4.9	4.7	4.7	4.7

Table 3.2.12: Final testing details

Modified FAST Control Chart								
Fabric:								
Bending				Extension				
C 1*	average of 5			E1 1#	average of 5		E1 3#	Average of 5
C 2*	average of 5			E1 2#	average of 5		E1 4#	Average of 5
C 3#	average of 5							
C 4#	average of 5			E2 1#	average of 5		E2 3#	Average of 5
				E2 2#	average of 5		E2 4#	Average of 5
B 1*	W x $C1^{3}$ x 9.81 x 10^{-6}							
B 2*	W x $C2^{3}$ x 9.81 x 10^{-6}			E3 1#	average of 5		E3 3#	Average of 5
B 3#	W x $C3^{3}$ x 9.81 x 10^{-6}			E3 2#	average of 5		E3 4#	Average of 5
B 4#	W x $C4^{3}$ x 9.81 x 10^{-6}							
				E4 1#	average of 5		E4 3#	Average of 5
Formability				E4 2#	average of 5		E4 4#	Average of 5
F 1*	((E20-E5)*B)/14.7							
F 2*	((E20-E5)*B)/14.7			**E5 1***	average of 5		**E5 3***	Average of 5
F 3#	((E20-E5)*B)/14.7			**E5 2***	average of 5		**E5 4***	Average of 5
F 4#	((E20-E5)*B)/14.7							
				E10 1#	average of 5		E10 3#	Average of 5
Shear				E10 2#	average of 5		E10 4#	Average of 5
G 1#	24.5/E1 3	24.5/E1 4						
G 2#	49.1/E2 3	49.1/E2 4		**E20 1***	average of 5		E15 3#	Average of 5
G 3#	73.6/E3 3	73.6/E3 4		**E20 2***	average of 5		E15 4#	Average of 5
G 4#	98.1/E4 3	98.1/E4 4						
G 5*	122.6/E5 3	122.6/E5 4		E30 1#	average of 5		E20 3#	Average of 5
				E30 2#	average of 5		E20 4#	Average of 5
Thickness								
T 2*	average of 5			E40 3#	average of 5		E25 3#	Average of 5
T 100*	average of 5			E40 4#	average of 5		E25 4#	Average of 5
ST*	T2-T100							
				E50 1#	average of 5		E30 3#	Average of 5
Weight*				E50 2#	average of 5		E30 4#	Average of 5
W	average of 5							
				E60 1#	average of 5		E35 3#	Average of 5
Drape				E60 2#	average of 5		E35 4#	Average of 5
DC FU#	cut out / original %							
DC FD#	cut out / original %			E70 1#	average of 5		E40 3#	Average of 5
Nodes FU#	average of 6			E70 2#	average of 5		E40 4#	Average of 5
Nodes FD#	average of 6							
				E80 1#	average of 5		E45 3#	Average of 5
				E80 2#	average of 5		E45 4#	Average of 5
Normal FAST = *								
Modified FAST = #				E90 1#	average of 5		E50 3#	Average of 5
1 = Warp				E90 2#	average of 5		E50 4#	Average of 5
2 = Weft								
3 = 45 °				**E100 1***	average of 5			
4 = 135 °				**E100 2***	average of 5			

3.2.7 Experiment

The results obtained from the modified FAST tests provided a lot of information about the characteristics of the fabrics. For example, the most flexible fabrics were those with the lowest bending rigidity; the easiest to distort were the fabrics with the lowest shear rigidity. By using the previous research in the field of Fabric Objective Measurement using the KES instruments, indications were provided as to whether high or low results could be associated with problems for each of the individual parameters. However, the actual combination of results that could indicate problems for these specific fabrics using either the standard or modified FAST equipment had not been established. Thus, in order to put the test results into context they must be related more definitely to possible problem areas.

Three areas where problem fabrics could be distinguished from quality ones were chosen for this assessment; ease of manufacture, distortion of garment dimensions, and final appearance of garments. These areas enabled a wide variety of characteristics to be correlated with the test results. The design of experiment for these problem areas was carefully developed in order that the greatest amount of information available from the limited fabric samples could be obtained.

3.2.7.1 Ease of Manufacture

This area was the most important to the collaborating company, as if garment manufacturers complained about the fabrics, they were mainly concerned with the difficulty in the garment manufacture process. The company had a limited amount of information about these problems and, because manufacturing companies that had different equipment provided the data, trends were difficult to establish. This is because the equipment the manufacturer used had a definite effect on whether problems were found with a particular fabric. A vacuum cutting table, for instance, can help to alleviate the majority of distortion problems these types of fabrics exhibit during the cutting procedure. Also different sewing machines (and their control settings for overfeed) can effect the amount of puckering seams display. Finally, the amount of experience the sewing machinist has with a particular fabric also effects the ease of manufacture. Thus it was not possible to use information provided from different sources because there was no control or consistency over the manufacturing variables.

It was therefore decided to implement an independent manufacturing trial that allowed the equipment and operator to be kept standard. The initial plan was to manually cut the fabrics (in order to be able to grade how difficult this operation was), but distortion of pattern piece dimensions could contribute to problems in the sewing operation and it would be hard to distinguish between the two problems. It was therefore decided that as the sewing operation was the most important variable under investigation, the cutting procedure would utilise vacuum equipment that would minimise distortion. A very experienced sample machinist was found to manufacture all of the garments. She was experienced in the production of garments with problem fabrics and therefore would not have a learning curve effect that would increase her perception of the grade of ease of manufacture as she gained experience with the fabric. To add to her experience and to help her focus on these particular fabrics, she manufactured two trial garments prior to the experiment.

The choice of garment was critical for the experiment; one that tested the distortion of the fabric to the greatest degree was required (a difficult style that presented as many potential problems as possible), as this would help to differentiate between problem and quality fabrics. A full-length bias cut slip dress was chosen with short sleeves and bias binding around the neck. In association with the fabric company and the sewing operator an information sheet was designed in order to gain as much information as possible about the production of the garments. It provided the manufacturing specification and allowed space for the operator to grade each operation. Operations 4, 5, 7 and 8 were ones that the technician was requested to fill in (where problems were expected). The others were left clear in order that unexpected problems could also be graded at the discretion of the machinist. This was found to be the case with operation 6 (the lock stitching of the neck opening) as it provided a number of difficulties.

Table 3.2.13: Manufacturing Information Sheet

Fabric:
Date:
Time:

No.	Operation	Difficult →	Normal →			Easy
		1	2	3	4	5
1	Lock stitch darts – front					
2	Overlock & join shoulders					
3	Overlock edge centre back seam					
4	Lock stitch join centre back (leave 13 cm at top for neck opening)					
5	Lock stitch neck binding inserting loop					
6	Lock stitch neck opening					
7	Overlock insert sleeve into armhole					
8	Overlock & join side seams					
9	Overlock edge sleeve hems & dress hem					
10	Lock stitch sleeve hems & dress hem					
11	Attach button					
	Average					

This enabled a lot of data to be gathered about the manner in which each fabric reacted to the manufacturing process. The average of all the grades for each fabric was then correlated with the test results.

3.2.7.2 Distortion

As well as assessing the fabric in terms of how easy it was to manufacture, it was also important to establish whether the fabric achieved the correct dimensions. Problems can be found with the sizing and fit of garments if the fabric stretches or distorts easily as a retailer will define a sizing specification that they expect a particular garment to conform to.

i) Control of Dimensions

The first step in the experiment was to establish the dimensions that were appropriate for the experimental garment; this was done using a control fabric. This fabric had a stable construction (twill weave mid-weight) and would not distort to the same degree as the weight reduced fabrics; it was therefore a good base to assess the differences between the fabrics in terms of the dress measurements.

The stable 'control' garment was compared to the measurements of the pattern. The data showed that even a stable fabric showed differences between the finished dress and the pattern it was made from. The dress had grown in the length measurements and shrunk in the width measurements. This was due to the bias nature of the cut; if the same fabric had been cut with the pattern pieces placed on the straight of grain (parallel to the warp direction), there would not have been such variations. Thus, it was not appropriate to assess the garments against the pattern measurements as no fabric cut on the bias would produce them.

ii) Flat measurements

Flat measurements were taken after the sewing of the garment (prior to pressing), and then again after pressing to establish if there was a trend in the distortion due to the pressing operation. Many difficulties were found whilst obtaining these initial results; for example, an average of three measurements was required because the fabric distorted so easily a single measurement was not reproducible; subsequent measurement gave slight different results. Thus an average of three was preferable in terms of accuracy.

iii) Measurement of drop

It was planned to obtain additional measurements to assess the amount of drop that each garment would exhibit when hung. As there would only be one opportunity to assess the drop of these garments, careful consideration of the measurement technique used was necessary. Thus, in order to establish how to accurately gain the information about drop, a trial was undertaken. Samples of three fabrics were hung and measurements obtained at hourly intervals during one day. Some unexpected findings were obtained, for example some of the fabric samples produced gradually shorter measurements over time. As the effect of gravity would make this improbable, it would seem that they were unintentionally either stretched initially or compressed subsequently. This experiment highlighted the difficulties in obtaining these types of measurements, as through the action of taking the measurements, the fabric was distorted. It was an example of the dictum that the act of observation alters the behaviour of the thing observed.

Several methods were investigated to try and combat the problem, such as the use of a labelled backdrop graduated in millimetres in order to assess the dimensions of the sample without disturbing it, or callipers that could take readings of the positions of the sample extremes. However due to the amount of data that was required, (length, width and girth measurements), it was decided to use a non-contact 3D scanning booth

iv) Non-contact 3D Scanning Booth

There were many advantages to this system. The object's data is stored on disk and can be re-evaluated at any time so that new or different measurements can be obtained subsequently. This would not have been possible using any other method. It can also establish girth measurements, which are very important in this case because the bust width would not equate to the bust girth as the way the fabric draped obscured the true measurements. It also fulfilled the brief that measurements could be taken without disturbing the sample.

However there were also disadvantages to this method; it uses light photography to capture the image and thus any part of the object not visible (due to darkness or being obstructed from the cameras) would leave a portion of the reconstructed object without data. In addition, the accuracy of the measurements taken depends to a large extent on the alignment of the eight clouds of information. Trials were undertaken to establish whether the scanning system could provide the information necessary to assess these dresses.

Practice dresses made from a similar fabric to those in the experiment were manufactured in order to test the system. This trial helped to establish several precautions necessary to ensure the best possible use of the equipment. Firstly, dark coloured dresses could not be measured as accurately as light fabrics. It was found that a dusting with printers' chalk (a very fine white powder) lightened the area enough for the cameras to pick up the surface contours of the garment. Trials were performed to establish if the addition of the chalk altered the measurements of the garment, but no significant differences were found.

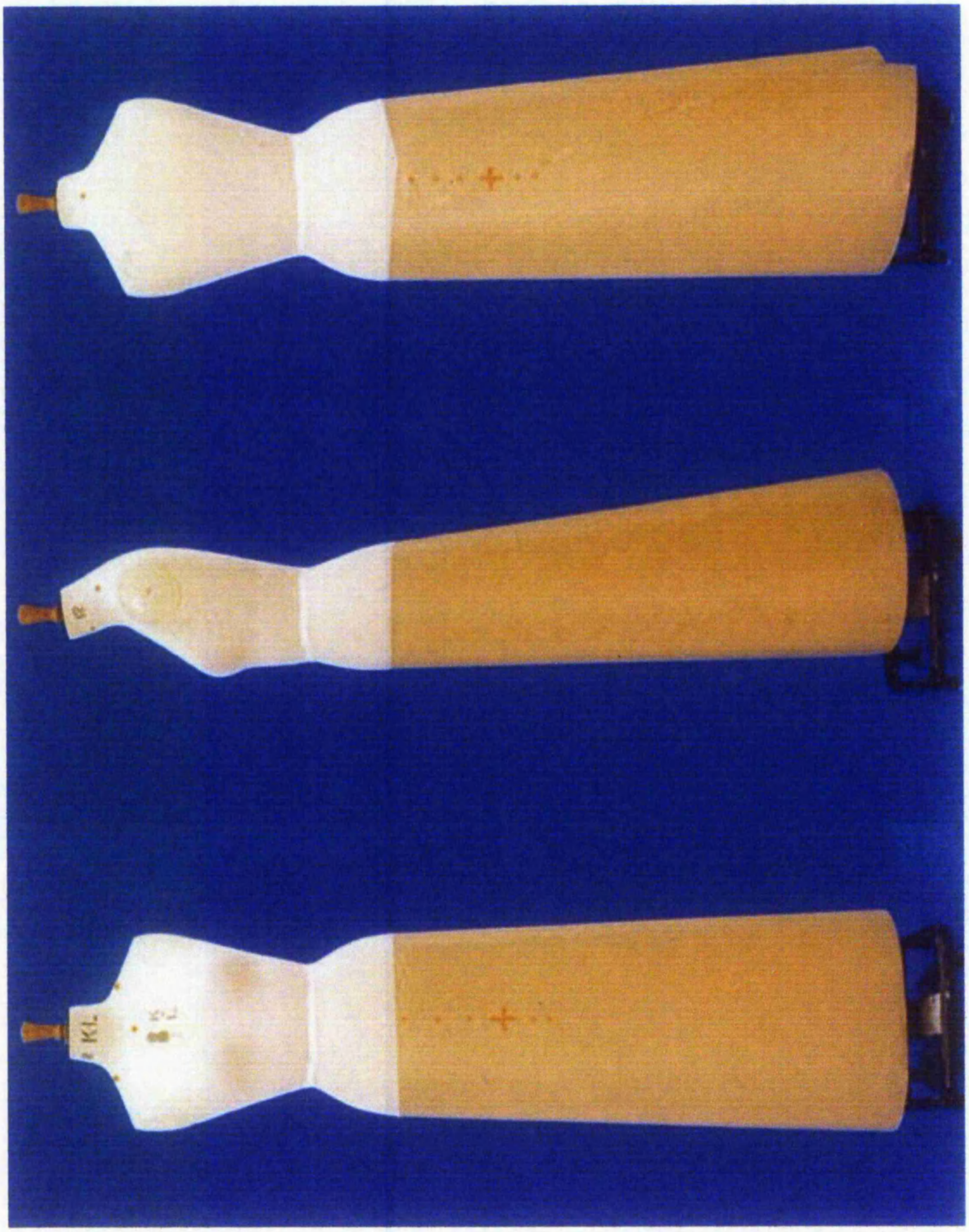
Secondly, more accurate measurements were achieved if the dresses were placed on the appropriate sized tailors' mannequin rather than on hangers during the scanning process. The mannequin was adjustable in height, although it was noticed that as it was mounted on a pole the hems of the dresses tended to gather round in small folds that created difficulties in the hem girth measurements. It was therefore given a long 'skirt' of stiff packing paper. This provided a wider base for the hems of the dresses to drape against, rather than the stand of the mannequin. The 'skirt' was slightly flared but care was taken that it had a narrower circumference than the dresses so as not to influence the measurements. It was also found that the dress sleeves obscured the bust and side seam measurements. Problems here were averted by pinning the sleeves up to the shoulders. To further aid the measurements of the dresses and alignment of the clouds, brightly coloured reference stickers were positioned on all of the dresses to indicate the levels from which the measurements should be taken. For example, the levels at which to assess bust and waist girths or the centre front point at neck and hem. This followed a protocol sometimes used when the booth was used for the measurement of people [168].

Measurements of the garments were obtained using the scanning booth immediately after they had just been placed on the mannequins (the dresses had been kept in a flat state prior to this time). They were then left on hangers (all the same size and shape) for just over a month, to ensure that each dress had dropped completely. They were then re-measured; the mannequin and its skirt had not been altered during this time, and the reference stickers insured that the identical points for measurements were used as during the initial scan.

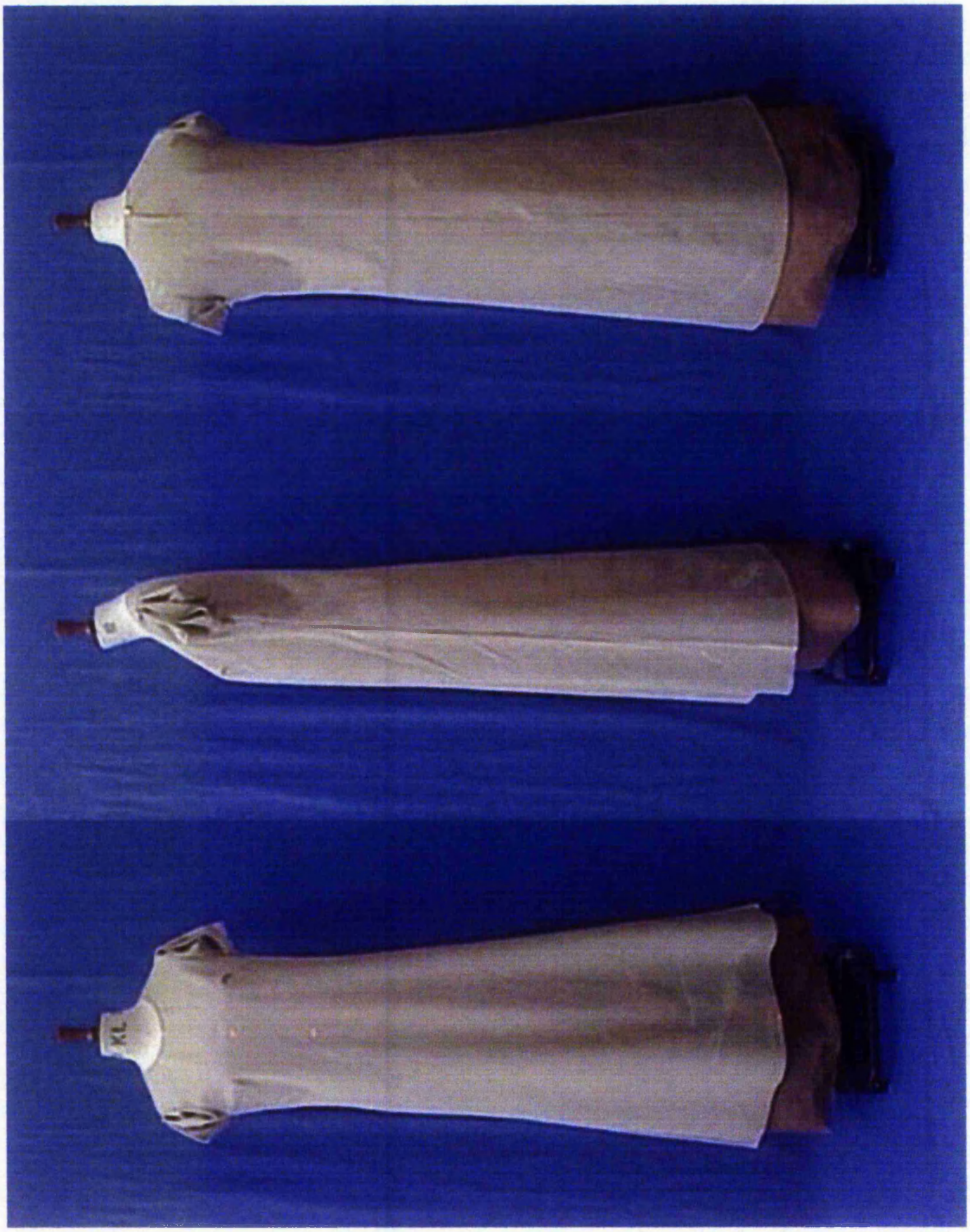
The software for the booth has an automatic alignment feature that allows the alignment of one object to be used as the standard for others. This feature was only accurate within a particular scanning occasion (scanning taking place during the same day with no alteration to the equipment). The clouds of the mannequin were easier to align than those of the garments because the mannequin was solid and had a constant shape; it was therefore used as the base for the dresses (two alignment scans of the mannequin were performed; one for the initial scan and another for the second scan). To ease the alignment of the mannequin further, it was also marked with reference stickers in the shape of a cross. An example of the setup for the distortion assessment for the mannequin and control dress is given below.

Figure 3.2.3 Set-up for Distortion Experiment (A-B)

A) Mannequin



B) Control Dress



v) Analysis of results

As a further control to ensure the fewest possible inaccuracies due to the measurement technique, the results of each garment were compared to the control. The distortion value for each dress would be given in the form of that dress's measurements after subtracting the measurements of the control dress.

The dresses exhibited distortion by increases in length measurement, a reduction in the bust and waist measurements and an increase in the hem girth. This was due to the bias extension of the fabric and is a distortion common in this type of garment [114]. Each measurement was allocated either a positive sign (if an increase in the measurement was caused by distortion) or a negative sign (if a decrease was caused by distortion) in the equation. Thus, the flat measurements were evaluated in the manner below.

Table 3.2.15: Calculation of distortion value for flat measurements

After Sewing	Centre Front: (+)	Right Side: (+)	Left Side: (+)	Centre Back: (+)	Bust line: (-)	Waist Line: (-)	Front hem (+)	Back R hem (+)	Back L hem (+)
Control	121.87	106.27	106.40	127.60	47.40	46.80	73.00	38.50	38.43
Juno 10	125.87	114.27	110.43	133.55	45.70	45.70	73.67	40.47	38.77
J10 – C	4.00	8.00	4.03	5.95	-1.70	-1.10	0.67	1.97	0.33
Distortion	4.00 + 8.00 + 4.03 + 5.95 - -1.70 - -1.10 + 0.67 + 1.97 + 0.33 = 27.75								

A slightly different method was used to assess the scanned measurements as despite the precautions taken, once the data was retrieved from the software it was found that the side seam values could not be calculated. The difference between the centre hem and the side hem was used, where a larger difference indicated the greater distortion.

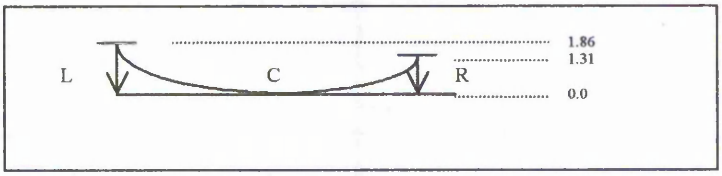
Table 3.2.16: Calculation of distortion value for hung measurements

Initial Scan	Centre Front: (+)	Visual r - c hem (+)	Visual l – c hem (+)	Bust (-)	Waist (-)	Hem girth (+)	Back length (+)
Control	120.10	0.91	0.67	98.75	95.72	151.85	124.70
Portia 7	125.32	1.31	1.86	94.85	88.61	154.61	129.06
P7 – C	5.22	0.40	1.18	-3.90	-7.11	2.76	4.37
Distortion	5.22 + 0.40 + 1.18 - -3.90 - -7.11 + 2.76 + 4.37 = 24.93						

r-c hem, right to centre hem = difference between vertical measurement at ride side measurement and that of the centre front (figure 3.2.4).

Thus the greater the distortion value, the greater the measurement of distortion of the fabric.

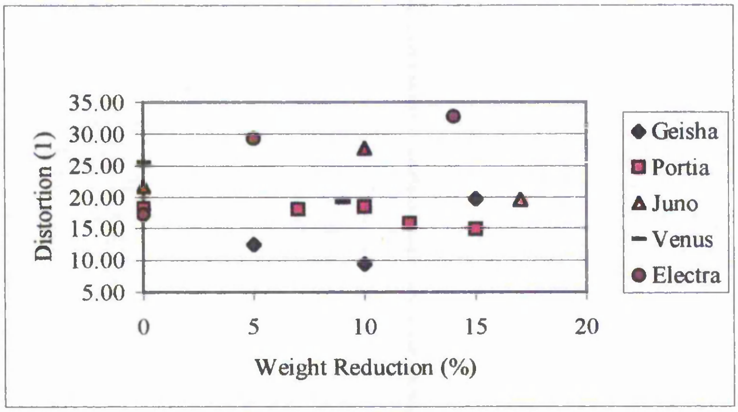
Figure 3.2.4 Schematic of Hem distortion for the scanned measurements:



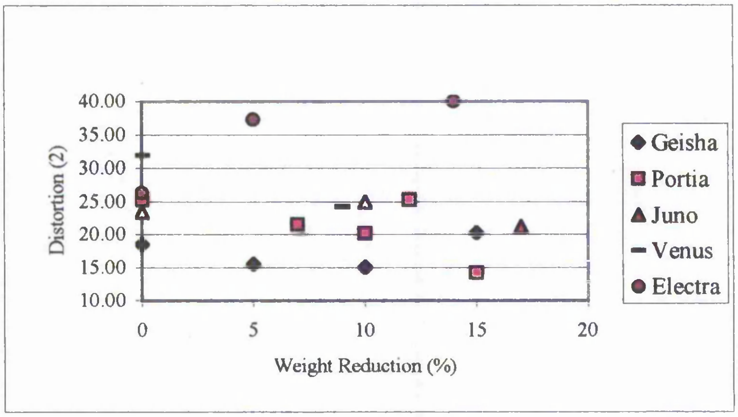
C = vertical measurement of the centre hem (P7 = 0)
L = vertical measurement of the left hem (P7 = 1.86)
R = vertical measurement of the right hem (P7 = 1.31)

Figure 3.2.5 Distortion Value for each Fabric Story

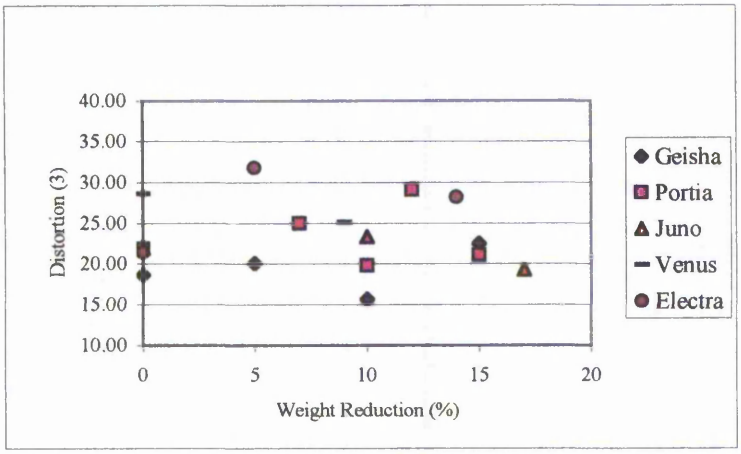
A) Distortion (1) – Flat – Before press



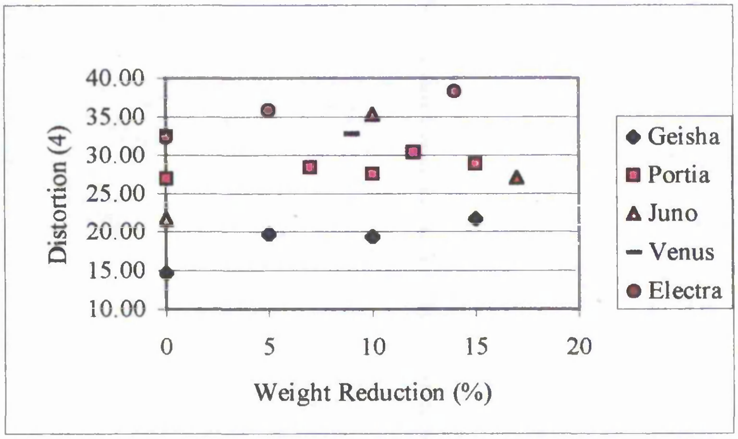
B) Distortion (2) - Flat – After press



C) Distortion (3) – Hung – Initial Scan



D) Distortion (4) – Hung – Second Scan



To simplify further analysis it was necessary to reduce the distortion parameters from these four to just one. To do this, equations were calculated that relate each pairing of the distortion measurements, which enabled linear regressions to be calculated. The R^2 value is described in the experimental methods chapter.

Table 3.2.17 Regression Coefficients for Distortion Experiment

	Before press	After press	Initial scan	Second scan
Before press	1.00	0.75	0.46	0.46
After press		1.00	0.66	0.57
Initial scan			1.00	0.54
Second scan				1.00

The four distortion values had different characteristics, so no single one could be used to represent them all. Thus a new measurement was defined that was the total of the four individual measurements; this correlated well with all the originals, and all subsequent analysis refers to the total distortion.

Table 3.2.18 Regression Coefficients for Total Distortion Measurement

	R^2
Before press	0.81
After press	0.91
Initial scan	0.76
Second scan	0.78

Table 3.2.19 New Total Distortion Measurement Details

Fabric	Total Distortion
G 0 Q_1	69.9
G 5 R_1	67.9
G 10 A_1	59.6
G 15 T_1	84.3
P 0 M	92.2
P 7 N	92.8
P 10 O_1	85.9
P 12 B	100.5
P 15 P_1	79.2
J 0 X	88.7
J 10 Y_1	111.3
J 17 Z	87.2
V 0 I_1	119.0
V 9 J_1	101.2
E 0 U_1	97.2
E 5 V_1	134.2
E 14 W	139.3

3.2.7.3 Appearance

The final assessment of the fabrics was a visual grading of the garments they were made into. The dimensions of the garments were a good indication of how easily each fabric distorted; however, this did not take into account visual distortions. For example, sewing the back seam was a particularly difficult operation, with some of the fabrics puckering causing the hem to be uneven, often flaring out at the back seam point or swinging to one side (see figure 3.2.6). These faults might not necessarily be picked up by measuring the physical dimensions of the garment. Another area where visual grading would establish additional detail to the distortion value was assessing how well the garment hung; this is a very difficult parameter to measure, but it is very important to the quality finish of the garments. As with the other experiments, great care was necessary for the results produced by this experiment to be valid.

i) Method of assessment

It was decided that the experiment should be purely visual, as to include touch could confuse the assessment. The purpose of the weight reduction process is to improve handle, but as this could be at the expense of the garment appearance, those fabrics that looked the worst would very possibly be the ones that had the best handle. It was therefore felt that such a conflict could reduce the validity of the results. Another reason to avoid the assessor touching the dress was that after some time this might have an effect on the fabric, causing a deterioration in appearance.

It was decided to assess the dresses by using photographs taken from three views (front, back and side) in order that a full appreciation of the visual aspect of the dress could be obtained. One of the reasons for using photographs instead of a direct visual evaluation was that it was not possible to obtain the necessary number of correctly sized mannequins to enable all the dresses to be assessed simultaneously, which was very important in order to carry out the ranking process reliably. In addition, as the data from the experiment would be improved if a larger number of assessors was used, it was decided to simplify the assessment as much as possible in order that more people would be able to participate. The photographs helped in this; rather than the assessors having to go the dresses, the photographs could be brought to the assessors. This was essential for the industry-based assessors and as all assessments should be made under the same conditions, the photographs were a valid tool for all the analysis. Every care was taken to ensure that the photographs were an accurate representation of the dresses by using slow exposure film, maintaining light quality and having the photographs printed in a sufficiently large size to ensure that the dress characteristics were clearly visible.

In order to check the accuracy of the assessors, three dresses were chosen at random to have duplicate photographs taken. This enabled the results for the same dress to be compared, and if the rankings were too far apart indicating inconsistency in the grading, the assessor was omitted from the final results.

A paired comparison technique (each dress compared against every other) would provide a lot of information about the validity of each assessor's data, and thus might have enabled consumer judges to be used. However, with this number of dresses, over 200 pairs would be required to be assessed which would involve a great deal of time for assessment. Research indicates that fatigue reduces accuracy of results [169] [170], and thus in this case paired comparison was not a suitable technique.

As the fabrics were all production samples, they varied in colour. This is known to affect subjective opinions and therefore this had to be taken into account when analysing the data. The colour of the dresses could affect the manner in which the characteristics were visible on the photographs. It was anticipated that because the colours were all relatively desaturated (particularly in relation to the heavy saturation of the blue background used in each case) and that all the garments were photographed from the same three angles, the effect would be reduced to a minimum.

ii) Choice of assessors

The choice of assessors was a very important parameter in the design of the experiment. There are differing views in the literature on the validity of consumer judges. Some researchers claim they are as valid as experts [171] [172], whereas others refute these claims [32] [8]. It was decided that only experts should be used for this experiment. This was largely due to the number of dresses that required assessing; twenty dresses is a large data set and thus would be quite difficult to grade. As the evaluation was based on photographs rather than a direct measurement, it also was necessary to use assessors that were experienced in garment evaluation and therefore in seeing important details.

The experts were derived from two different backgrounds; a selection of academic staff from the Fashion and Textiles department of Nottingham Trent University each with over five years experience of fabrics and garments. As a contrast to this, a selection was taken from the quality department of a fabric manufacturer (also with 5 years individual experience), as research indicates that the two group opinions may differ [172].

iii) Questionnaire

The questionnaire below was given to each assessor; the ranking of the garments was an efficient way of obtaining information on the extremes of the visual appearance of the dresses (the four worst and the four best). However, it could not be relied upon to differentiate clearly between those in the middle section. Further details could be obtained about why a fabric was ranked in a particular position by asking the assessors to grade the hang of the garment, levelness of the hem and the puckering of the seams as these are the three main visual properties. The overall appearance should correlate with the initial ranking position.

Table 3.2.20 Questionnaire for Visual Assessment of the Dresses

Name:

Please rank the garments from the worst to the best by placing the number of the garment in the corresponding box below.

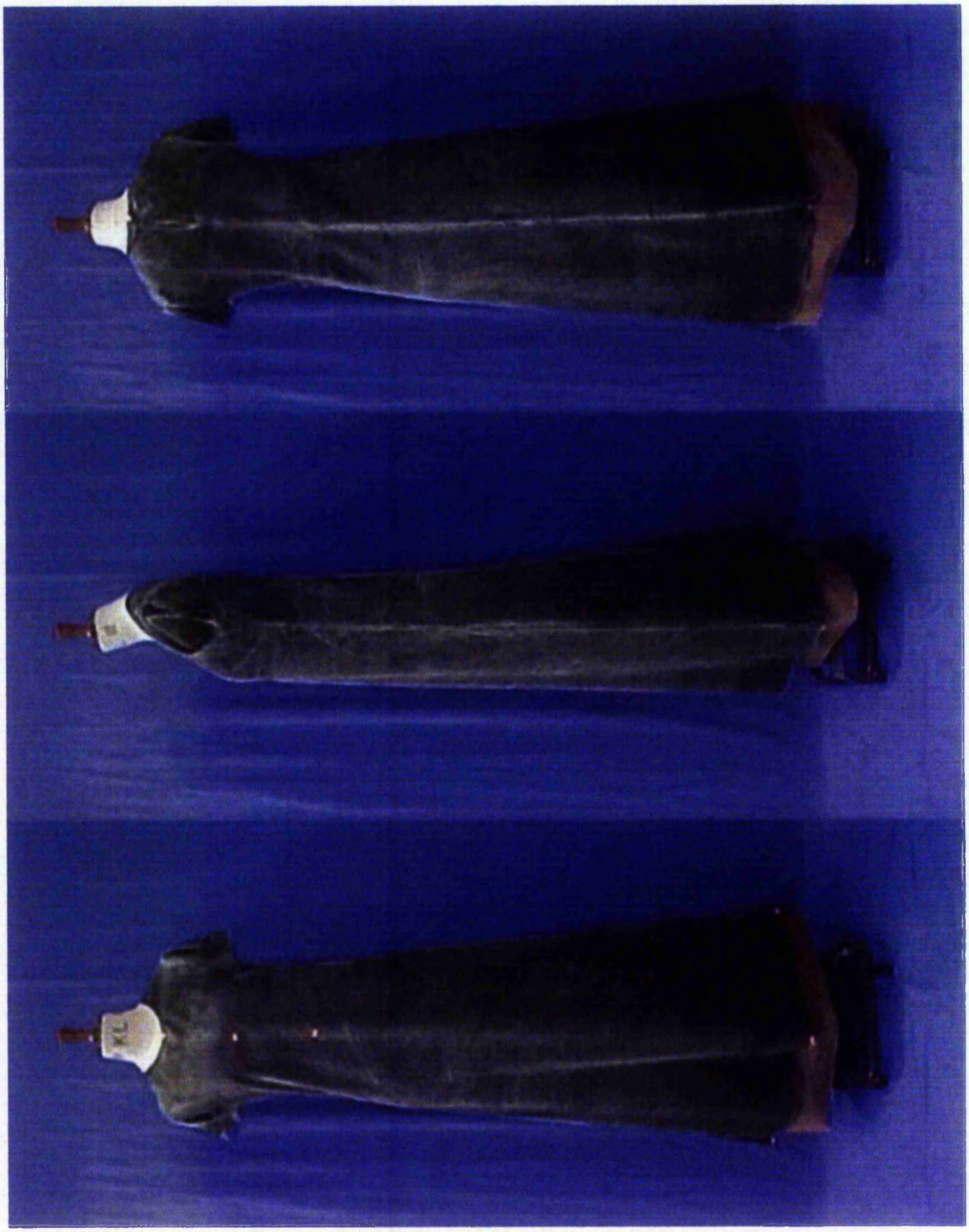
Worst	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	Best

Please grade the individual dresses from 1 (worst) to 5 (best) in terms of the following properties.

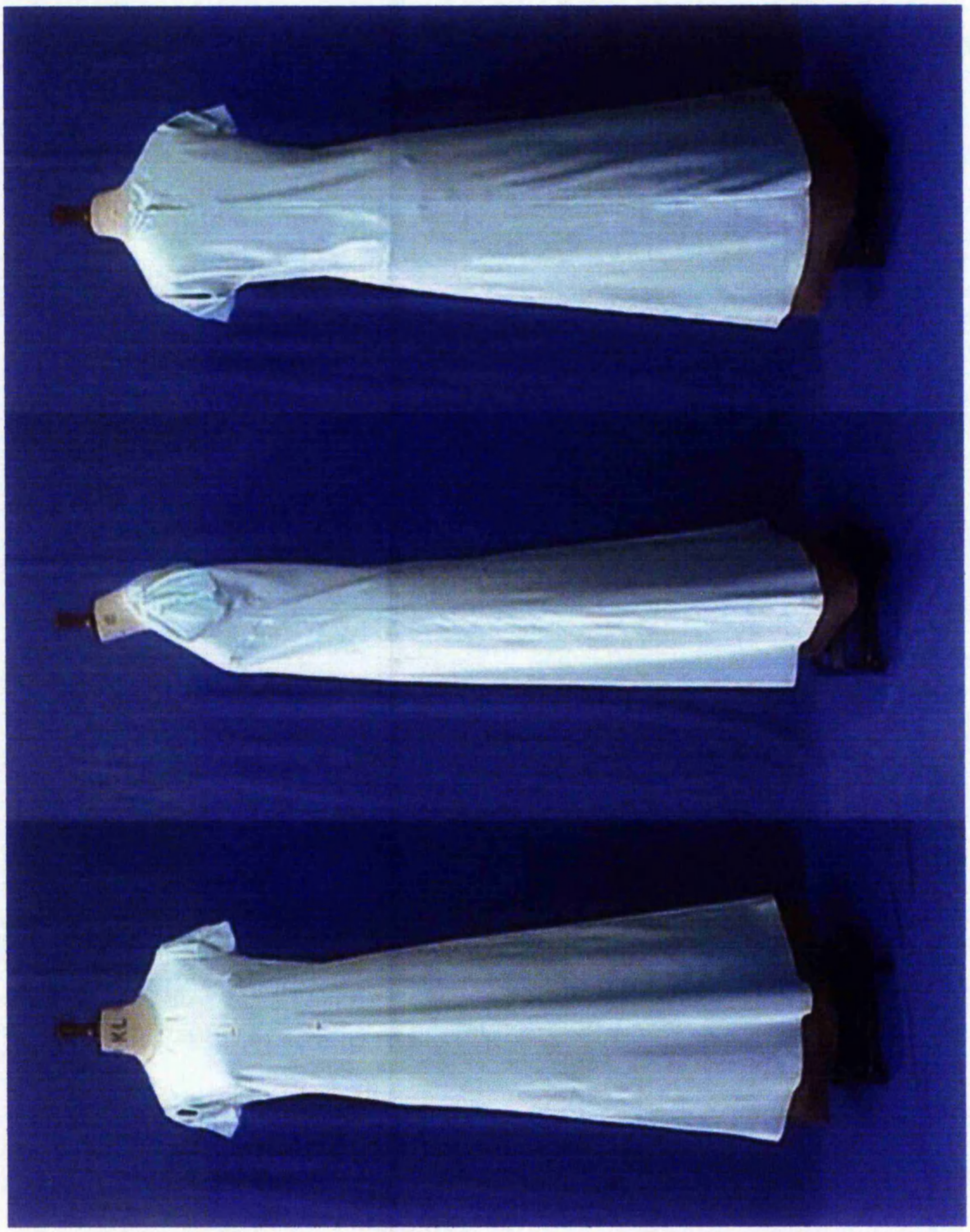
	Hang	Puckering	Levelness of Hem	General Appearance	Any other comments
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					
13					
14					
15					
16					
17					
18					
19					
20					

Figure 3.2.6 Dress Photographs (A-Q)

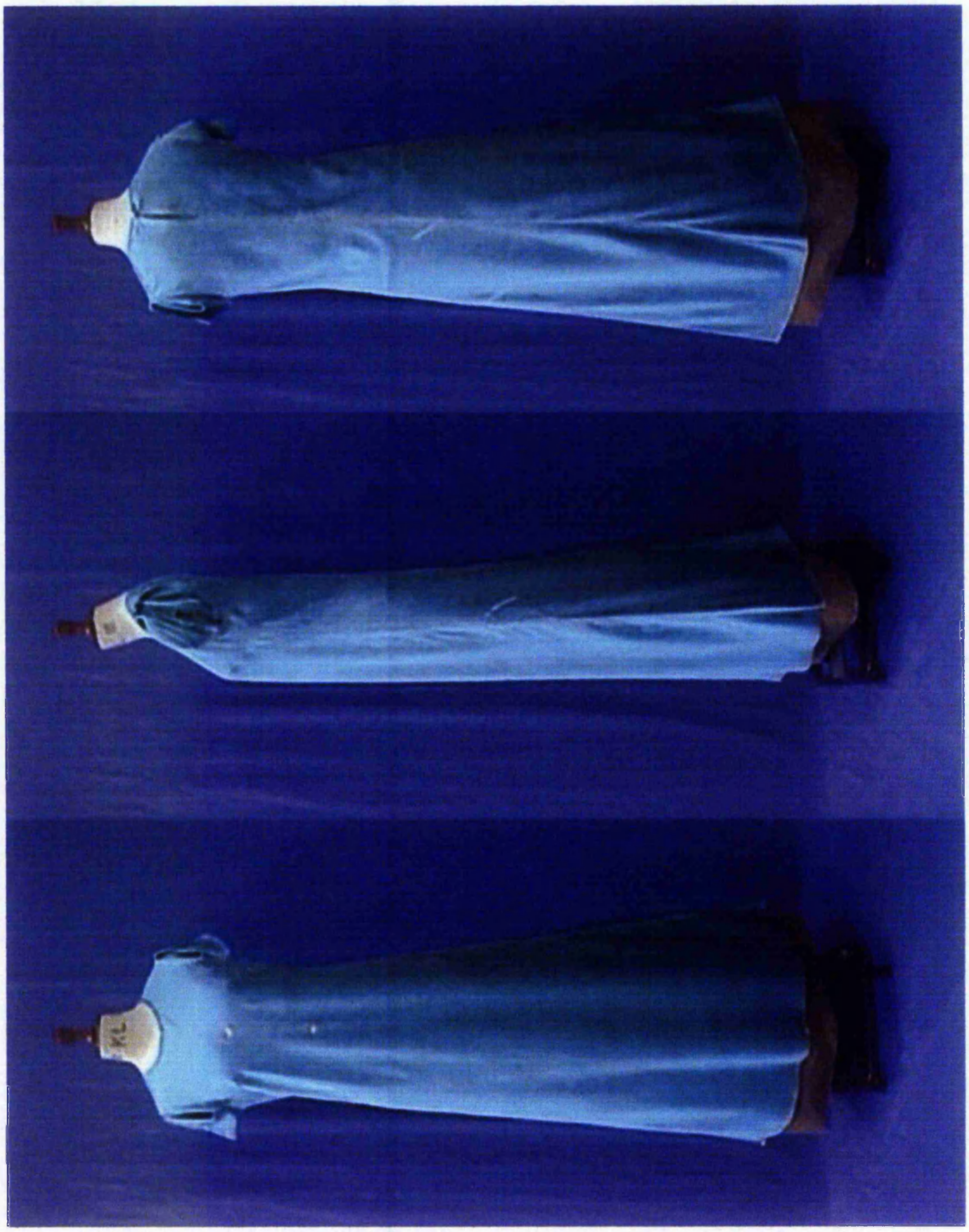
A) Geisha 0% (Q1)



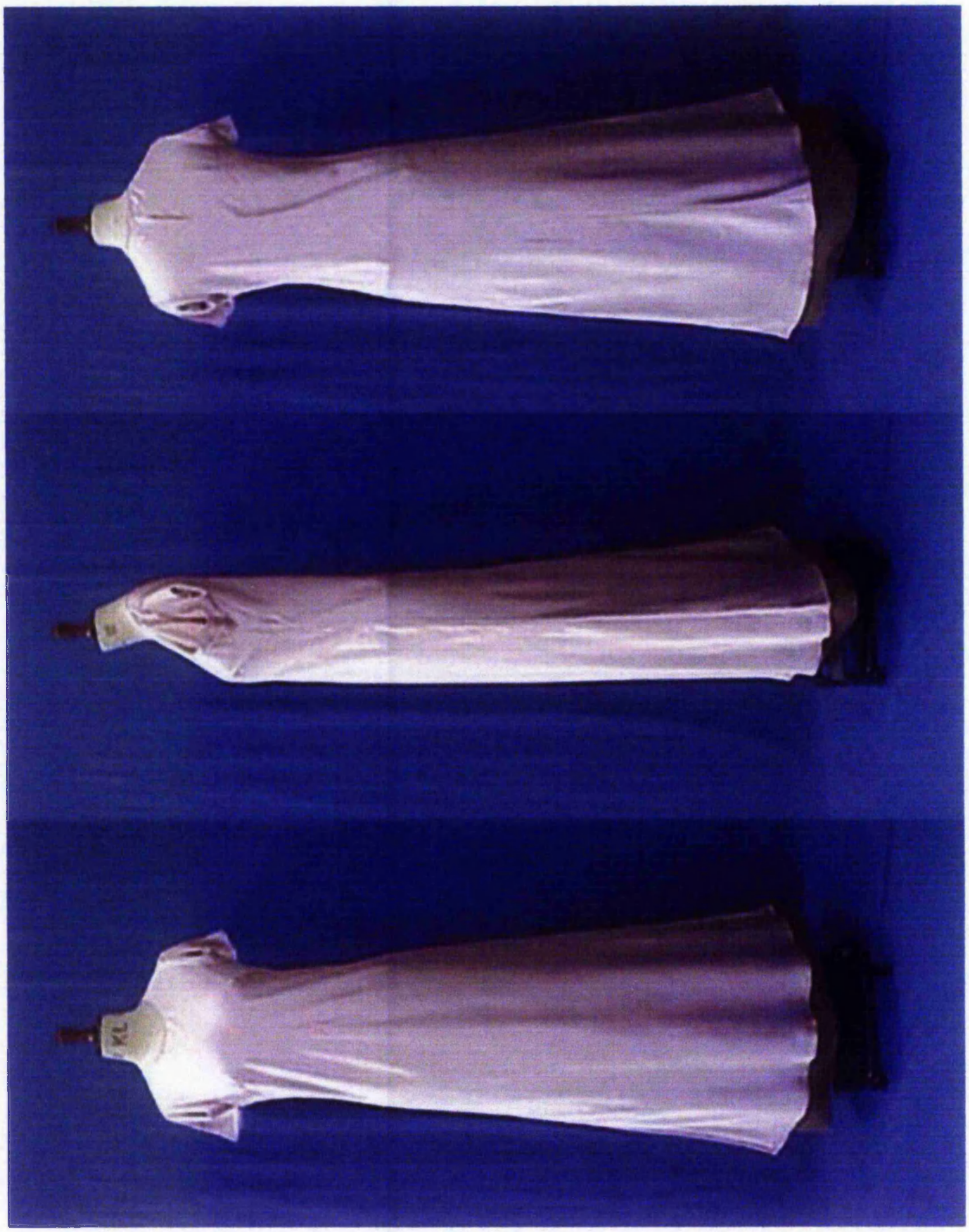
B) Geisha 5% (R1)



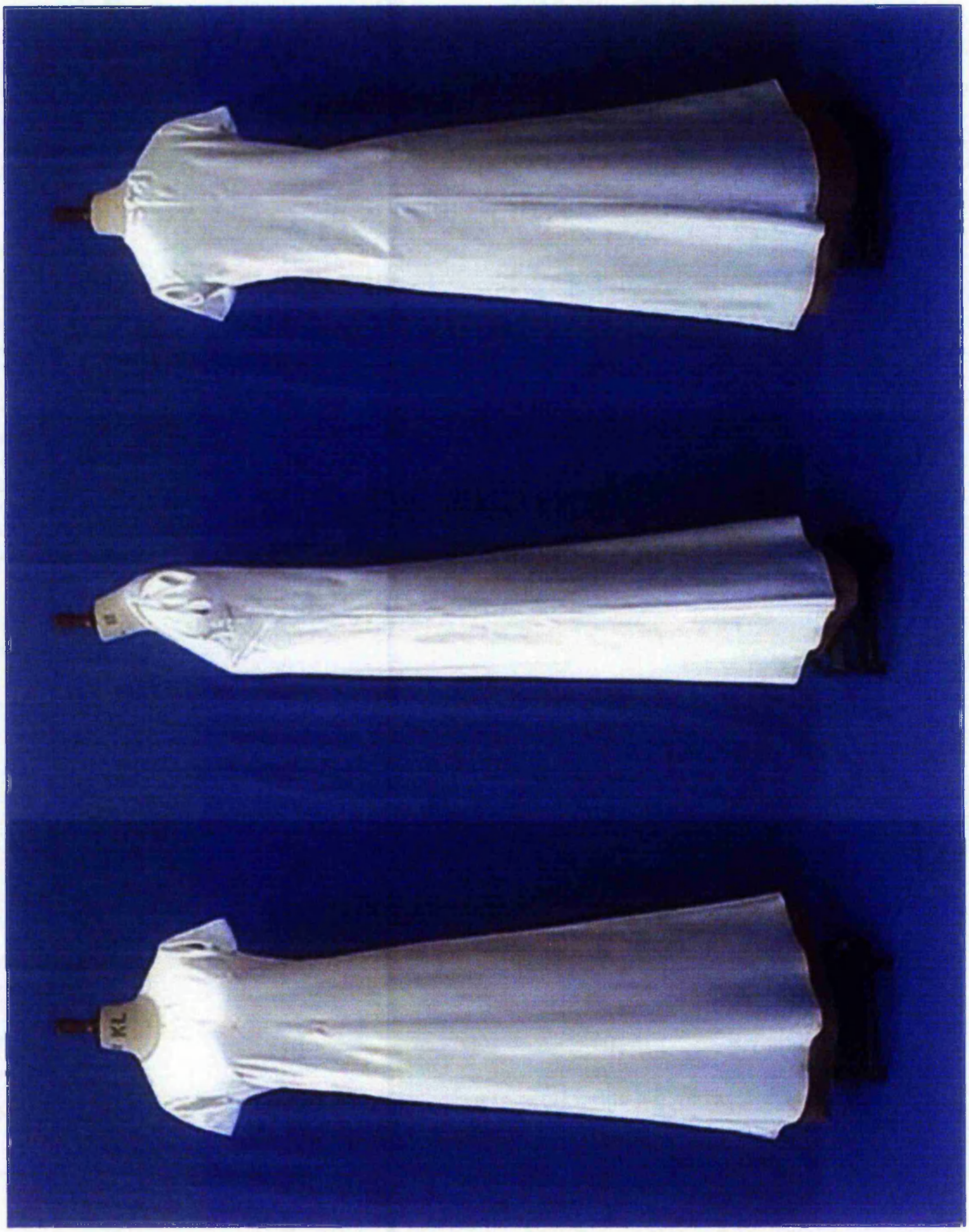
C) Geisha 10% (A1)



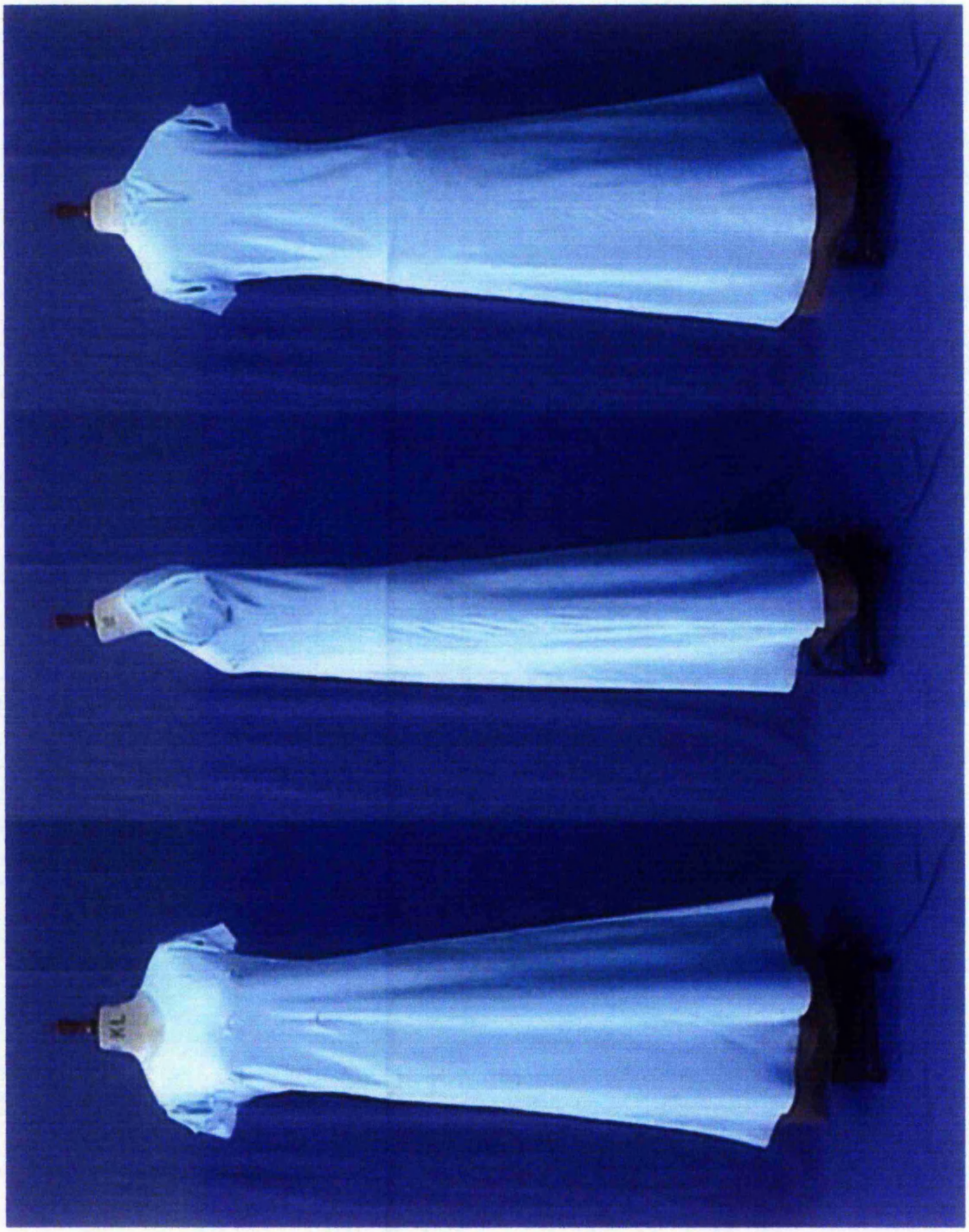
D) Geisha 15% (T1)



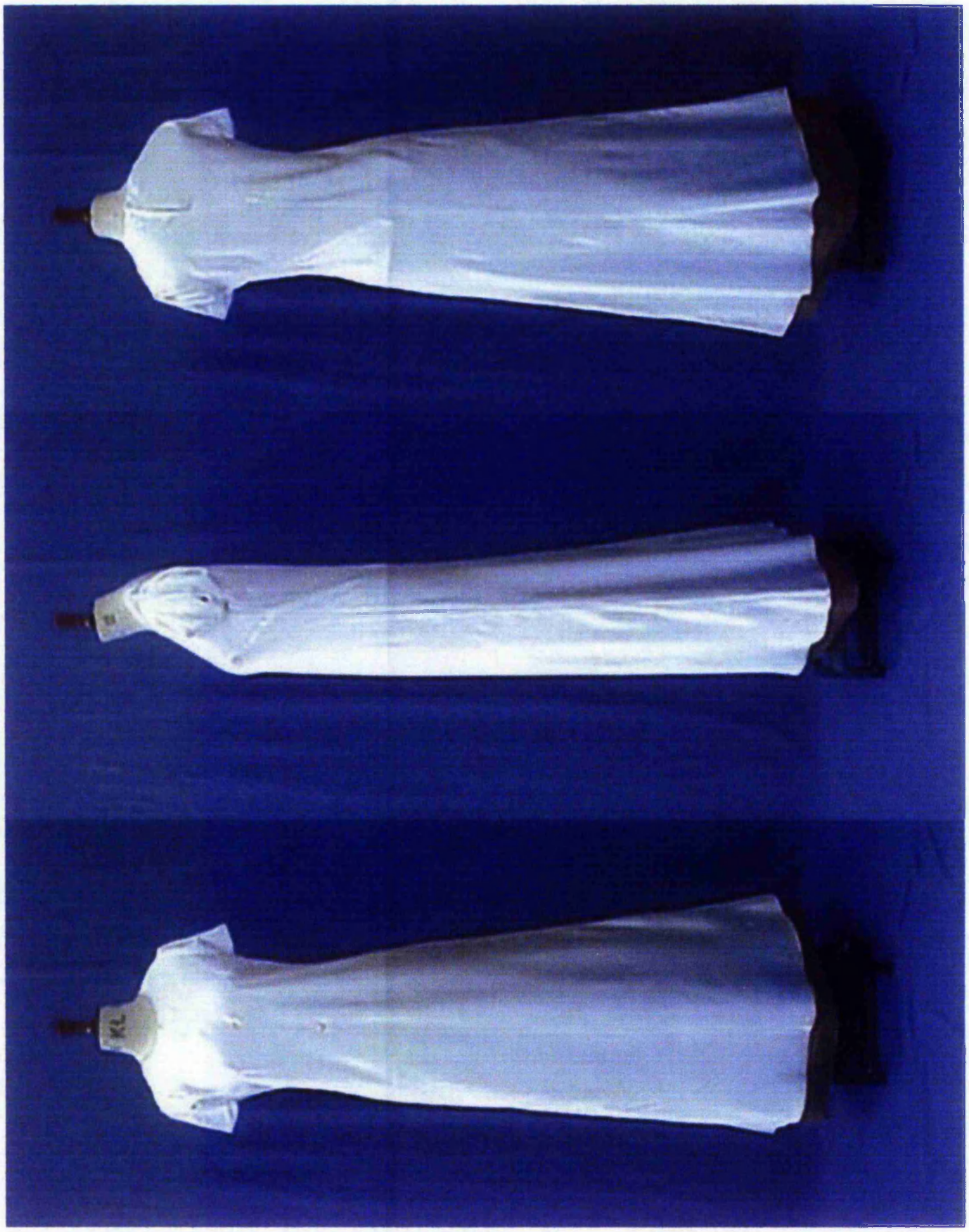
E) Portia 0% (M)



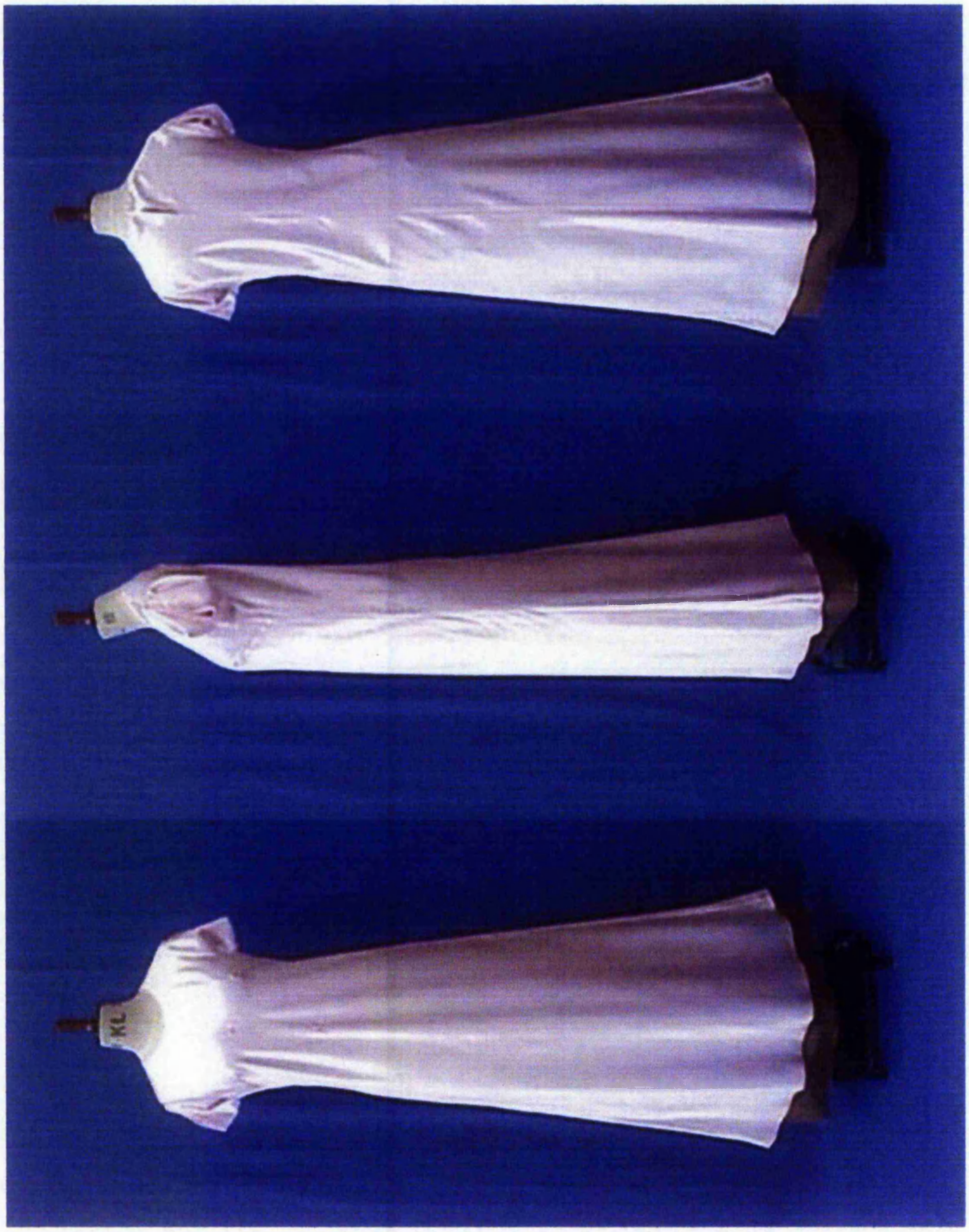
F) Portia 7% (N)



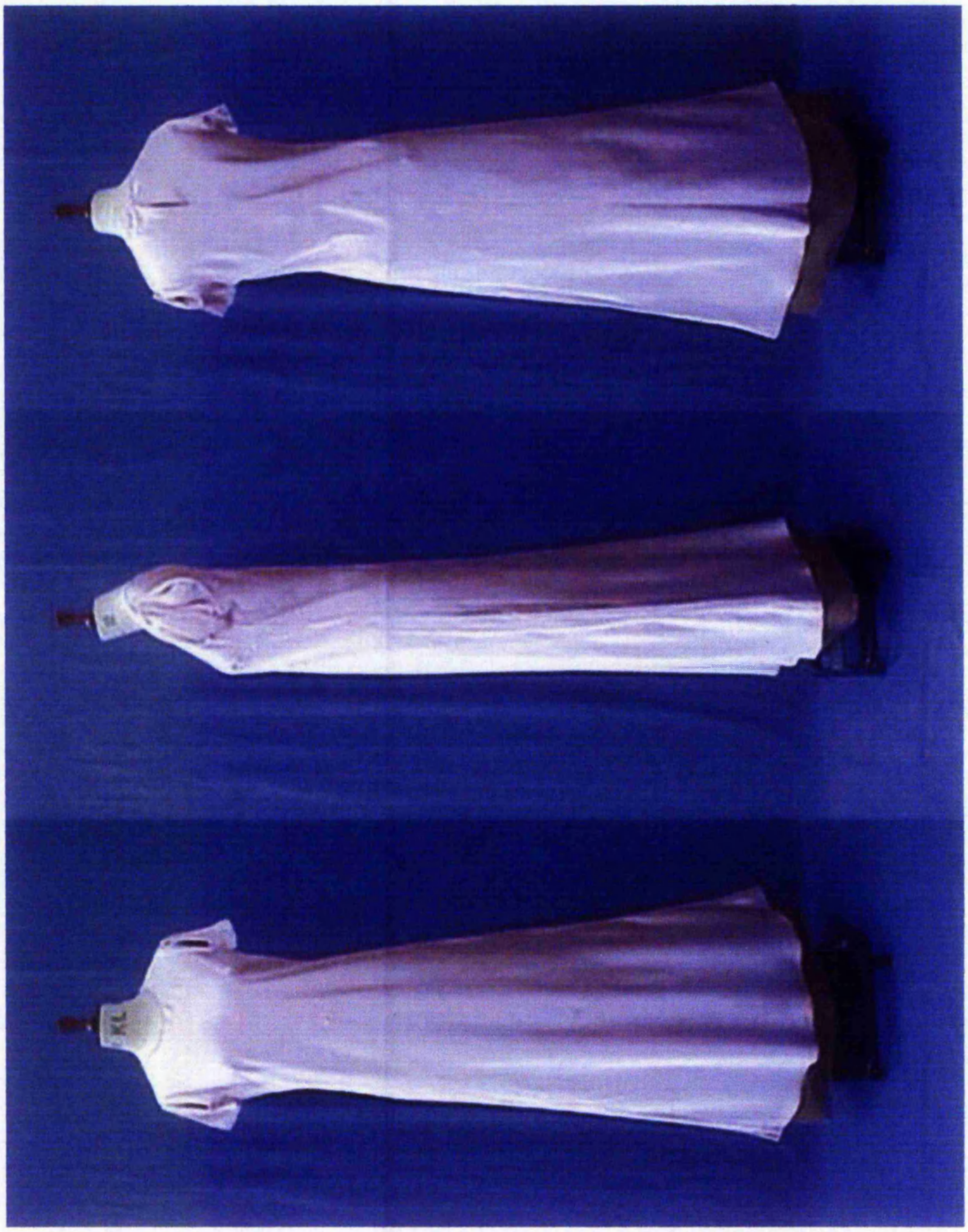
G) Portia 10% (O1)



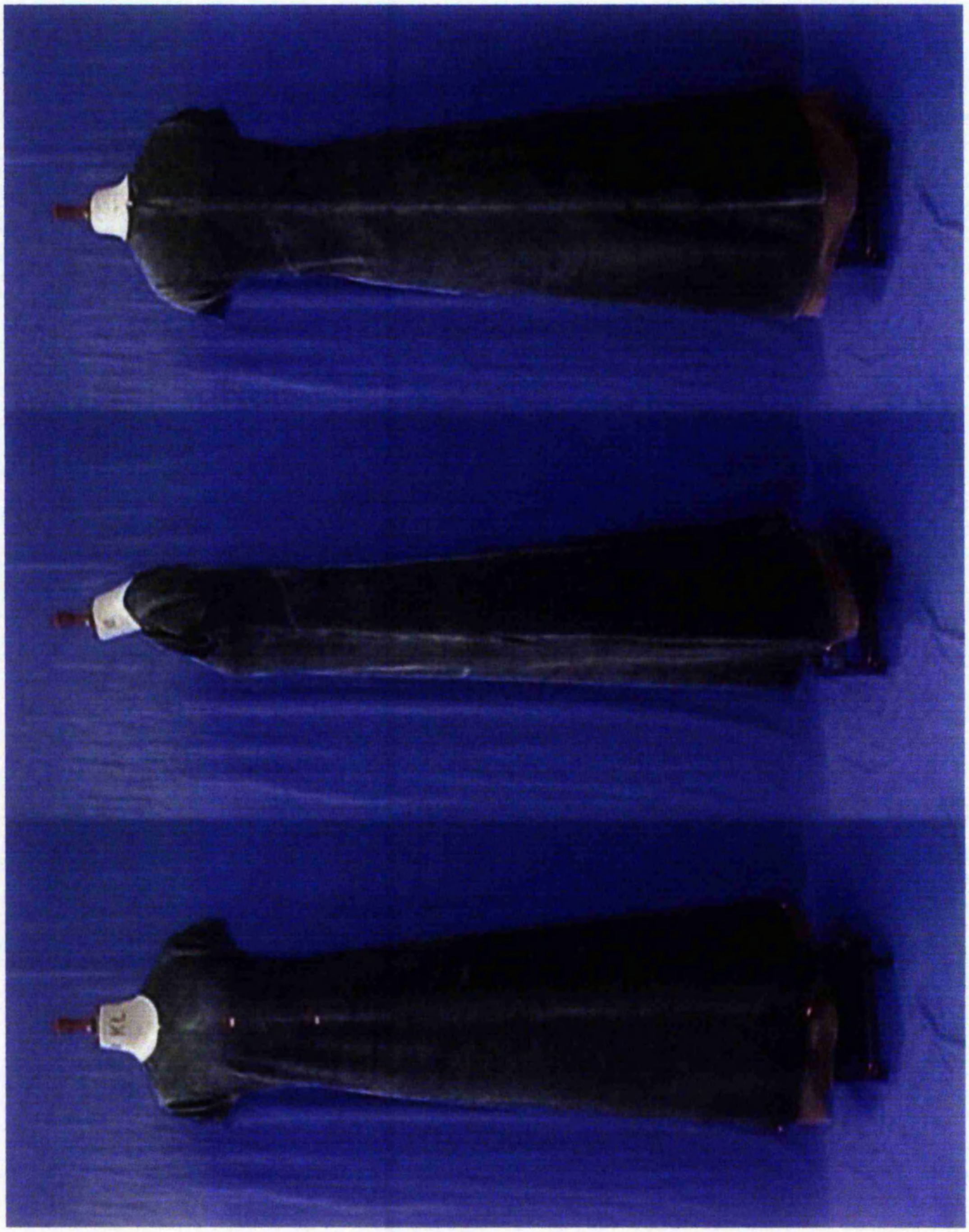
H) Portia 12% (B)



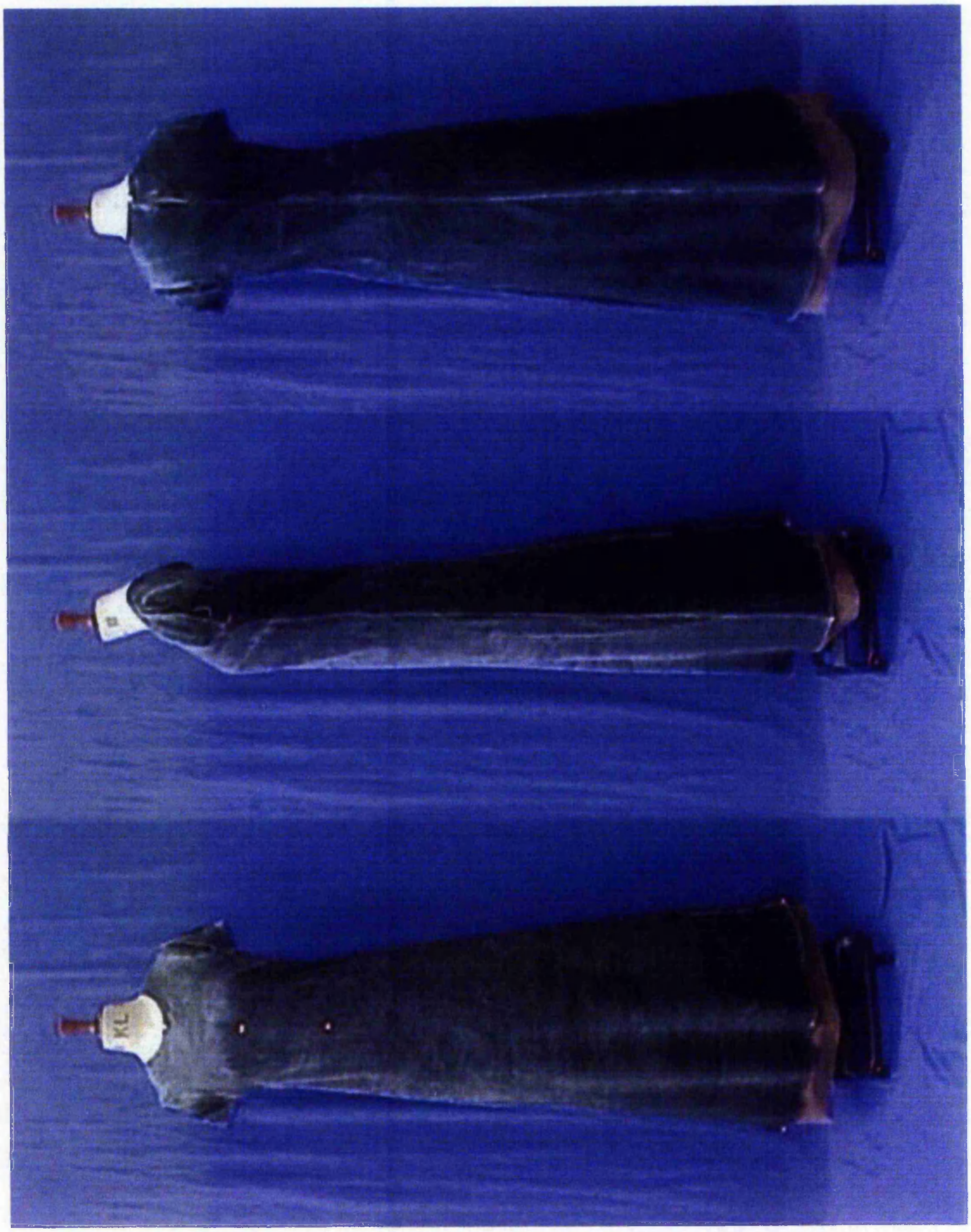
I) Portia 15% (P1)



J) Juno 0% (X)

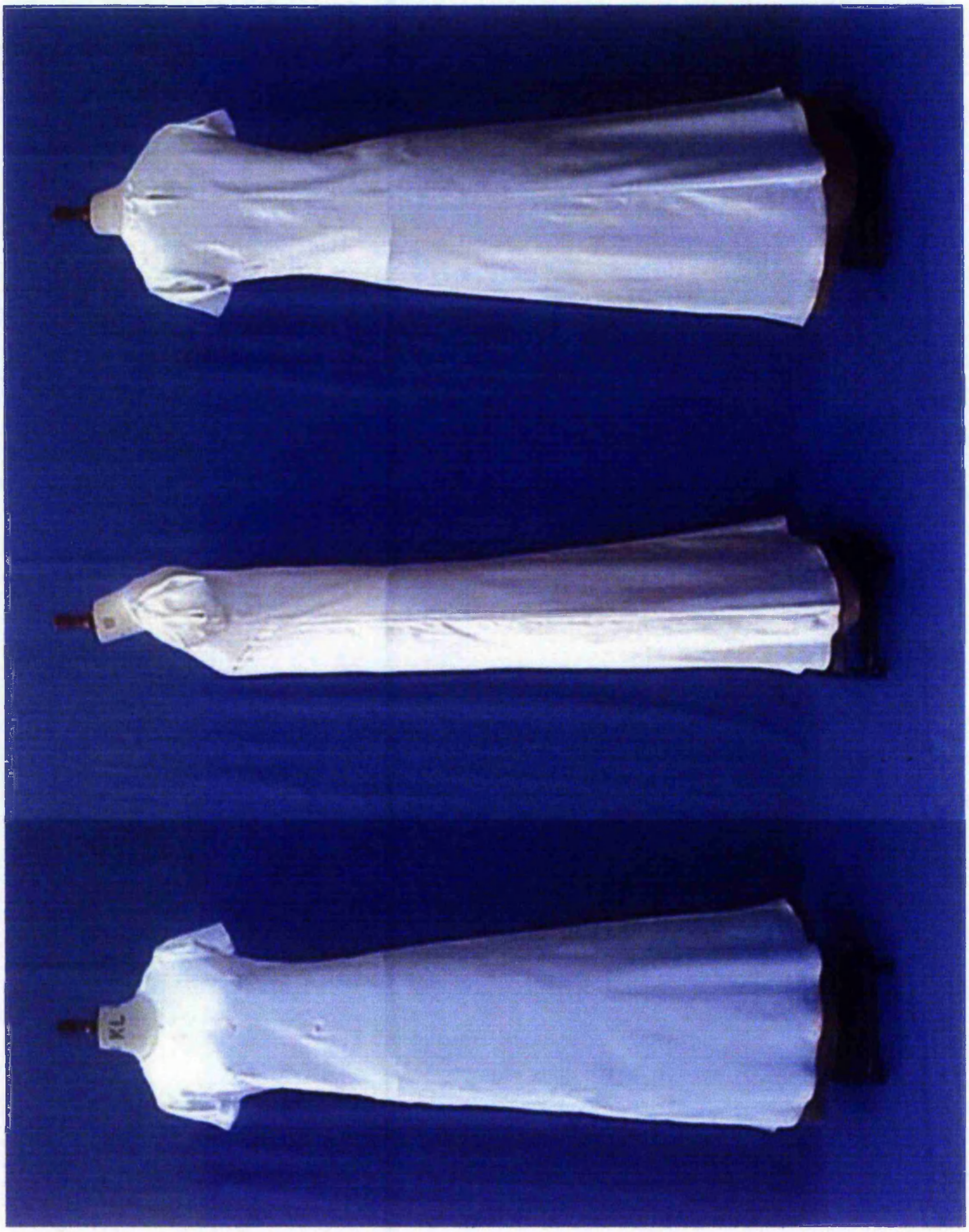


K) Juno 10% (Y1)

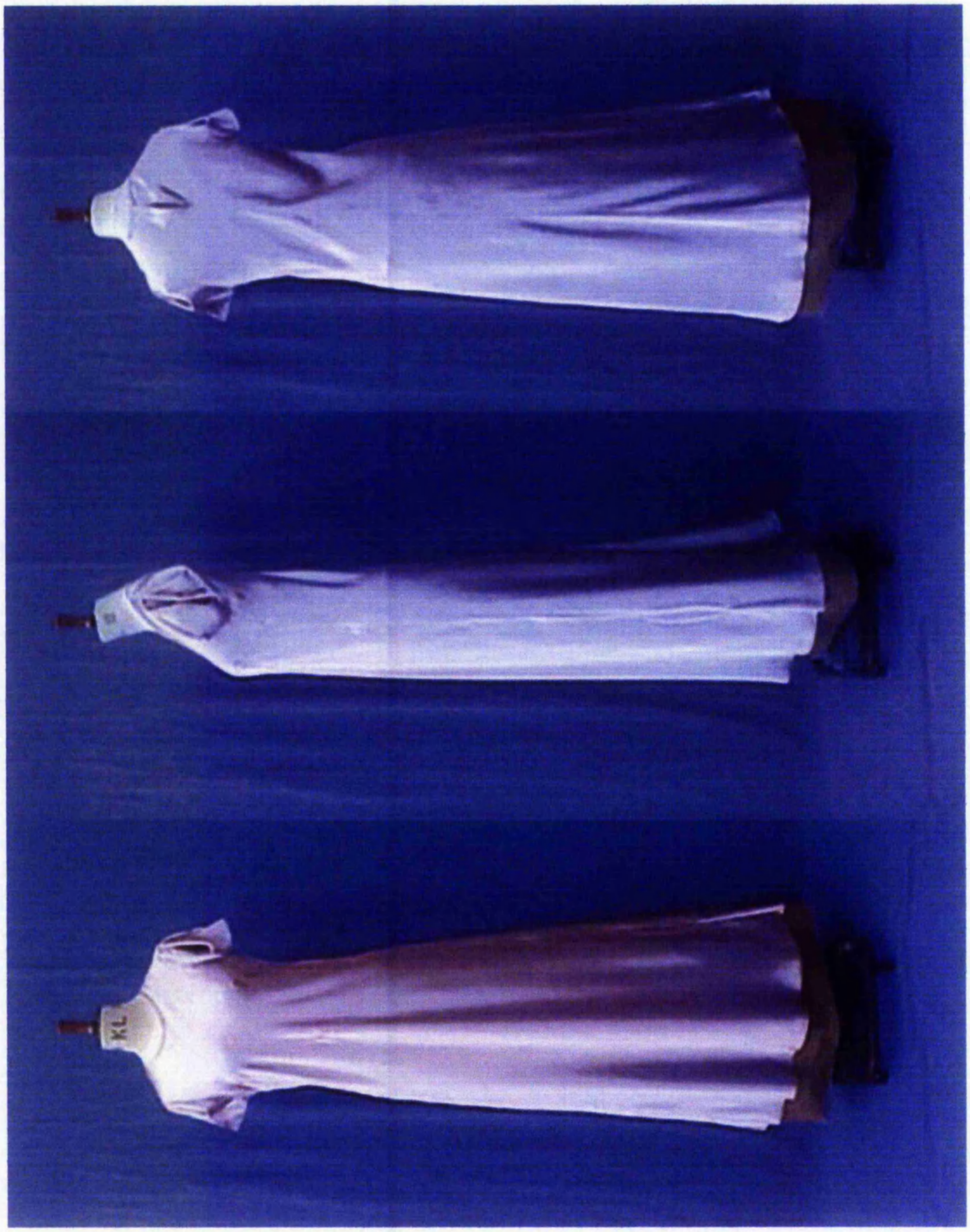


L) Juno 17% (Z)

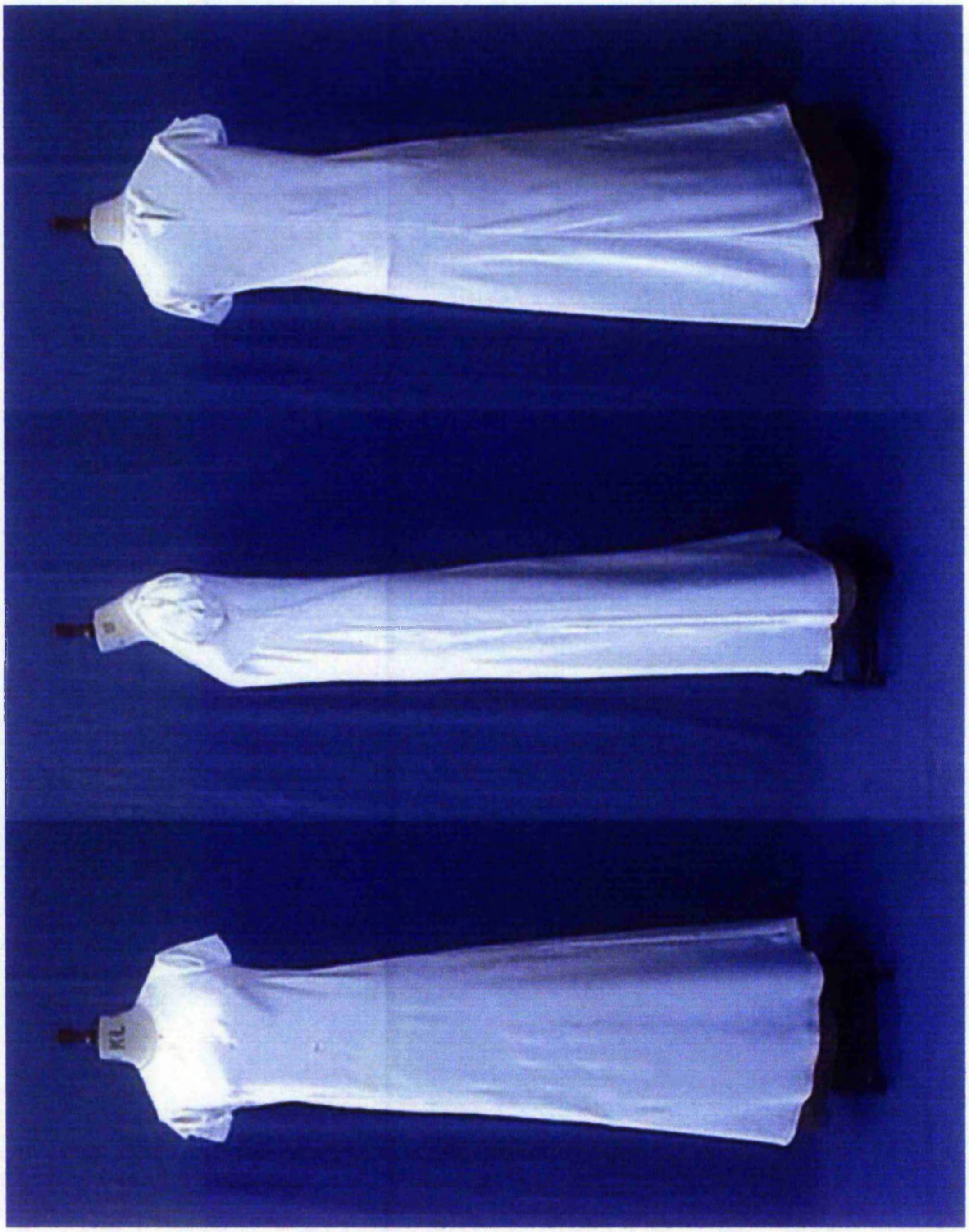
M) Venus 0% (I1)



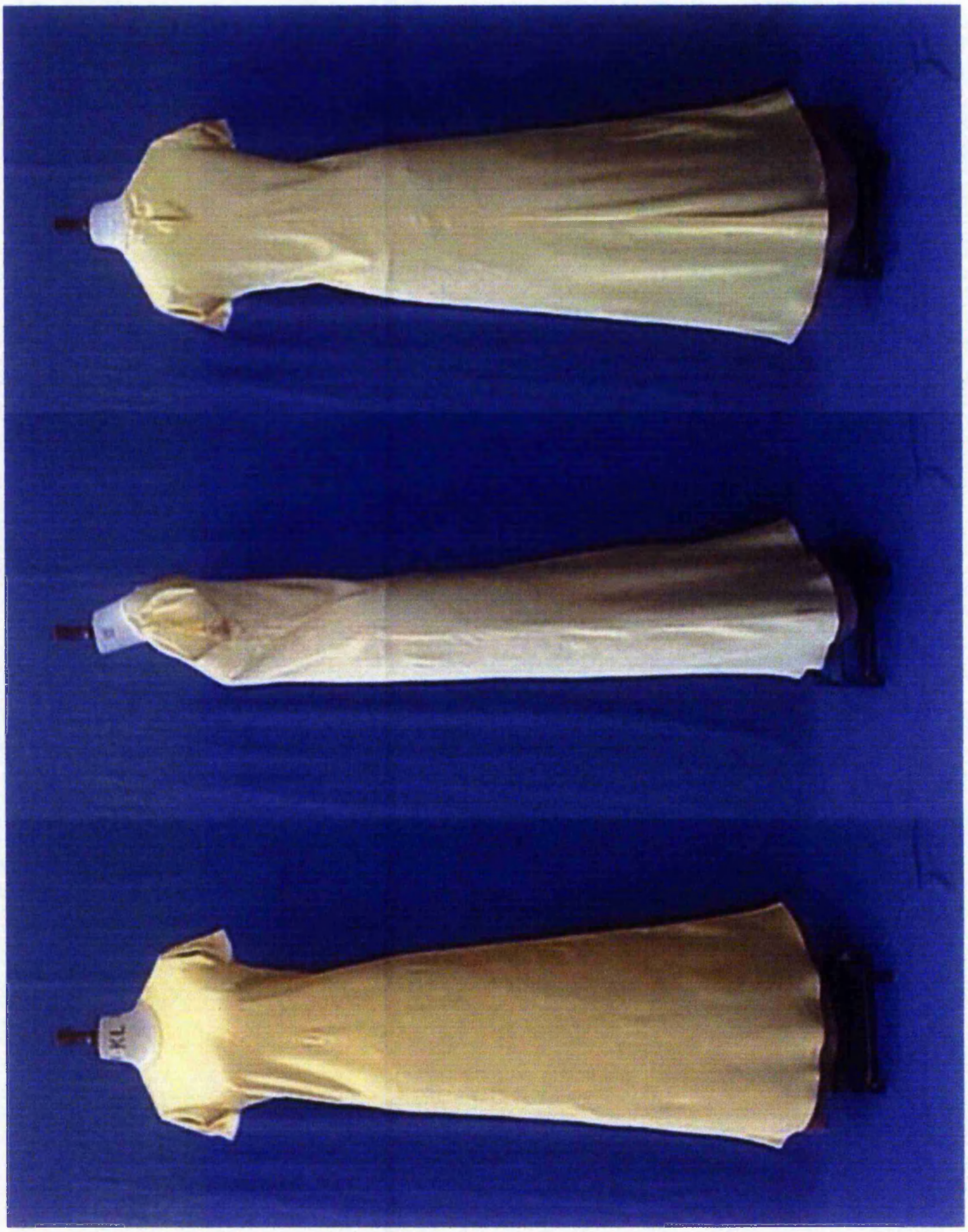
N) Venus 9% (J1)



O) Electra 0% (U1)



P) Electra 5% (V1)



Q) Electra 14% (W)

iv) Analysis

The first step when assessing data gathered by a ranking system is to establish if the assessors are in agreement about the ranking order. The ranking data between six and fourteen was considered unreliable, as in this middle area between the very good and the very bad discrimination becomes very difficult. Thus, as the three repeat dresses were included in order to assess the repeatability of each assessor, their positioning was assessed first. Any assessor ranking the same dress more than ten positions apart (this difference was chosen to span the inconsistent area) was omitted from the overall results due to inconsistency of their results. Only one assessor had to be omitted from the results on this basis as he graded the same dress at positions two and fourteen. The average grade in table 4.6.21 was calculated without this assessor. In general, the averages shown that the repeat dresses were graded in a very similar manner, the largest difference being 1.2 grades, which was not unacceptable. Thus, with the three repeat dresses removed the analysis commenced on the seventeen test dresses.

As a further test for agreement between the assessors, the Kendall's coefficient of concordance (W) was calculated for each dress. This established the agreement between the assessors on the ranking order of the dresses. It was not expected that all the assessors would rank the dresses in the same order, but there are standards for this type of experiment to ensure the results are valid. In this case $W = 0.68$, which indicated good agreement between the assessors. This was tested for significance by assuming that the rankings were independent (not related), with the alternative hypothesis being that the rankings were related. The p-value found for the test was less than 0.05 (1×10^{-38}) and thus the null hypothesis was rejected in favour of the alternative that the assessors agree with each other.

Table 3.2.21 Data for Ranking Position for Garment Appearance

	Ave Rank		Corresponding		Actual rank	Range	
G 0 Q1	16.1		16		**15**	5-20	
G 5 R1	11.6	12.7	12	13	13	7-20	6-18
G 10 A1	1.7		2		**1**	1-4	
G 15 T1	4.5		5		**3**	2-7	
P 0 M	17.4		17		**17**	9-20	
P 7 N	11.4		11		11	4-18	
P 10 O1	11.9	11.6	12	12	12	7-16	5-19
P 12 B	10.0		10		7	5-18	
P 15 P1	7.6		8		6	3-12	
J 0 X	15.9		16		**14**	4-20	
J 10 Y1	16.3	17.5	16	18	**16**	7-20	6-20
J 17 Z	10.3		10		8	6-17	
V 0 I1	10.8		11		10	5-19	
V 9 J1	2.1		2		**2**	1-8	
E 0 U1	5.5		6		5	1-17	
E 5 V1	10.5		11		9	3-16	
E 14 W	4.7		5		**4**	2-8	

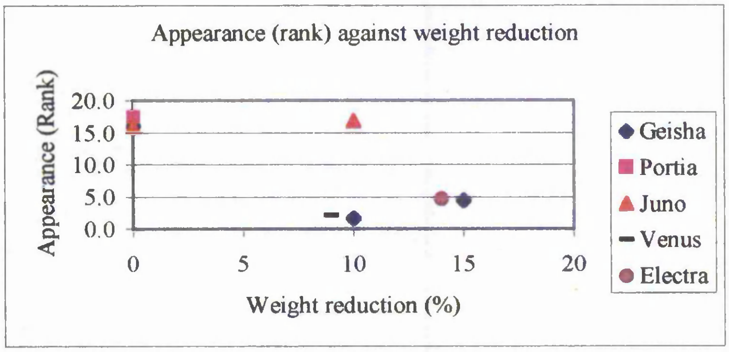
The 20 assessments were reduced to 17 due to the duplication of G5, P10, and J10 in order to act as a control of repeatability of each assessor.

The corresponding table for parameters of hang, puckering, levelness of hem and general appearance can be found in Appendix 2.

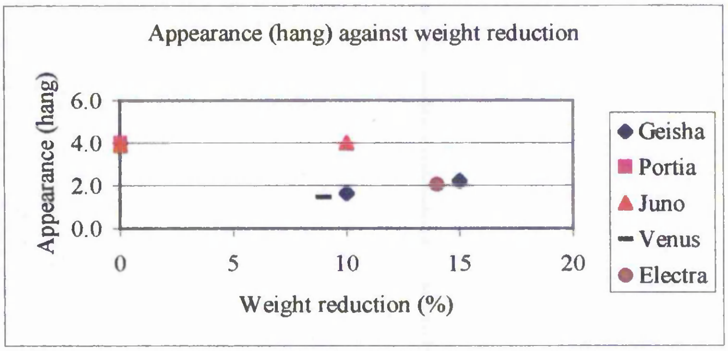
An interesting fact was noticed: there was much less variation in the bad dresses (ranked 1-4) than any other section. This was logical, as people tend to agree more on what they do not like than what they do and, as mentioned above, the middle ranks were inconsistent by their nature. The average ranks were transferred into actual ranks of the 17 dresses, but only those with grades 1-4 and 14-17 were plotted against the mechanical properties (these were fabrics G10, V9, G15, E14, J0, G0, J10 and P0 respectively).

Figure 3.2.7 Appearance Characteristics against Weight Reduction (A-E)

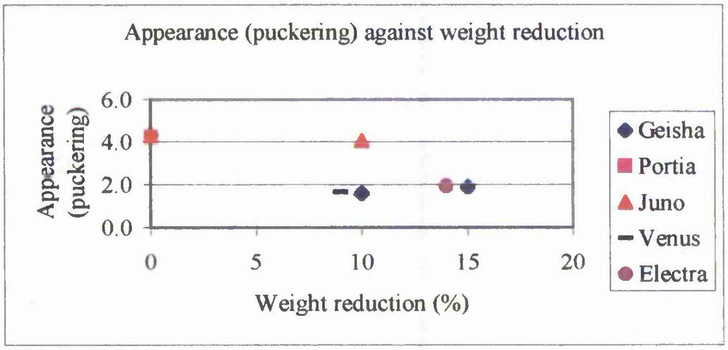
A) Appearance (rank) against weight reduction



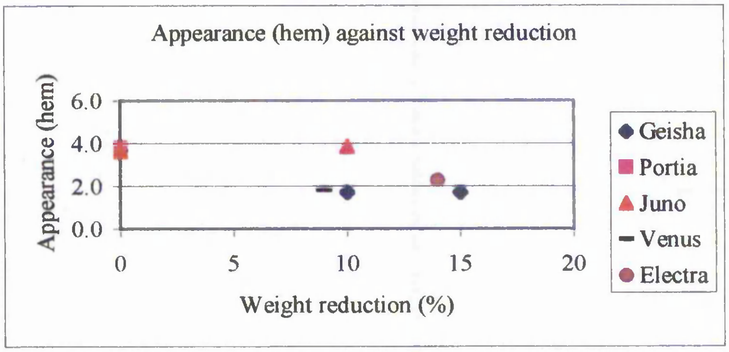
B) Appearance (hang) against weight reduction



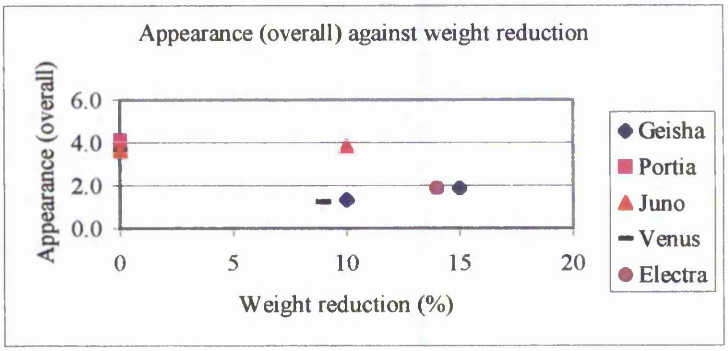
C) Appearance (puckering) against weight reduction



D) Appearance (levelness of hem) against weight reduction



E) Appearance (overall) against weight reduction



The graphs for the grades linked to hang, puckering, hem levelness and overall appearance were taken from the order established in the ranking experiment (e.g. G10 was the worst and P0 was the best). This was because the calculation for the ranking experiment was more accurate as it involved twenty grades whereas the individual grades of hang, puckering, hem levelness and overall appearance could only be separated into five. Certain common elements were found, however, for all assessments, V9 and G10 were always included in the worst four, and J0, G0 and J10 were always included in the best four. In order to simplify the analysis only the ranking appearance of the fabrics was compared to the mechanical properties as it was representative of the other parameters.

3.2.8 Results

The fabric details in table 3.2.5 had to be slightly revised because not all of the fabrics were available in enough meterage to be a part of the dress experiment. Where another fabric was needed this was denoted by the addition of a subscript (1) after the letter to differentiate from the original fabric. Where there was a duplicate of the fabric type (for example fabrics C and Z were both Juno 17%), only one was chosen for the dress experiment.

Table 3.2.22 Revision of Fabric Details 3

Letter	Colour	Quality No	Fabric Story	Weight Reduction	Weft Type		Problem
					Text	Twisted	
Q_1	Black	02516	Geisha	0 %	Yes	V low	No
R_1	Aqua	02131	Geisha	5 %	Yes	V low	No
A_1	Teal	02584	Geisha	10 %	Yes	V low	No
T_1	Pink	00000	Geisha	15 %	Yes	V low	No Info
M	White	01019	Portia	0 %	Yes	No	No
N	Aqua	02130	Portia	7 %	Yes	No	No
O_1	White	02913	Portia	10 %	Yes	No	No
B	Light Pink	02871	Portia	12 %	Yes	No	No
P_1	Pink	01256	Portia	15 %	Yes	No	Sewing
X	Black	02500	Juno	0 %	Yes	Med	No
Y_1	Navy	01054	Juno	10 %	Yes	Med	No
Z	Green	01136	Juno	17%	Yes	Med	Buttonhole
I_1	White	02608	Venus	0 %	No	High	No
J_1	Purple	02541	Venus	9 %	No	High	No
U_1	White	00000	Electra	0 %	Yes	Low	No
V_1	Yellow	02926	Electra	5 %	Yes	Low	No
W	Peach	01134	Electra	14 %	Yes	Low	No

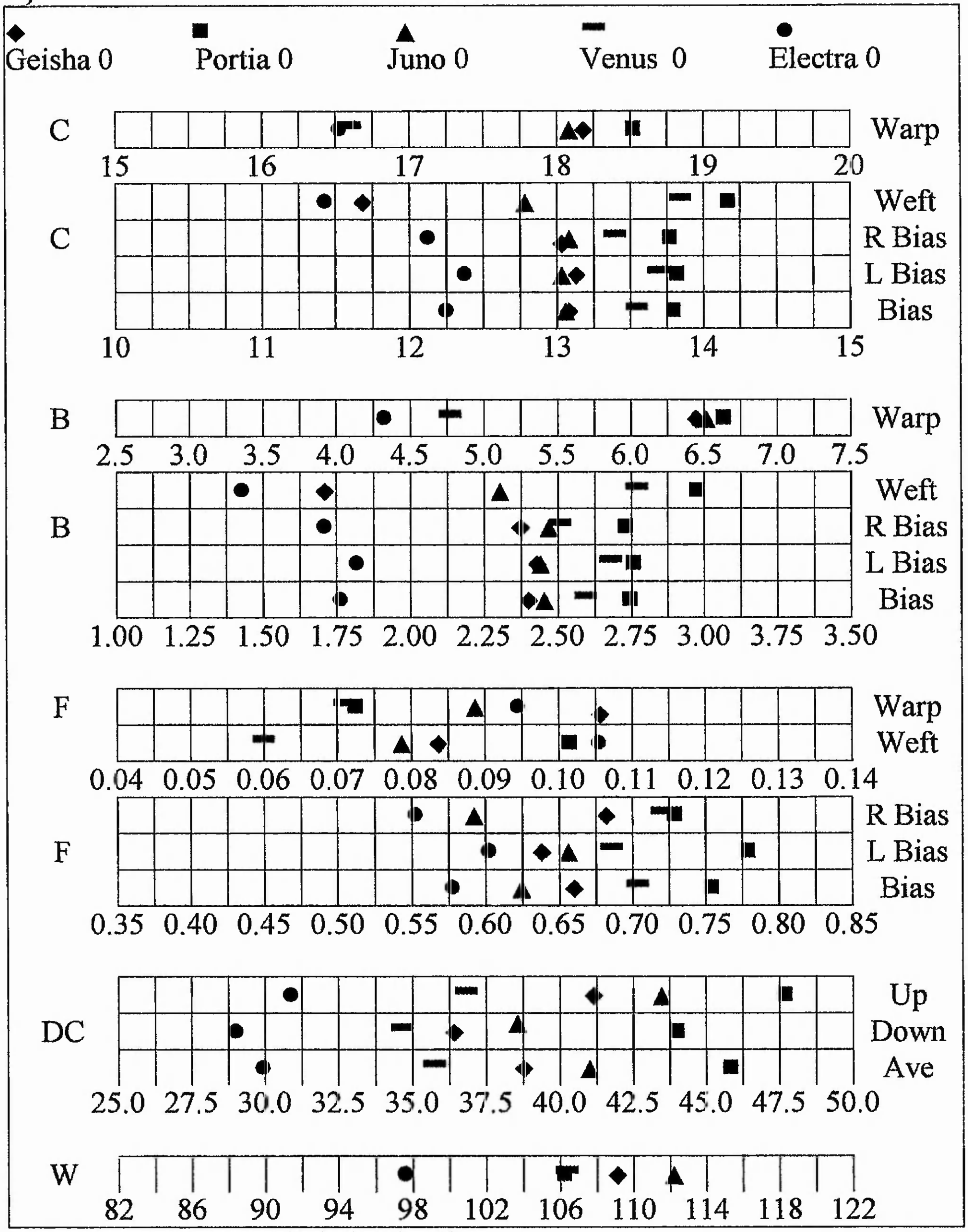
Vast amounts of information had been gathered on each of the fabrics; thus a method that aided the visual interpretation of the data was required. A process similar to the FAST control chart was developed for the assessment of the modified mechanical data described above. No limits were given due to the differences in nature of these fabrics to the suiting fabrics the FAST was designed for. In addition, the modifications made to the test methods and instrument were original and therefore there was no previous data to base the limits on. Thus, a chart format was developed that enabled a quick visual comparison of the data and the range was set to encompass all the results obtained.

3.2.8.1 The base fabrics

A chart with a selection of the results for the base fabrics was produced. It was anticipated that analysis of these results would be very important in order to establish trends that might predict when a fabric could have problems when weight reduced to a high percentage. Results can be found in Appendix 3 that relate the change of each of the mechanical parameters measured with the increasing amount the weight reduction percentage.

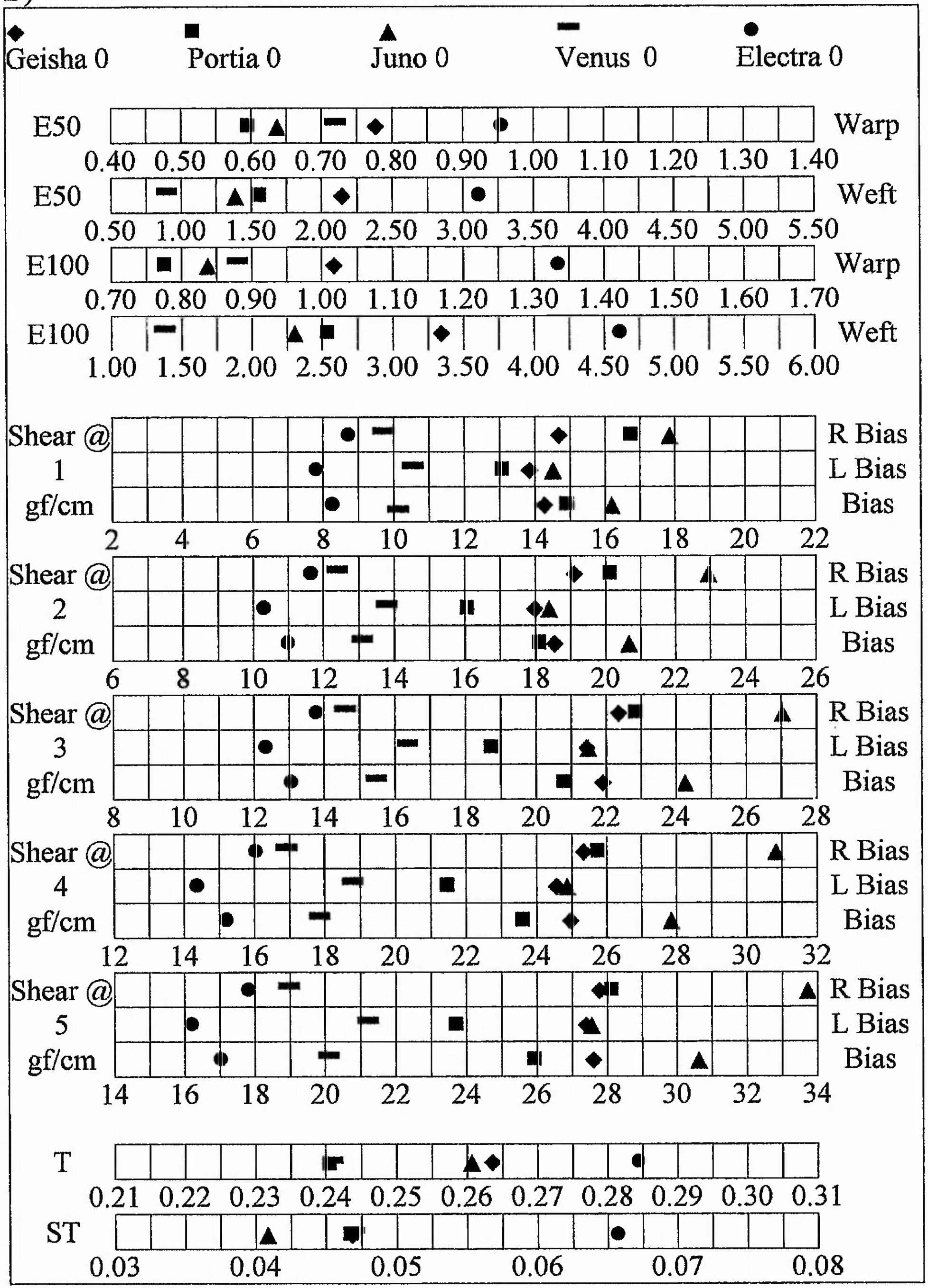
Figure 3.2.8: The base fabrics

A)



Bias = average of right and left direction bias

B)



Bias = average of right and left direction bias

From the results of the base fabrics, one can distinguish that fabric stories Electra and Venus both have results that are different from the others in terms of the shear rigidity parameters. The Electra fabrics also have much lower results in bending rigidity, drape and weight results than the other fabric stories. As low results in all of these parameters are usually linked to problem fabrics, one might expect fabrics from these two stories to present problems.

Interestingly, these two fabrics have very different profiles. The bending parameters for the Venus fabric are similar only in the warp direction to Electra. In the other directions the Venus fabric is grouped with the other 3 fabric stories. Although the formability results do not differentiate between fabrics to the degree that some of the parameters do, it is interesting to note that while in the warp and weft directions the Venus fabric is the lowest and Electra fabric being one of the highest, the reverse is true for the bias formability results, where the Venus fabric is the highest and Electra is the lowest. Both the drape and the weight parameters indicate that the Venus fabric is the closest to the Electra, although the results are still within the grouping of the other 3 fabrics.

The Electra fabric produced the highest results for warp and weft extension whereas Venus was amongst the lowest. This is particularly interesting if one takes into account the fact that warp and weft extension is dependent on the yarns themselves being extensible, whereas shear rigidity is measured by the bias extension (between the yarns). Thus, if one fabric that is less extensible in the yarn directions has similar shear rigidity results to a fabric with highly extensible yarns, it would indicate the fabric was easier to distort. This is because the shear rigidity parameter is due to distortion between the yarns rather than extension of them.

In order to compare the fabrics more fully, one must have an idea of the manner in which the weight reduction process affects the quality of the different fabric stories. It was not straightforward to compare the fabrics as they do not all have the same percentage weight reductions (due to their commercial nature), but broad identification of trends could be made. The table below provides the results for each of the fabrics for the three elements of the dress experiment.

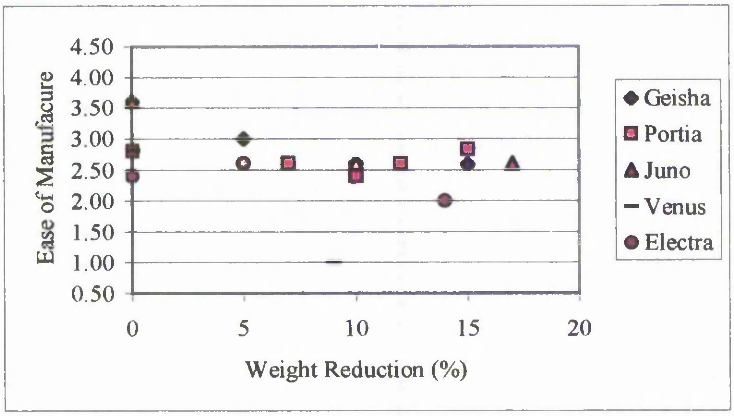
Table 3.2.23 Dress Experiment Results

	Manufacturing Grade	Distortion Total	Appearance Rank
G 0 Q_1	3.6	69.9	16.1
G 5 R_1	3.0	67.9	12.1
G 10 A_1	2.6	59.6	1.7
G 15 T_1	2.6	84.3	4.5
P 0 M	2.8	92.2	17.4
P 7 N	2.6	92.8	11.4
P 10 O_1	2.4	85.9	11.8
P 12 B	2.6	100.5	10.1
P 15 P_1	2.8	79.2	7.6
J 0 X	3.6	88.7	15.9
J 10 Y_1	2.6	111.3	16.9
J 17 Z	2.6	87.2	10.3
V 0 I_1	2.8	119.0	10.8
V 9 J_1	1.0	101.2	2.1
E 0 U_1	2.4	97.2	5.5
E 5 V_1	2.6	134.2	10.5
E 14 W	2.0	139.3	4.7

The notation for each fabric was shortened to the first letter from the fabric story, the percentage weight reduction, the corresponding letter and the subscript to indicate if the fabric was a replacement e.g. E 14 W stands for Electra 14% weight reduced and it was the original peach fabric.

3.2.8.2 Ease of Manufacture

Figure 3.2.9 Ease of Manufacture for each Fabric Story

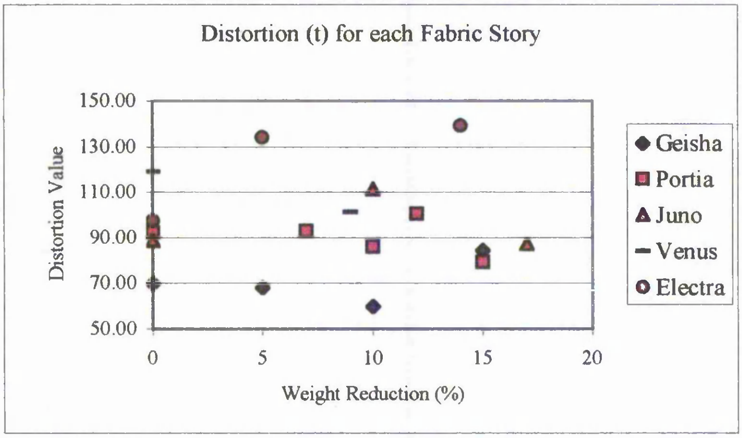


A trend was identified for a reduction in the ease of manufacture with an increase in weight reduction percentage. Geisha, Portia and Juno were all considered fairly stable fabrics, with initial grades that were gradually reduced as the percentage weight reduction increased. The Electra fabric had the lowest initial grade, but the weight reduction process did not alter the fabric properties as much as the previous group. The results from all of the fabrics in the Electra story were low, and thus, its inherent properties were more liable to cause problems in manufacturing. The Venus fabric was the most affected by the weight reduction process; fabric V9 (Venus at 9%) had the lowest grade of all.

Thus it was noted that Venus and Electra fabrics were the ones that presented the most problems and that the previous interpretation of the base fabrics chart suggested reasons why. This indicated that both fabrics were liable to give problems in manufacturing, as both were very soft and easy to distort. It was theorised that the fact that the Electra fabrics produced high extension results indicated that part of their distortion was due to the yarns used and not to inherent instability in the fabrics, as was the case for the Venus fabrics.

3.2.8.3 Distortion

Figure 3.2.10 Total Distortion for each Fabric Story



The order of increasing distortion was Geisha, Portia, Juno, Venus, with Electra fabrics being the worst. The Geisha story fabrics had much lower distortion values than the other fabrics. The results of the mechanical properties did not suggest a reason for this, as the fabrics did not differentiate themselves in any parameter. The Geisha results showed a general trend for an increased weight reduction to give increased distortion with the notable exception of G10, which had the lowest distortion value.

The Portia and Juno fabrics did not follow the trend of increased weight reduction giving increased distortion, in fact P15, J0 and J17 produced very low distortion results. There was no identifiable trend for these fabrics.

Venus 0 had the highest initial distortion value, however fabric V9 produced a lower grade (less distortion). V9 was the worst fabric in terms of ease of manufacture and thus this result was surprising. It was not clear why the increase in weight reduction percentage had reduced the distortion, especially when the results for the mechanical properties indicated the fabric would have problems. One possible explanation was that V9 fabric was so difficult to manufacture that the extra care necessary in manufacture resulted in an actual reduction in distortion, or that part of the distortion could not be measured.

The Electra story was also similar to the Geisha story as a trend was evident where an increase in the percentage weight reduction increased the distortion present in the garment. The E0 fabric produced less distortion than V0, but results from E5 and E14 indicated the greatest distortion of all the fabrics. The results indicated that distortion was not directly linked to the weight reduction process; further investigation was necessary to establish the effect the individual parameters had on distortion.

3.2.8.4 Appearance

It is difficult to make anything other than general assumptions from the graphs shown in figure 3.2.7, as the nature of the experiments makes other conclusions invalid. However, it can be seen that the experts generally preferred the fabrics that were the least weight reduced. This was not unexpected as these fabrics were intended for a variety of lingerie uses and some of them would have been more suited to camisole type garments rather than slip-dresses that require such long seams. However, it was necessary to take the worst possible scenario in order to have enough of the problem garments to perform the analysis.

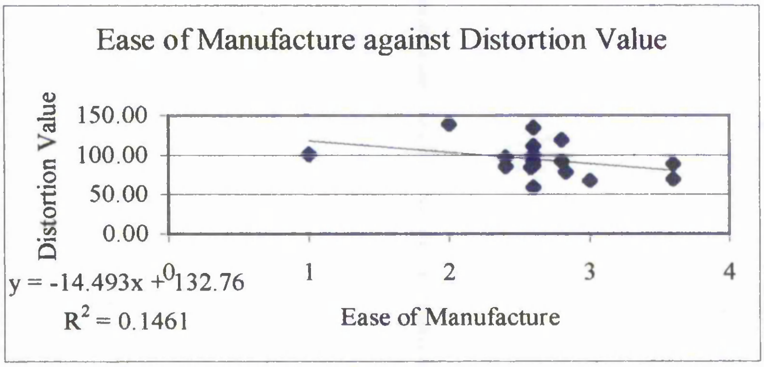
It was noted that three of the four garments that were rated as having the best appearance were the fabrics without any weight reduction. It was interesting that the zero weight reduced fabrics in the Venus and Electra stories were not included, the base fabrics in these stories being ranked closer to the worst appearance. In this way, the appearance data can be seen as similar to the manufacturing problem data and these fabrics also showed signs of becoming problematic at higher weight reductions.

The trend was that the best garments were made from fabrics that had not been weight reduced, with fabrics J10 and E5 being were the exception to this rule. Another trend for the worst garments (in terms of appearance) was that they were made from fabrics with high percentages of weight reduction; here, fabric E0 was the exception. As for the other problems, it would seem that a distinction between best and worst appearance garments can only be made on a combination of factors.

3.2.8.5 Comparisons of All problems

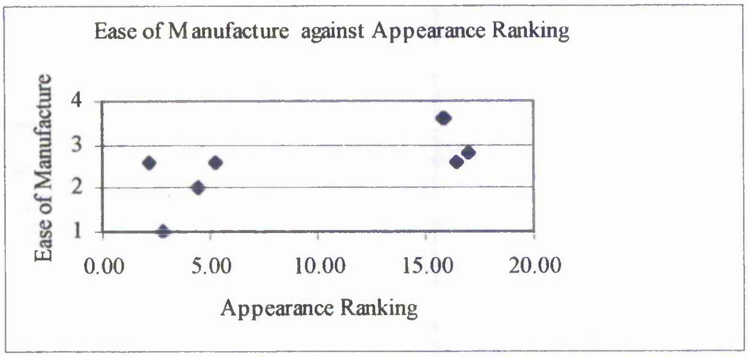
The ease of manufacture and distortion parameters did not correlate well with each other; they are problems that reflect different fabric characteristics. Thus it was sensible to assume that they would be affected by different mechanical properties.

Figure 3.2.11 Ease of Manufacture against Distortion Value



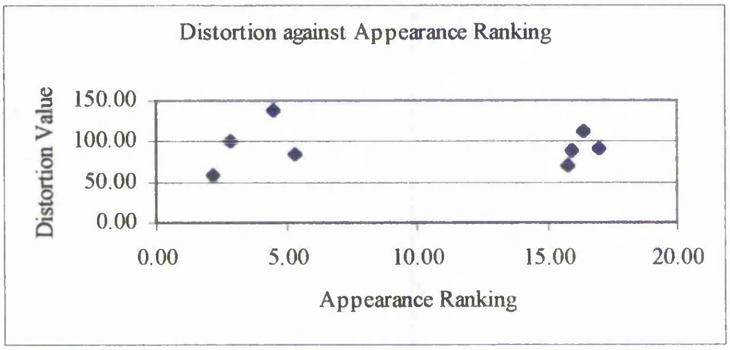
There was a relationship between the manufacture grade and the ranking of appearance, which indicated that those fabrics that had the highest grades in terms of appearance would also be those that were the easiest to manufacture.

Figure 3.2.12 Ease of Manufacture against Appearance Ranking



There was no obvious relationship between the distortion values and appearance rankings, which was due to the wide spread of distortion values for the low appearance rankings making it impossible to assess whether there is a negative or positive relationship between the variables.

Figure 3.2.13 Distortion Value against Appearance Ranking



3.2.9 The effects of the weight reduction process

The next stage in the analysis was the correlation of each mechanical property with the garment problems to establish if trends could be identified between change in their results due to the weight reduction process and their effect on ease of manufacture, distortion and appearance. As mentioned in section 1.4, this was an area of research that has not been carried out previously, either on the FAST or the

KES-FB. Thus, it was very important in the overall aim of assessing whether FAST can be used for different applications.

3.2.9.1 Bending

An increase in the percentage weight reduction led to a generalised reduction in the bending results (both bending length and rigidity), in all four directions tested. The bias results did not differ between the directions tested and therefore it was sufficient to use the average. It was not possible to predict the results of a fabric's bending parameters from the percentage of weight reduction, as they were dependent on the fabric's initial characteristics.

However, in order to gauge ease of manufacturer, it was not the amount of change in bending that was important; the Portia fabrics showed the largest changes, especially notable in the warp and bias directions. This would no doubt contribute to the reduction in its manufacturing grade, but as the initial base fabric was quite stiff, this increase in flexibility did not make fabric P15 (Portia at 15%) a problem. The results of the Electra fabrics showed the least amount of changes due to the weight reduction process; as they had the lowest results in all directions, and this accounted for their difficulties in manufacturing and their high distortion values.

There was less percentage difference in the weft directions for the Geisha, Portia and Juno stories (from the initial base fabric) than in the warp and bias directions. The Venus fabrics and, to a lesser extent the Electra fabrics, showed a greater reduction in the bending rigidity results in the weft direction than in the other directions. As these were the problem fabrics, this suggests that perhaps the weft direction bending might be an important parameter to predict manufacturing problems. However, the pair-wise plot of manufacturing grade against weft bending produced a very low R^2 value.

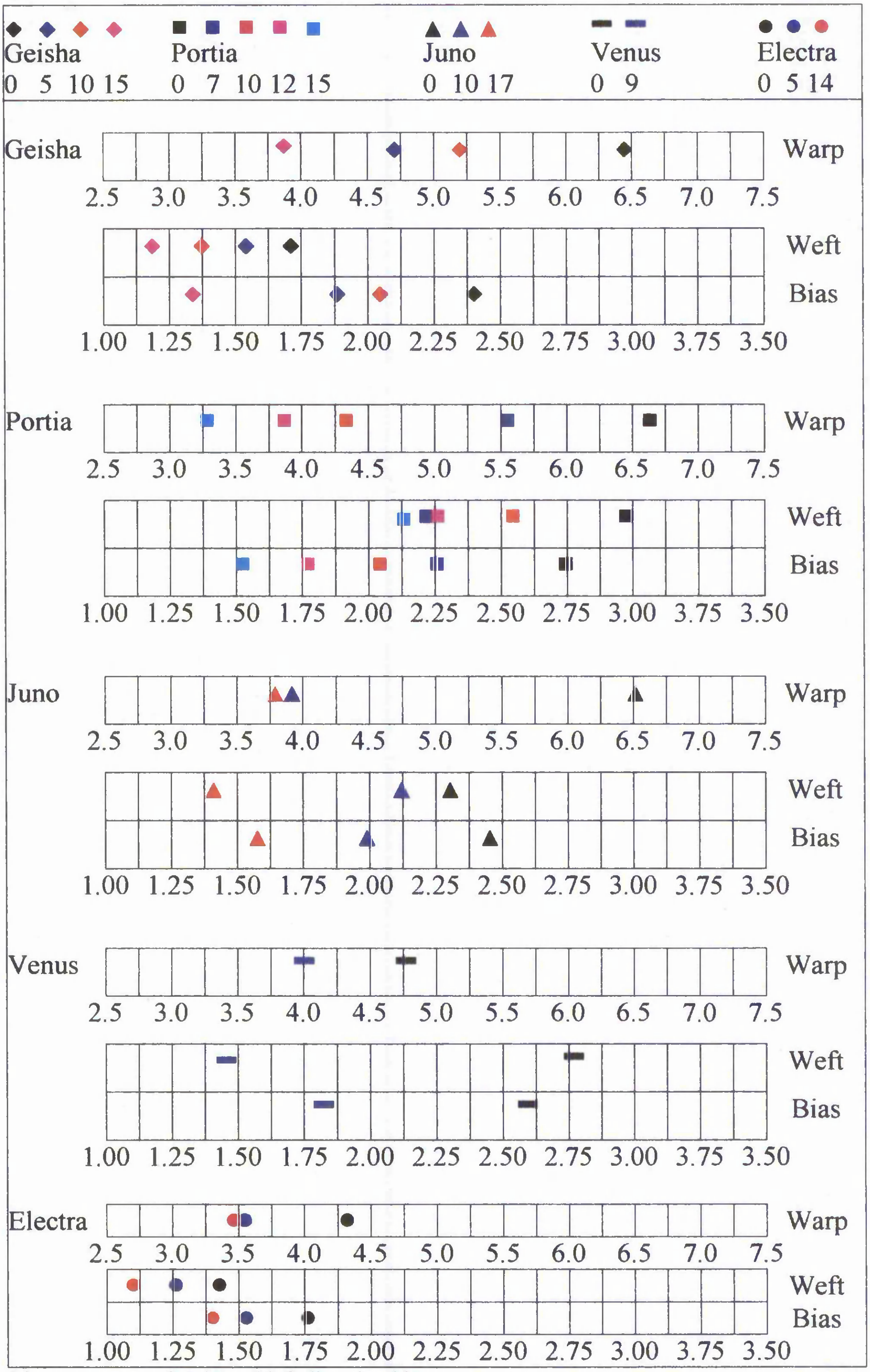
The bending rigidity results explained a larger amount of the ease of manufacture parameter than their corresponding bending length results. The order of importance was that the warp results predicted the most, then the bias and weft results predicted the least amount of the problem. The results suggested that although bending rigidity was undoubtedly a factor in ease of manufacturing, it was in combination with other parameters. Thus the more resistance to bending a fabric has, the easier it is to manufacture. This would be up to a limit, as a certain amount of pliability is necessary to manufacture garments. However, all of these fabrics were at the low end of bending rigidity results, and thus it was not surprising that the more rigid the fabric the greater the ease of manufacture.

Bending was not as important an indicator of the distortion parameter as it was of the ease of manufacture, which is seen by the lower correlation factors. The order of importance was the same, with the warp direction being the most important parameter, then the bias and finally the bending in the weft direction.

Conversely, to their relationship to the ease of manufacture, the bending length explained more of the distortion value parameter than the bending rigidity. There is a trend that fabrics with lowest bending length and rigidity values are those with the highest distortion. This follows the above argument that such low results on all these fabrics mean that the stiffest of them are actually the best fabrics, in this case with the least distortion.

Although the same kind of information cannot be obtained for the relationship between the bending parameters and appearance, the graphs did suggest that higher results (in both bending length and rigidity) produced garments that were graded higher in the appearance rankings. Again this is a similar phenomenon to that discussed above with reference to ease of manufacture and distortion.

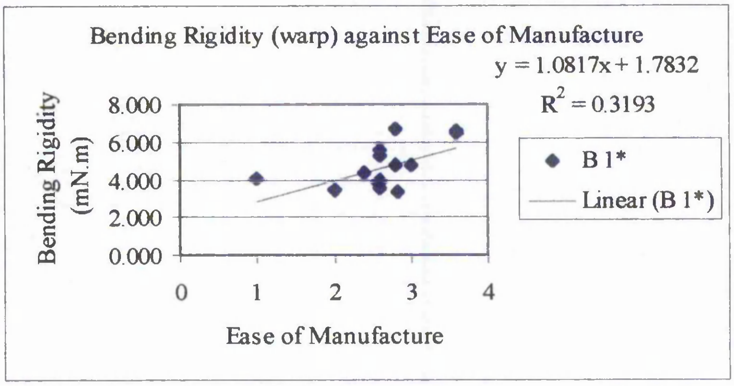
Figure 3.2.14 Bending Rigidity Visual



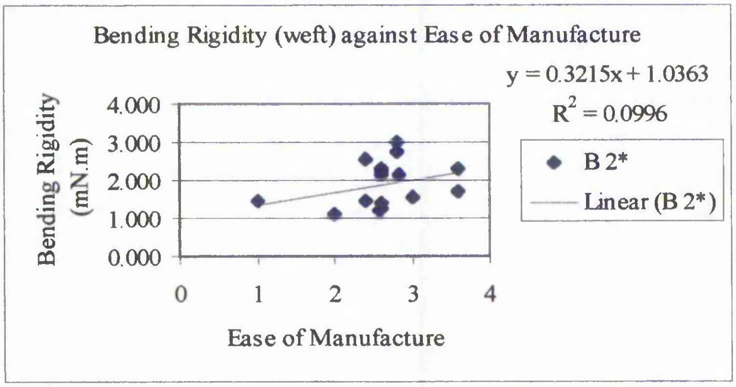
Bias = average of right and left direction bias

Figure 3.2.15 Bending Parameters against Ease of Manufacture (A-F)

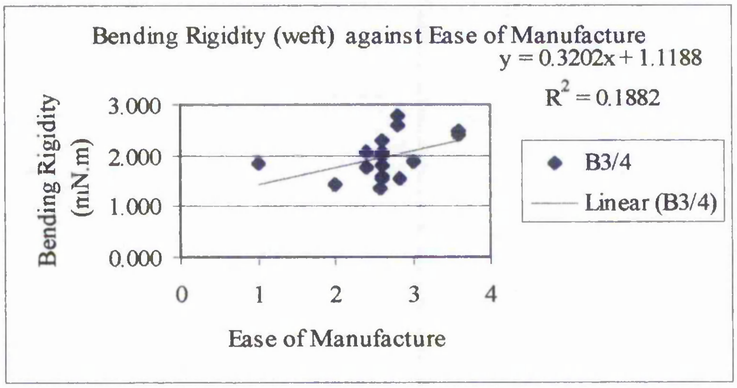
A) Warp Bending Rigidity against Ease of Manufacture



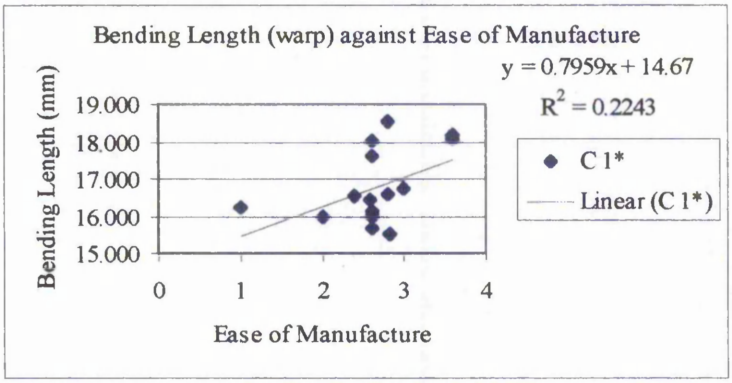
B) Weft Bending Rigidity against Ease of Manufacture



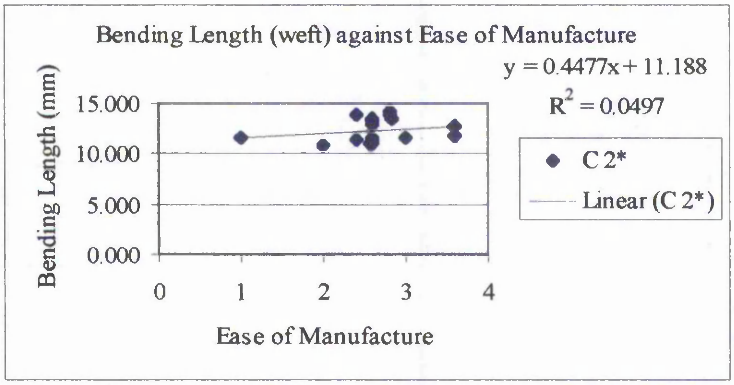
C) Bias Bending Rigidity against Ease of Manufacture



D) Warp Bending Length against Ease of Manufacture



E) Weft Bending Length against Ease of Manufacture



F) Bias Bending Length against Ease of Manufacture

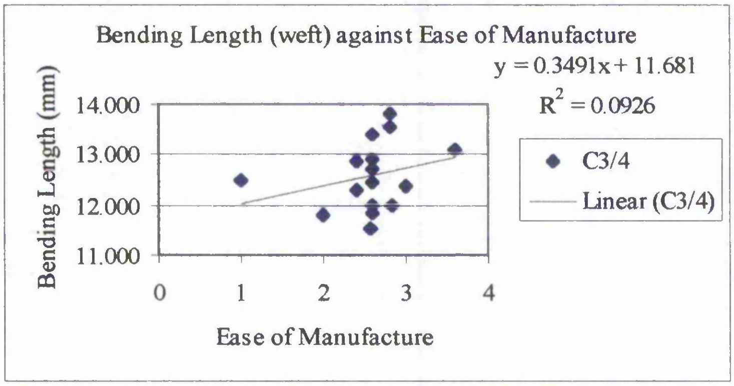
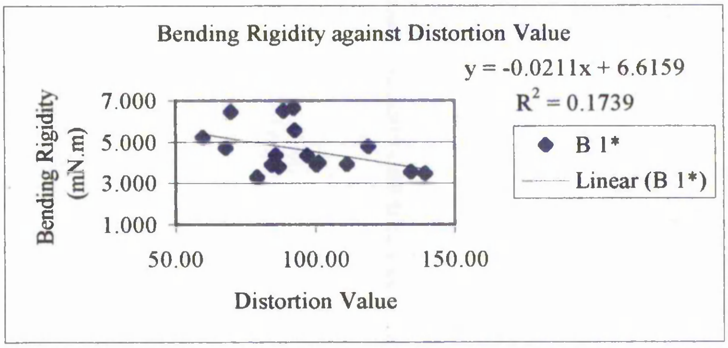
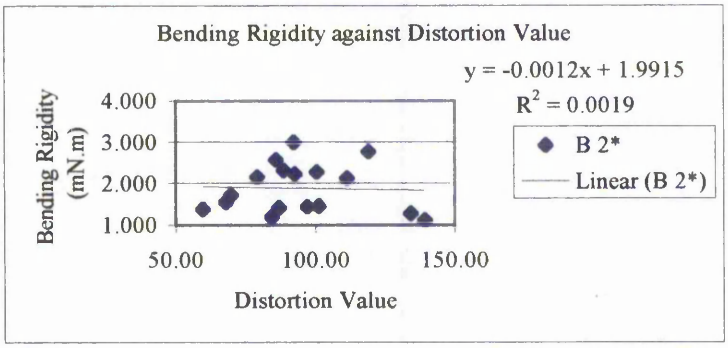


Figure 3.2.16 Bending Parameters against Distortion Value (A-H)

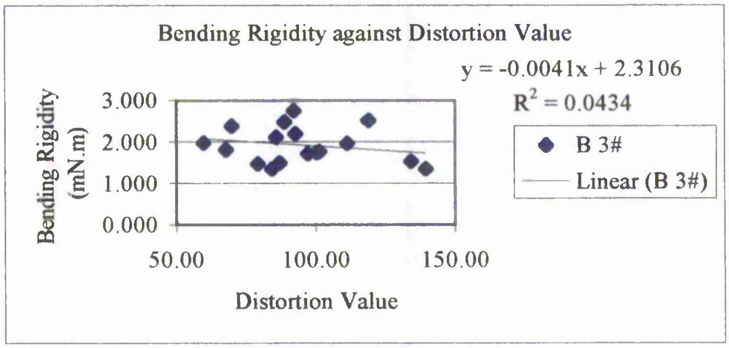
A) Warp Bending Rigidity against Distortion Value



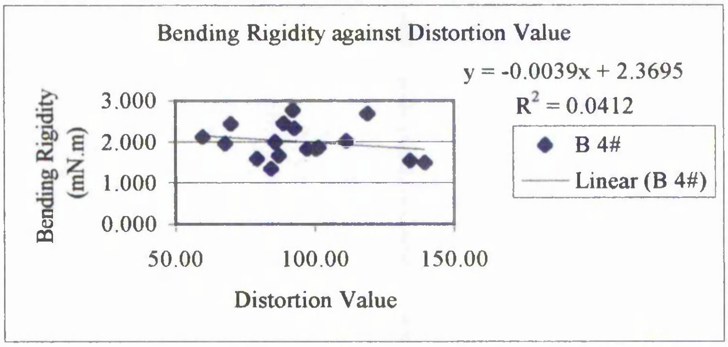
B) Weft Bending Rigidity against Distortion Value



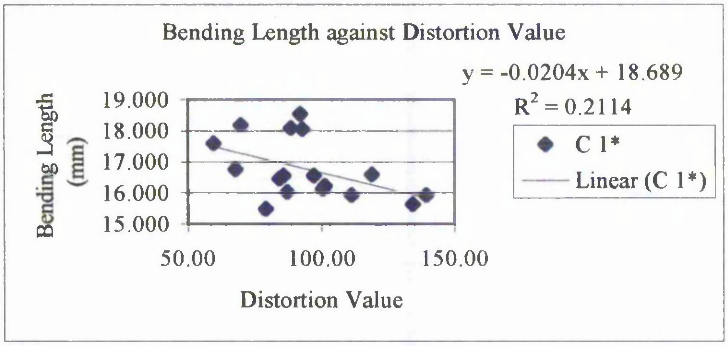
C) Right Bias Bending Rigidity against Distortion Value



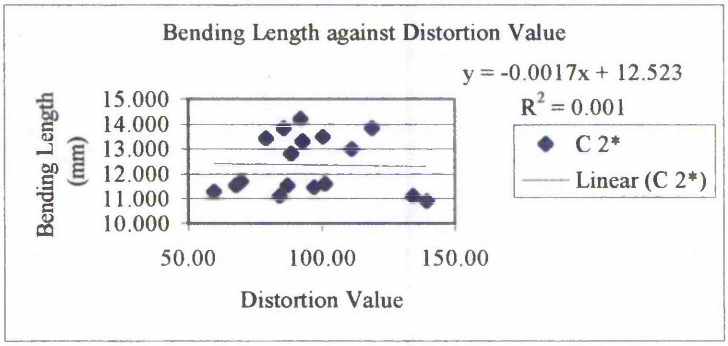
D) Left Bias Bending Rigidity against Distortion Value



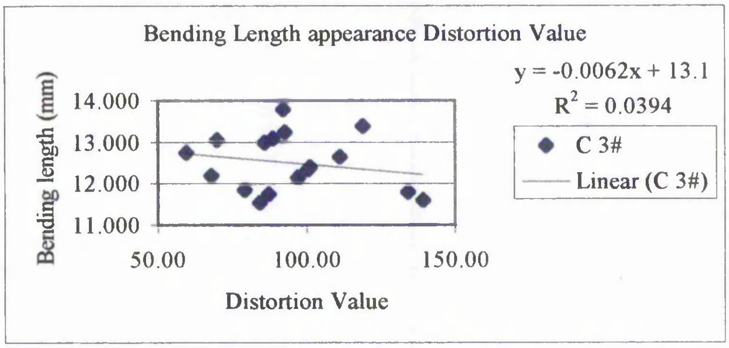
E) Warp Bending Length against Distortion Value



F) Weft Bending Length against Distortion Value



G) Right Bias Bending Length against Distortion Value



H) Left Bias Bending Length against Distortion Value

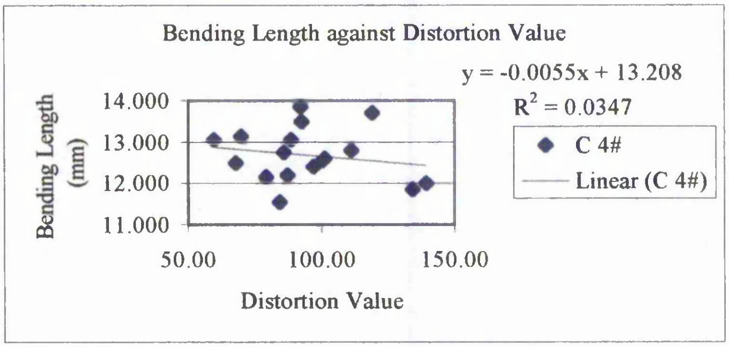
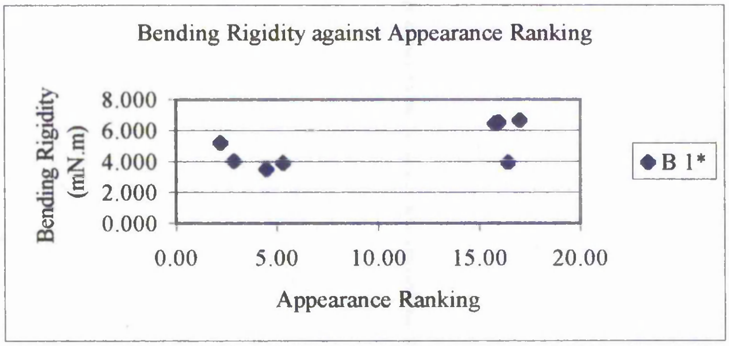
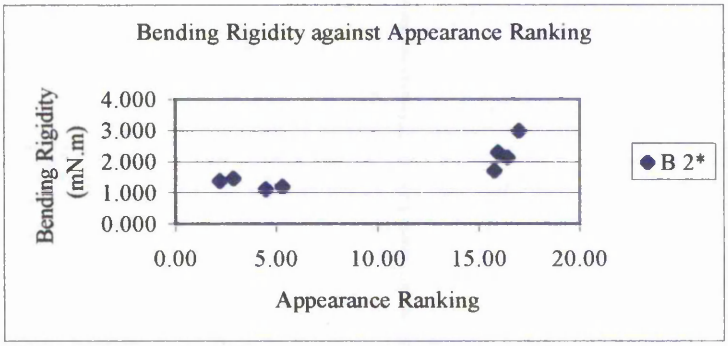


Figure 3.2.17 Bending Parameters against Appearance Ranking (A-K)

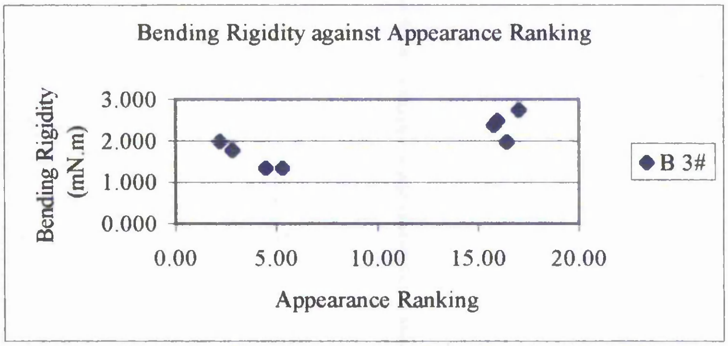
A) Warp Bending Rigidity against Appearance Ranking



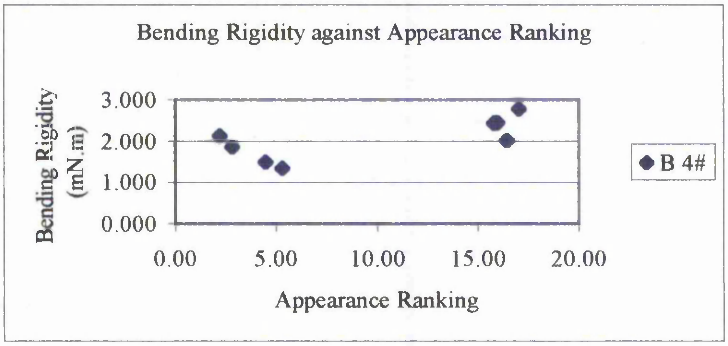
B) Weft Bending Rigidity against Appearance Ranking



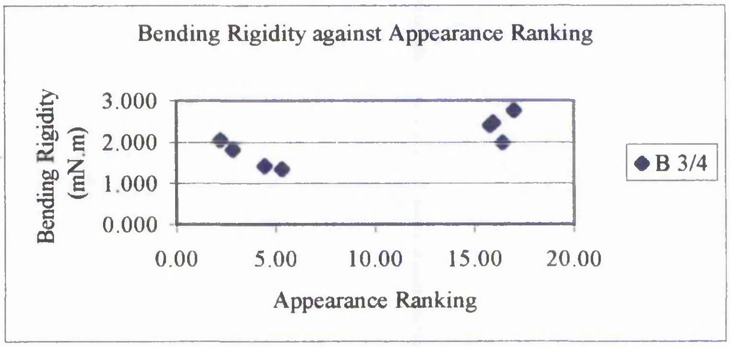
C) Right Bias Bending Rigidity against Appearance Ranking



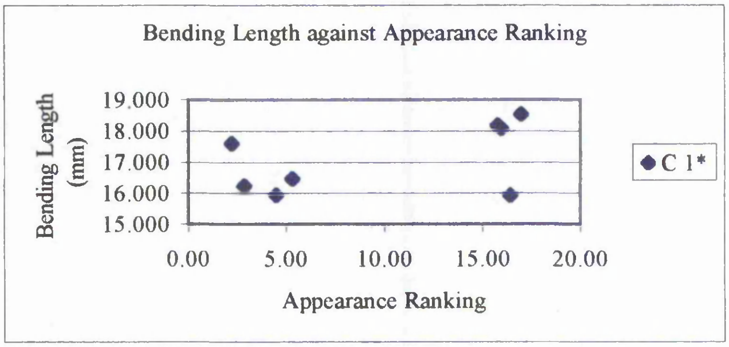
D) Left Bias Bending Rigidity against Appearance Ranking



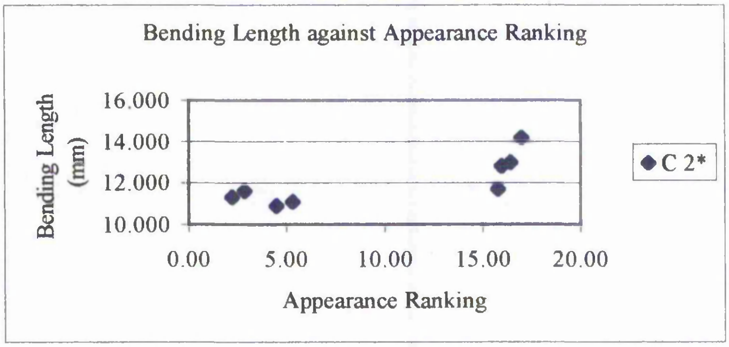
E) Bias Bending Rigidity against Appearance Ranking



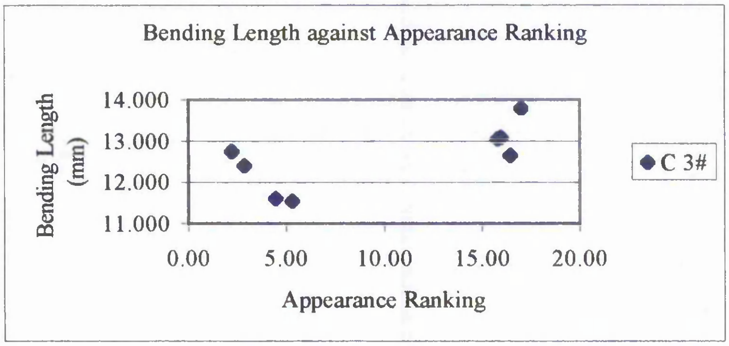
F) Warp Bending Length against Appearance Ranking



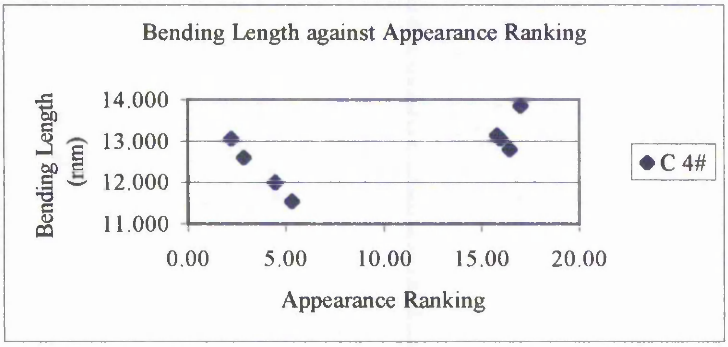
G) Weft Bending Length against Appearance Ranking



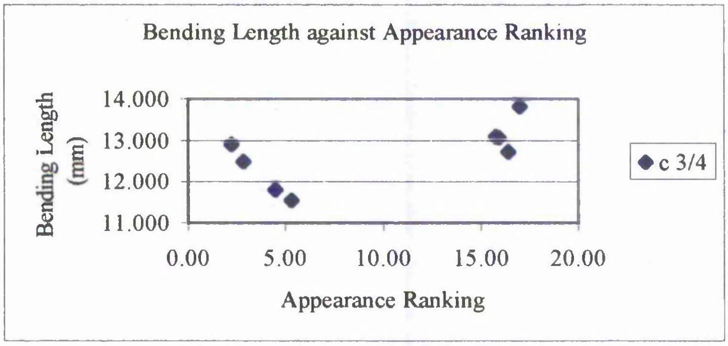
H) Right Bias Bending Length against Appearance Ranking



I) Left Bias Bending Length against Appearance Ranking



J) Bias Bending Length against Appearance Ranking



3.2.9.2 Formability

There is a trend evident, in figure 3.2.18, of the results of formability decreasing as the percentage weight reduction increases. This was found on samples prepared in all directions except the weft direction, which showed an overall increase in the formability resulting from an increasing weight reduction percentage. It is possible that this was because an increase in formability would result from an increase in either the extension or the bending rigidity parameters. There was a closer relationship between weight reduction and the extension parameter than between the former and the bending rigidity parameter. The weight reduction process had a contrasting effect on the two parameters; as the weight reduction percentage increased, the extension results increased, but the bending rigidity results decreased. Thus, for the weft direction, the increase in extension must have been more significant than the reduction in bending rigidity, and conversely so for the other directions. There were no major differences in the results for the two bias directions for formability; an average could therefore be used. The addition of the formability measurement in the bias directions was proved valid as the graph clearly indicates that it differentiates between the fabrics within the same story, but with differing weight reduction percentages, to a greater degree than the warp direction results.

The formability control chart shows that in the warp direction the Electra fabrics have high results whilst the Venus fabrics have low results. As both these fabrics have problems in manufacturing this posed some interesting points. The high results for the Electra fabrics could be attributed to their high extension values. The low results for warp (and bias) formability for the Venus fabrics contributed, with the bending and shear results, to give V9 the lowest manufacturing grade. It was therefore noted that there were different combinations of the mechanical properties that contributed to problems in manufacture.

The Geisha fabrics were the most affected fabrics in the warp direction and were moderately affected in the bias directions. The Portia fabrics were the most affected in the bias directions; these reductions in formability contributed to the reduction in their manufacturing grades, although as mentioned previously, as the initial results were high, these reductions did not alter the fabrics enough to cause problems.

The formability parameter has a very strong relationship with ease of manufacture when used for suiting fabrics where low results indicate problems. In this case, a similar relationship was found for the warp and bias direction samples, but the opposite was true for the weft samples. The equations between the formability parameter (measured in all directions) and the ease of manufacture parameter indicated that the results obtained from the bias-cut samples explained the largest amount of the problem, closely followed by the warp results; the weft direction results did not correspond with ease of manufacture.

There was no straightforward relationship between formability and the distortion value as results in all directions explained very little of the problem. The weft and bias results suggested that an increase in formability results correlated with distortion; this was a relationship that was expected given the definition of the parameter, despite the fact that the warp results suggested the opposite.

The warp and bias formability parameters had a positive correlation with the appearance rankings, although the graphs suggested that the weft parameter had a negative relationship with appearance. These results suggests a similar relationship to the one that formability has with the ease of manufacture. This is logical as factors that increase the ease of manufacture would also be linked to the appearance of the end product. The results in the warp direction produced a stronger correlation than the results in the other directions.

Figure 3.2.18 Formability Visual

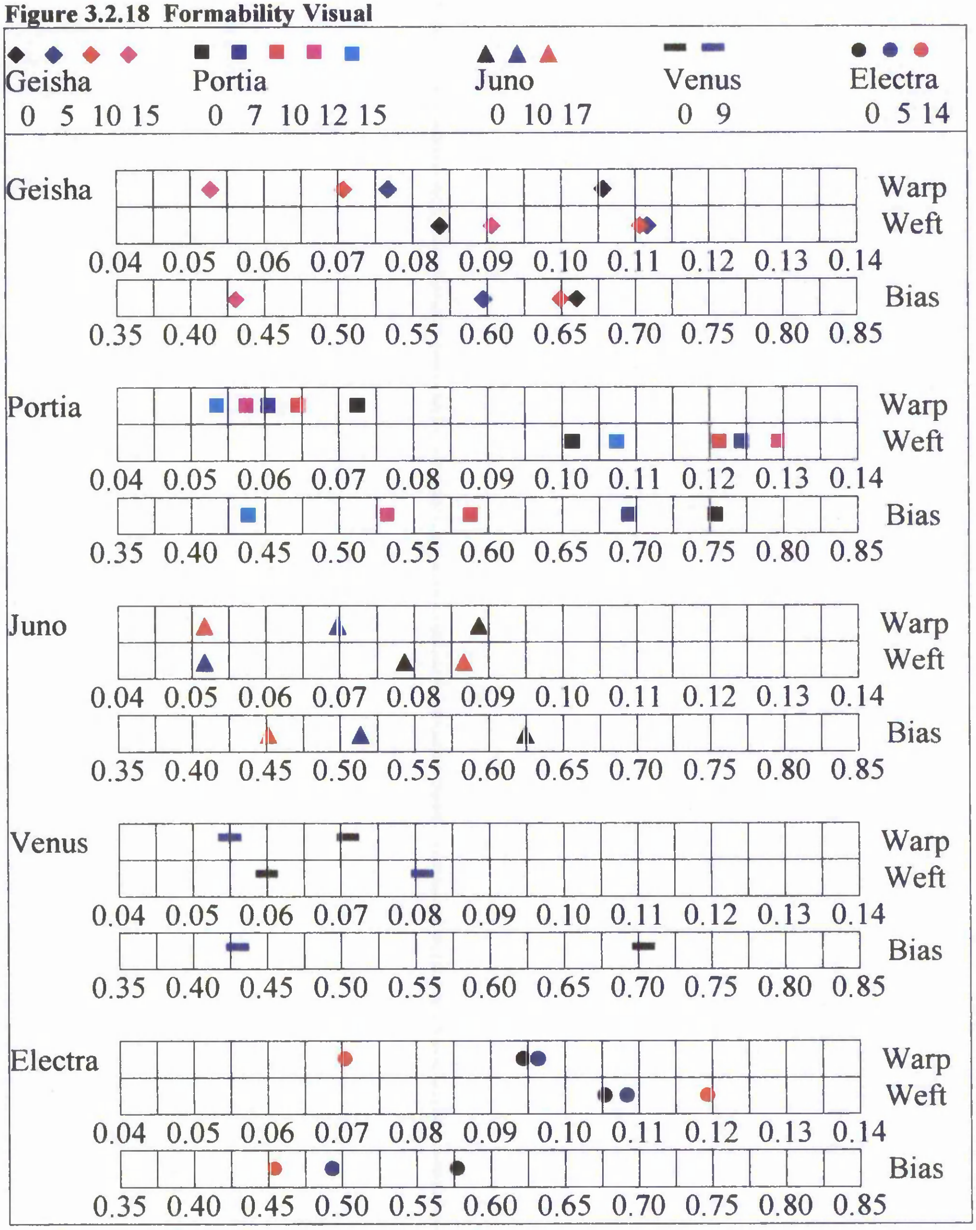
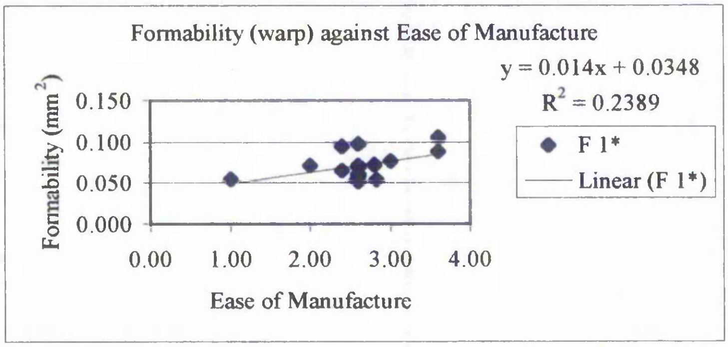
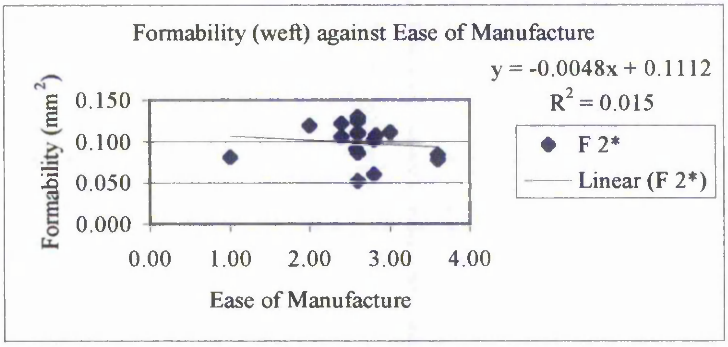


Figure 3.2.19 Formability Parameters against Ease of Manufacture (A-C)

A) Warp Formability against Ease of Manufacture



B) Weft Formability against Ease of Manufacture



C) Bias Formability against Ease of Manufacture

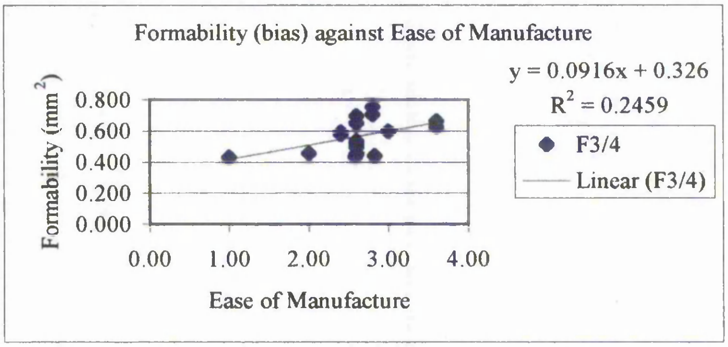
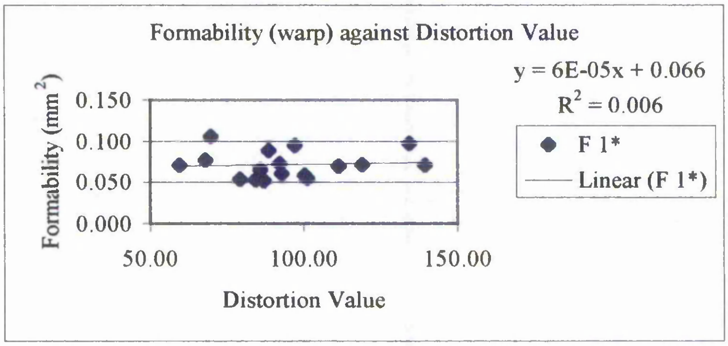
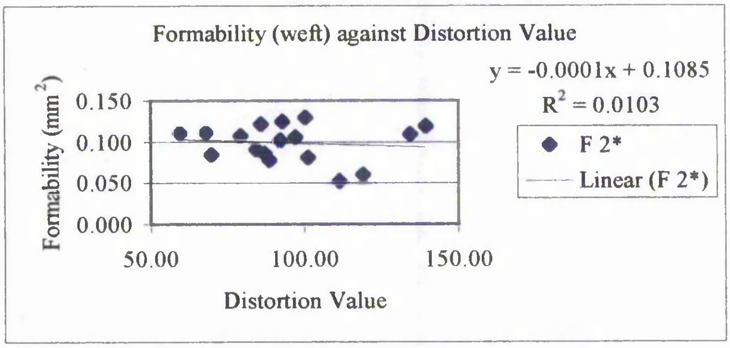


Figure 3.2.20 Formability Parameters against Distortion Value (A-D)

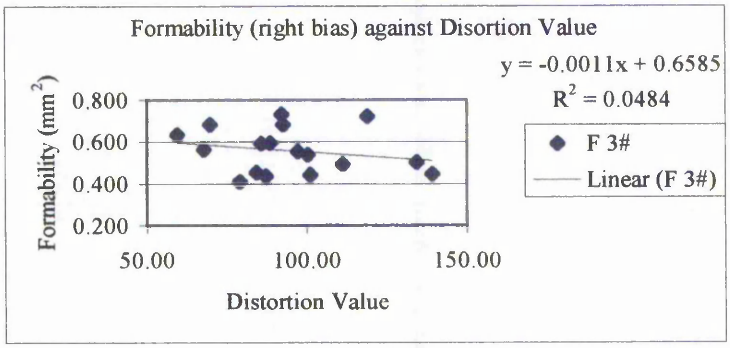
A) Warp Formability against Distortion Value



B) Weft Formability against Distortion Value



C) Right Bias Formability against Distortion Value



D) Left Bias Formability against Distortion Value

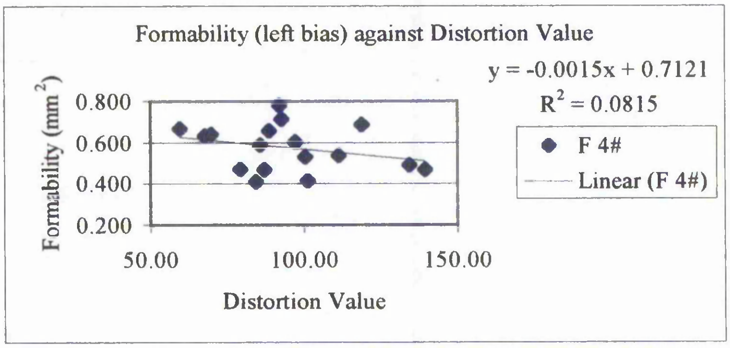
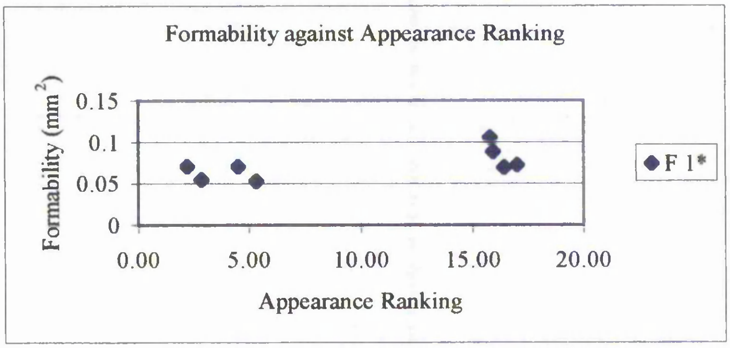
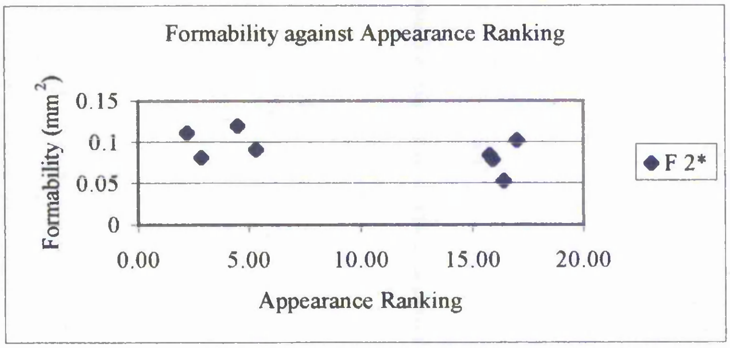


Figure 3.2.21 Formability Parameters against Appearance Ranking (A-E)

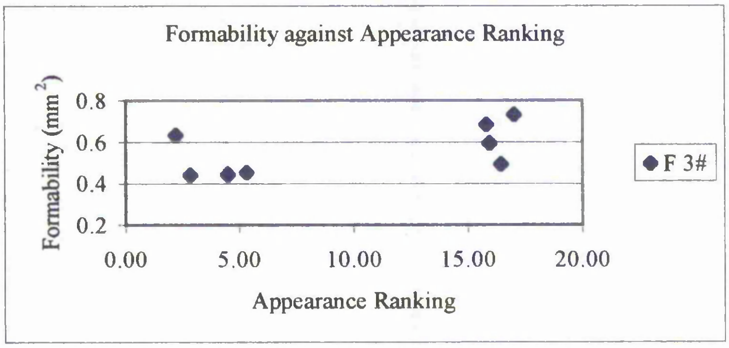
A) Warp Formability against Appearance Ranking



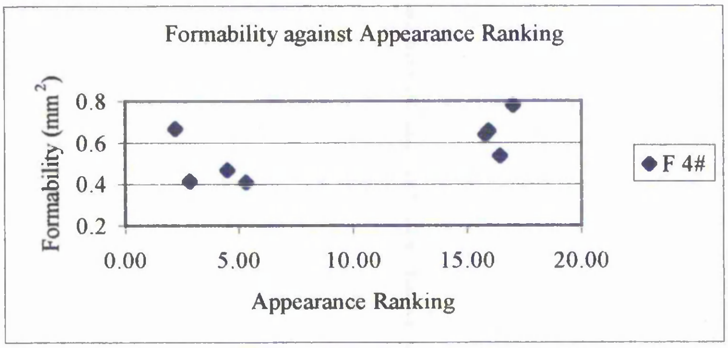
B) Weft Formability against Appearance Ranking



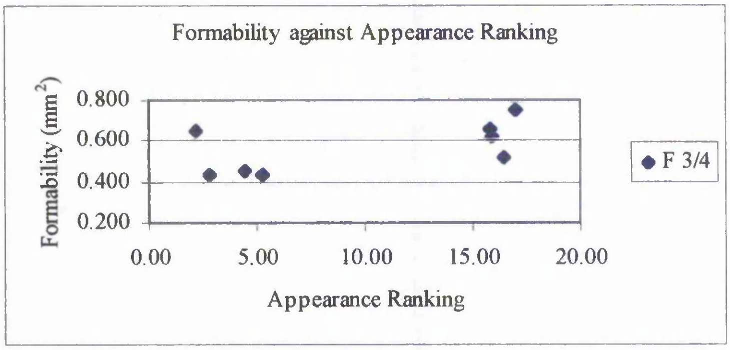
C) Right Bias Formability against Appearance Ranking



D) Left Bias Formability against Appearance Ranking



E) Bias Formability against Appearance Ranking



3.2.9.3 Shear

A trend for the shear rigidity results to reduce as the weight reduction percentage increased was evident on all loads. There was a slight difference in the results obtained using samples from the two bias directions, with the right bias samples producing results that varied more than the left bias. This difference was statistically assessed, but was found not to be significant, indicating that the average could be used.

The shear properties of the Electra and Venus fabrics were the least affected by the weight reduction process. However, the results from their base fabrics were both lower than the other base fabrics and lower in comparison with the other fabric stories when at equivalent weight reductions. The Geisha and Portia stories were the most affected, with up to 50% reduction in shear rigidity from the initial base fabric results at 15% weight reduction.

The shear parameter was initially thought to be one of most important parameters for predicting ease of manufacturing [38, 79, 115]. This hypothesis was confirmed with the fact that the right bias shear rigidity explained 43% of problems in manufacture; the results obtained from samples prepared in the left bias direction explained less of the problem (25%), although this is still a good correlation. The use of a variety of loads was proven valid, as ease of manufacture was more fully explained at the lower loads. It was evident that an increase in the shear rigidity results increased the ease of manufacture; this was an understandable relationship as the parameter is a sign of the resistance to distortion, and therefore low values indicate little resistance to distortion, which result in problems in manufacturing. A note was made of the positioning of the V9 fabric in the graphs, as it seemed out of line with the rest of the fabrics. It was not clear whether this was due to the fact that its manufacturing grade was much lower than that of the other fabrics or whether it was so easy to distort that the apparatus was not producing accurate results that properly reflected the fabric characteristics. It was recognised that the difference was greater at the higher loads.

As shear rigidity was such a good indicator for problems in manufacturing, one might expect it also to predict the distortion value. Unfortunately, this was not the case. The left bias results explained more of the distortion parameters than the right bias (although the difference was not great). Despite the fact that the results did not explain a great deal of the distortion problem, there was a slight overall trend that an increase in shear rigidity results coincided with reductions in the distortion value. This could indicate a similar relationship, if not as clearly defined, as that with the ease of manufacture variable.

The relationship was also similar for the appearance variable. There was a trend that those fabrics with larger results in the shear rigidity parameter were linked with a better appearance. Once more, the results suggest a relationship between the appearance rankings and the ease of manufacture; and in both cases the more stable fabrics were preferred. It is not possible to conclusively decide if there was a difference in the predictive nature of the loads, however the graphs did suggest that the lower loads were again better than the higher loads.

Figure 3.2.22 Shear Rigidity Visual

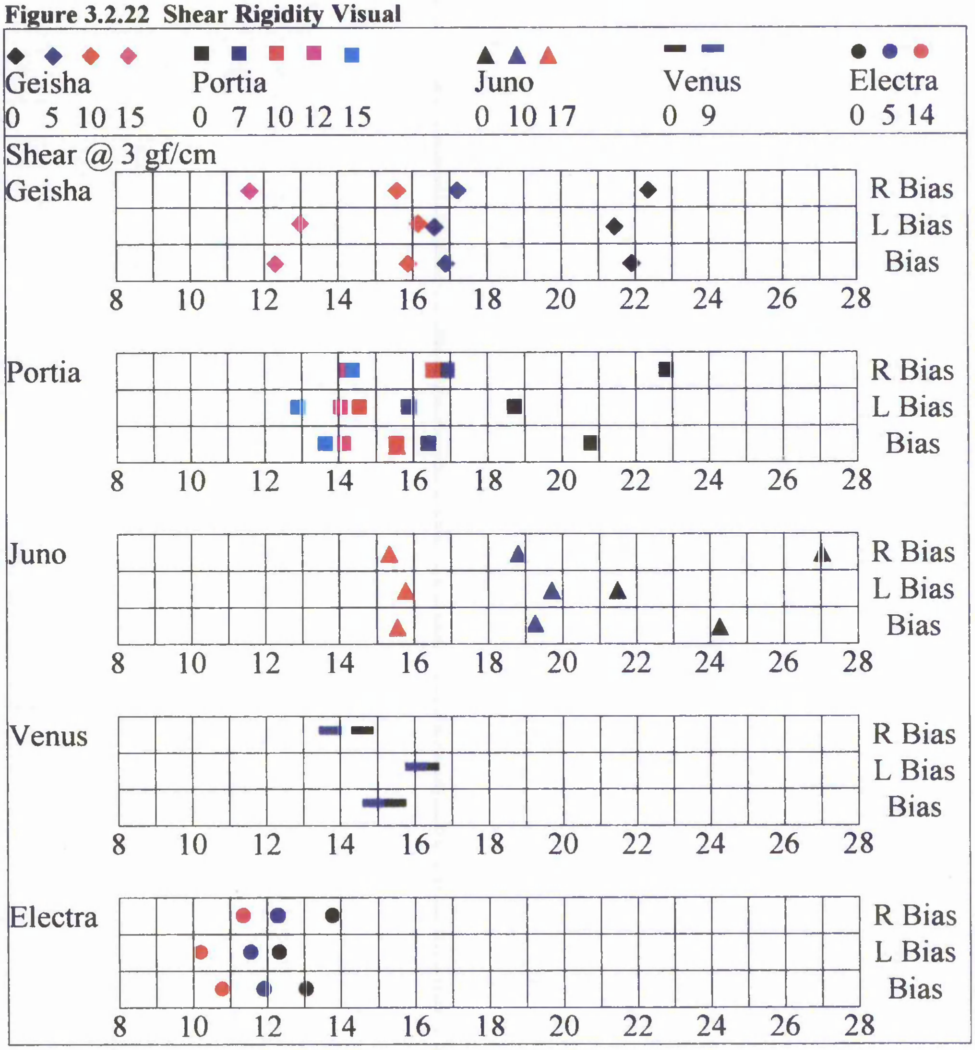
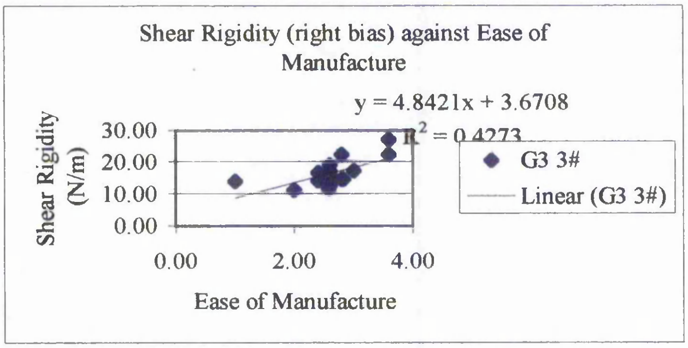
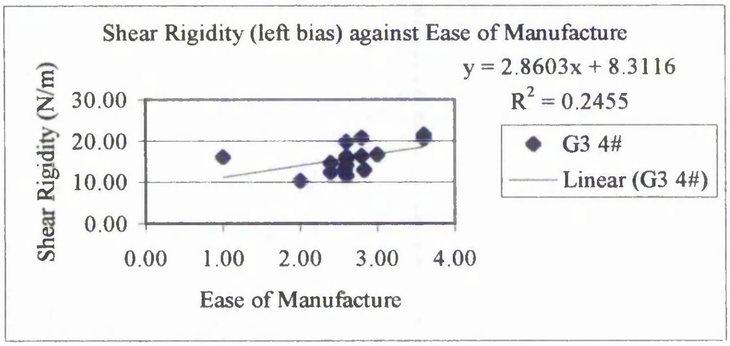


Figure 3.2.23 Shear Rigidity Parameters against Ease of Manufacture (all fabrics) (A-F)

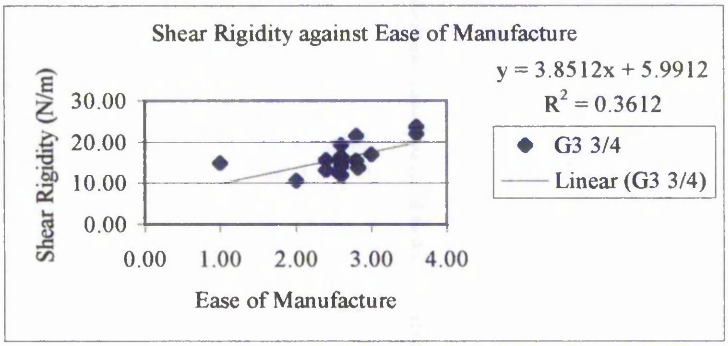
A) Right Bias Shear Rigidity @ 3 gf/cm against Ease of Manufacture



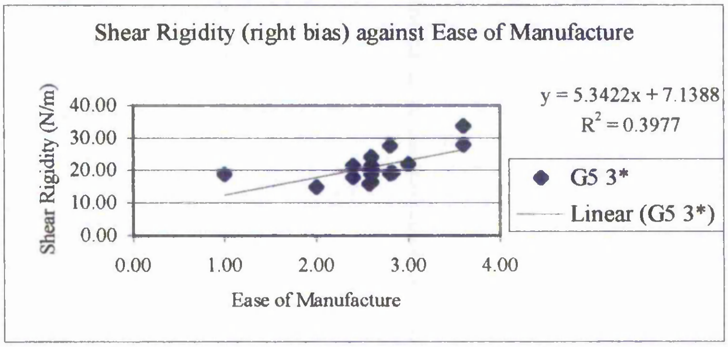
B) Left Bias Shear Rigidity @ 3 gf/cm against Ease of Manufacture



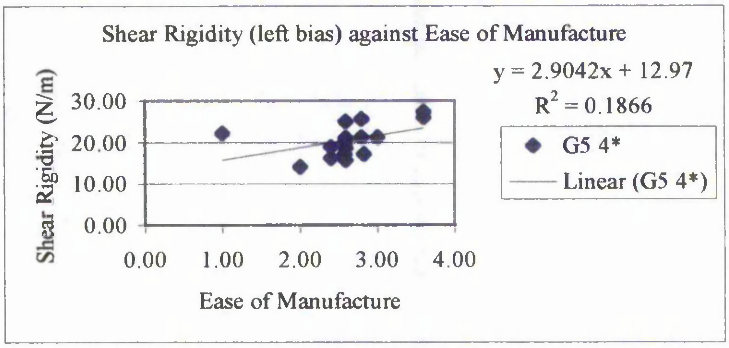
C) Bias Shear Rigidity @ 3 gf/cm against Ease of Manufacture



D) Right Bias Shear Rigidity @ 5 gf/cm against Ease of Manufacture



E) Left Bias Shear Rigidity @ 5 gf/cm against Ease of Manufacture



F) Bias Shear Rigidity @ 5 gf/cm against Ease of Manufacture

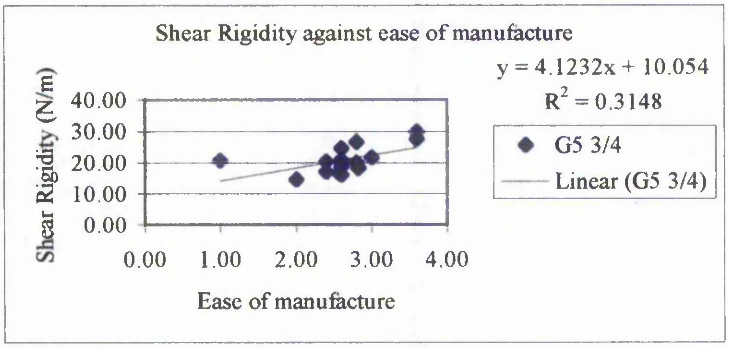
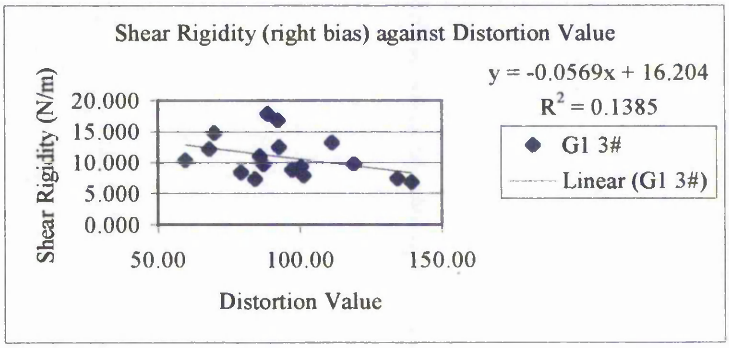
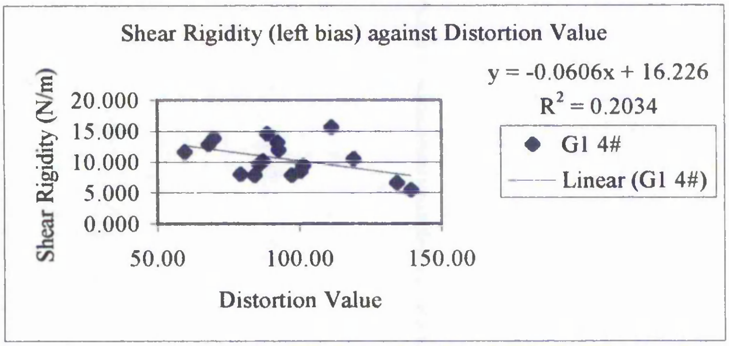


Figure 3.2.24 Shear Rigidity Parameters against Distortion Value (A-D)

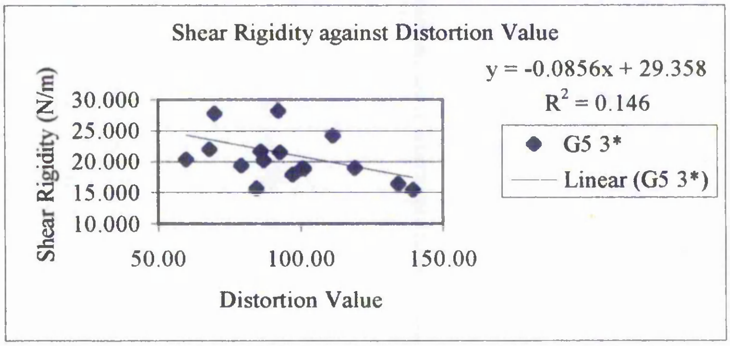
A) Right Bias Shear Rigidity @ 1.gf/cm against Distortion Value



B) Left Bias Shear Rigidity @ 1.gf/cm against Distortion Value



C) Right Bias Shear Rigidity @ 5.gf/cm against Distortion Value



D) Left Bias Shear Rigidity @ 5.gf/cm against Distortion Value

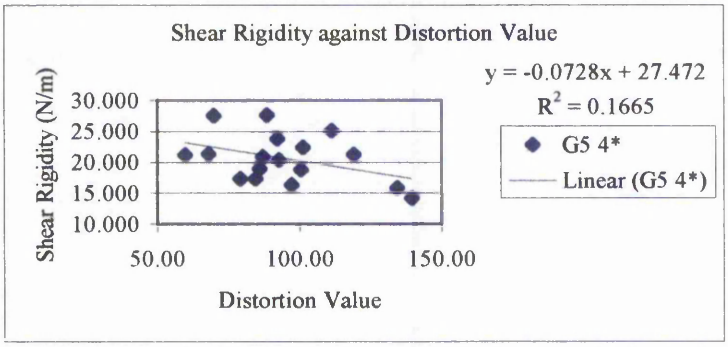
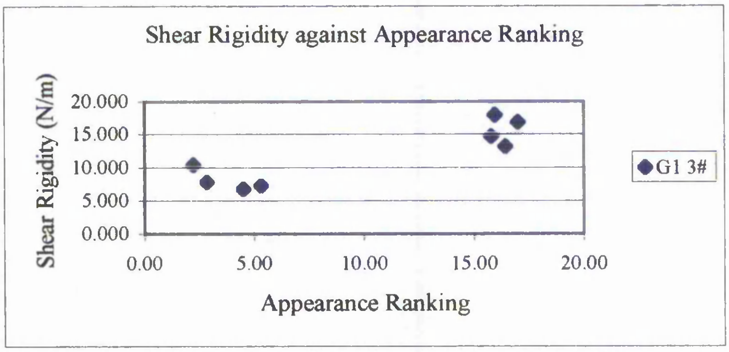
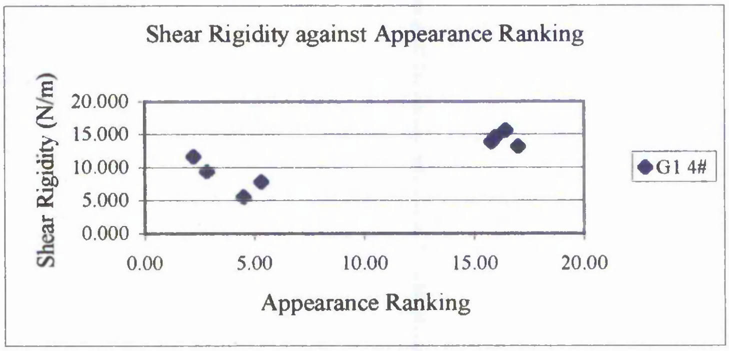


Figure 3.2.25 Shear Rigidity Parameters against Appearance Ranking (A-I)

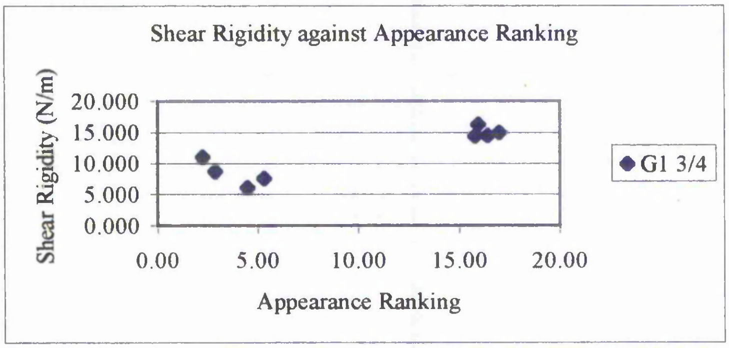
A) Right Bias Shear Rigidity @ 1 gf/cm against Appearance Ranking



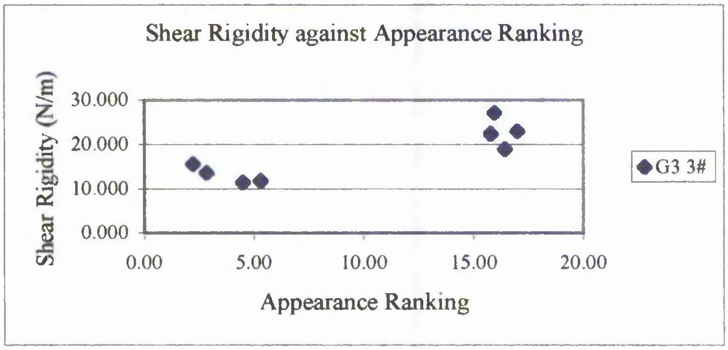
B) Left Bias Shear Rigidity @ 1.gf/cm against Appearance Ranking



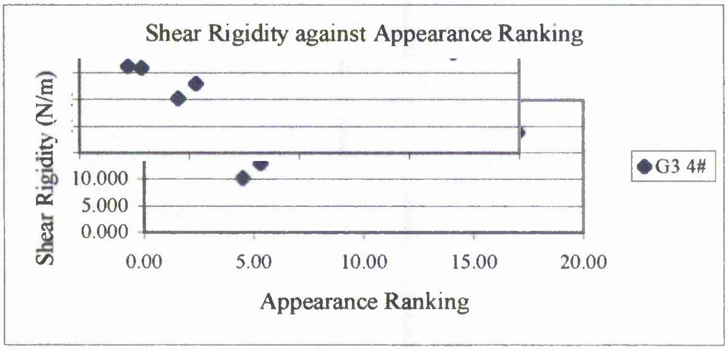
C) Bias Shear Rigidity @ 1.gf/cm against Appearance Ranking



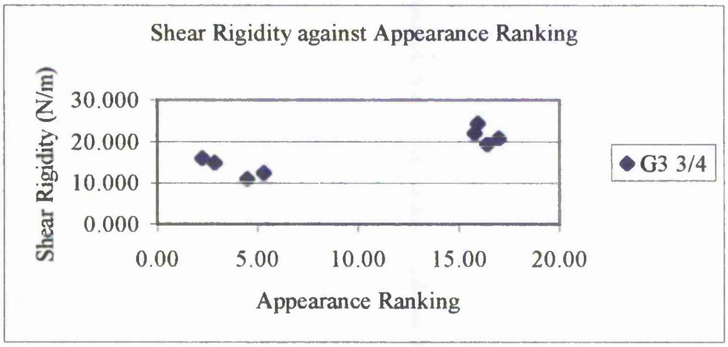
D) Right Bias Shear Rigidity @ 3.gf/cm against Appearance Ranking



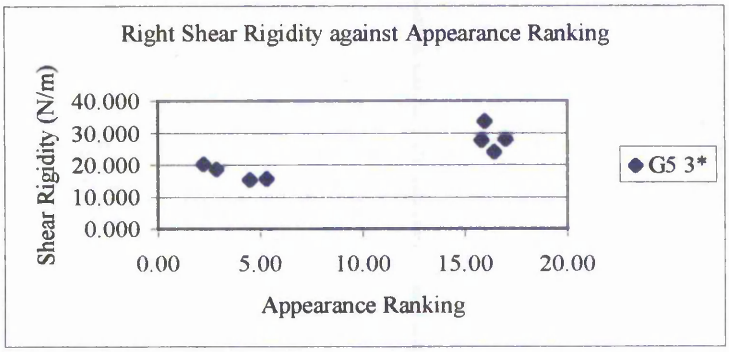
E) Left Bias Shear Rigidity @ 3.gf/cm against Appearance Ranking



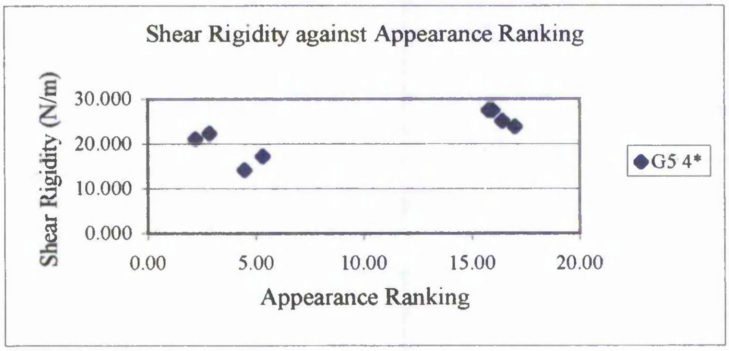
F) Bias Shear Rigidity @ 3.gf/cm against Appearance Ranking



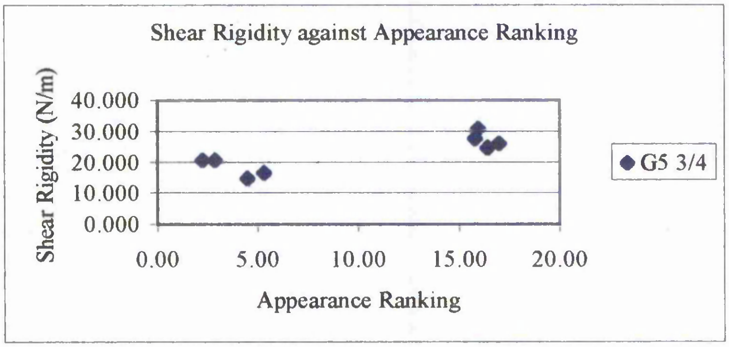
G) Right Bias Shear Rigidity @ 5.gf/cm against Appearance Ranking



H) Left Bias Shear Rigidity @ 5.gf/cm against Appearance Ranking



I) Bias Shear Rigidity @ 5.gf/cm against Appearance Ranking



3.2.9.4 Bias Extension

The bias extension results are normally only used to obtain the shear rigidity results. However, for this experiment, it was decided to assess the parameter directly as well as the shear rigidity results, to assess if any important data was lost during the conversion equation. It was also considered important that there was more data available for bias extension, as results for extension at loads up to 50 gf/cm had been obtained, but only the results of a small number of loads had been converted to produce the shear rigidity results.

An increase in percentage weight reduction at finishing resulted in an increase in the bias extension results, which was evident in all cases except for Venus fabrics in the left bias direction. As mentioned previously, the graphic results suggested that this fabric behaved differently from the other. It was proposed that this distortion, together with the vertical positioning of the test specimen, resulted in elongation due to the force of gravity. A high degree of waisting of the test specimens was noted which suggested that there was an uneven distribution of the load whilst stretching. At loads 1-3 the V9 fabrics produced results higher than V0, which was consistent to the findings of the other fabric stories, which suggested that small loads minimised this problem. However, the inverse relationship of extensibility results at high loads between V0 and V9 was unusual; for example, at 50 gf/cm, V0 extended more than V9 (the results in the right bias direction were 14.0 for V0 and 13.4 for V9). It was inconsistent when compared with the results of the other fabric stories at the same load (J10 – 12.1 and J17 14.3). Hence, it is possible that for fabrics that distort very easily (to the degree of V9) the FAST apparatus is not suitable even in its modified state. The KES-F1 instrument assesses shear when the fabric sample is laid horizontally and thus is not prone to this type of problem.

When the bias extension results were correlated to the ease of manufacture grades, they were found to predict a smaller percentage of the problem than the shear rigidity results. However, the bias extension results were better predictors of the distortion problem than the shear rigidity results. No noticeable differences between the results taken from the two bias directions were found. It is not possible to state whether either shear rigidity or bias extension is a significantly better parameter to predict garment appearance, but the graphs suggest that the lower loads on both parameters are more likely to be indicative of appearance.

Figure 3.2.26 Bias Extension Visual

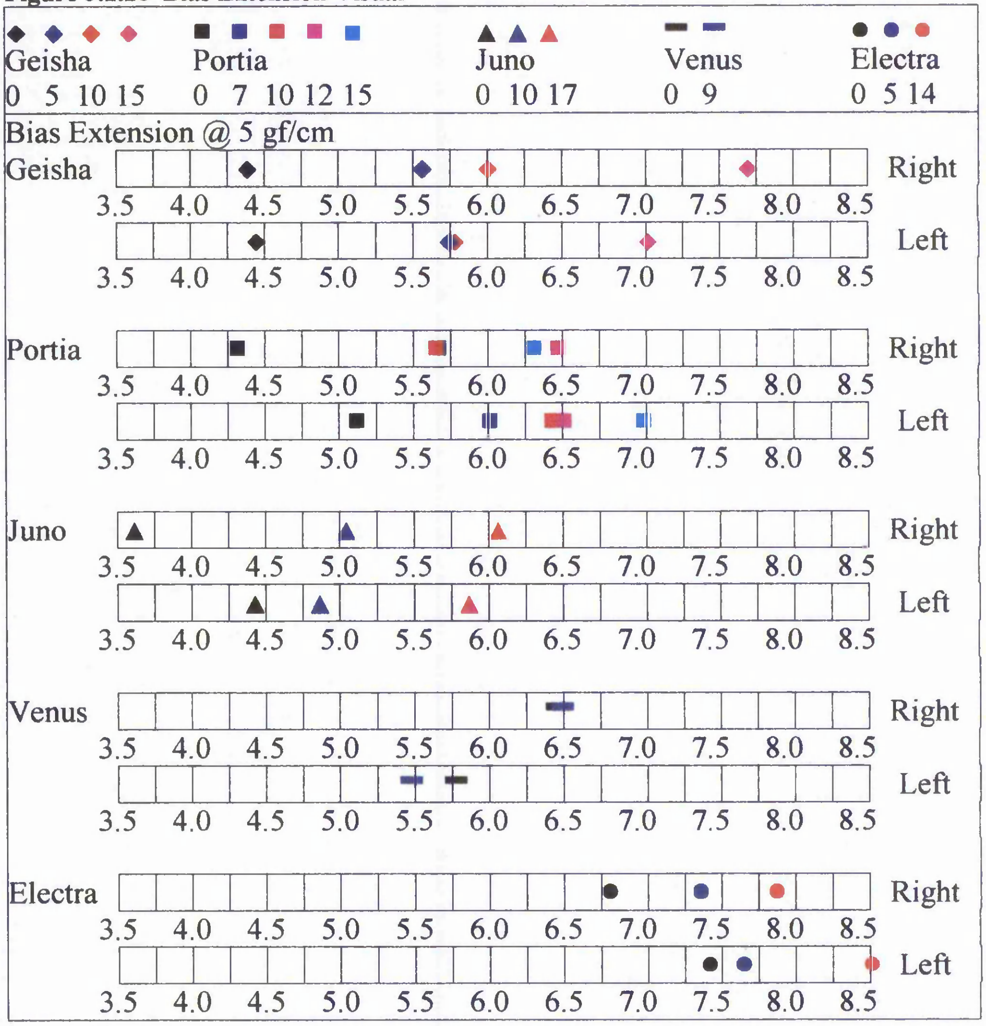
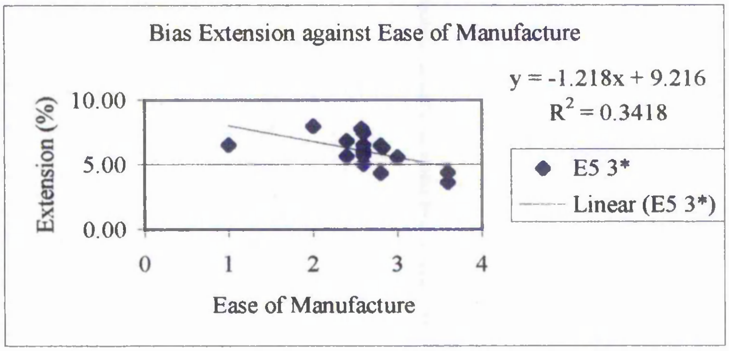
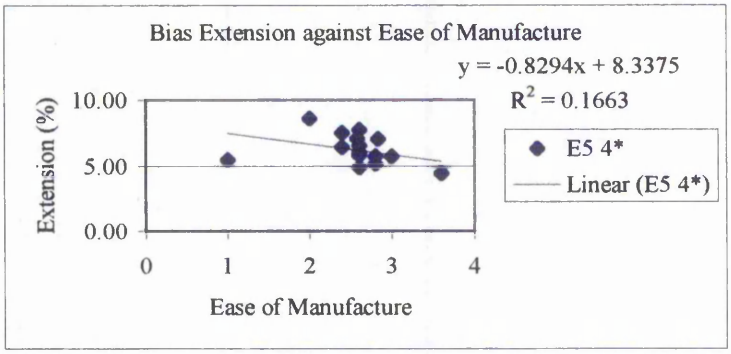


Figure 3.2.27 Bias Extension Parameters against Ease of Manufacture (A-F)

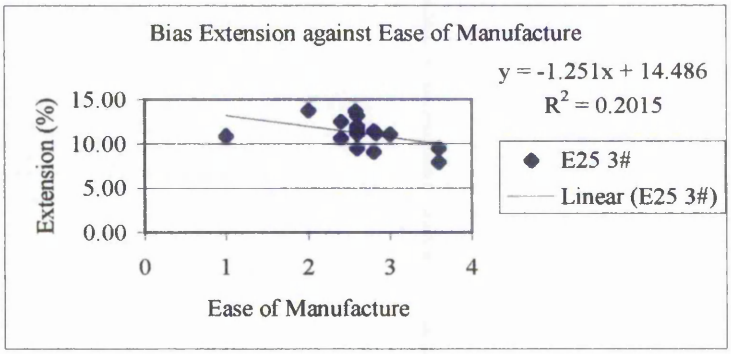
A) Right Bias Extension @ 5 gf/cm against Ease of Manufacture



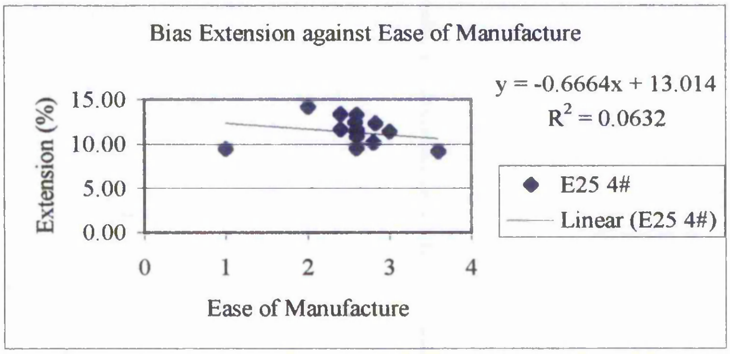
B) Left Bias Extension @ 5 gf/cm against Ease of Manufacture



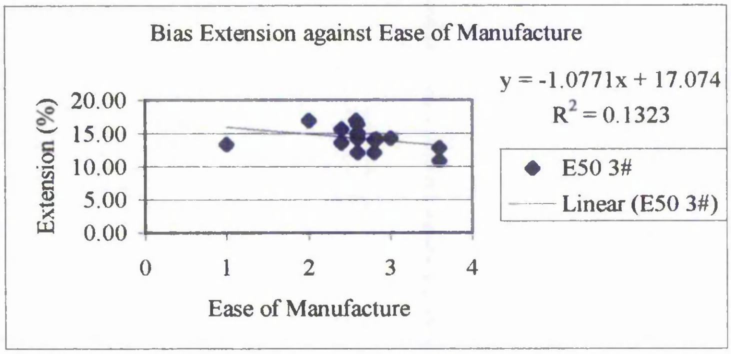
C) Right Bias Extension @ 25 gf/cm against Ease of Manufacture



D) Left Bias Extension @ 25 gf/cm against Ease of Manufacture



E) Right Bias Extension @ 50 gf/cm against Ease of Manufacture



F) Left Bias Extension @ 50 gf/cm against Ease of Manufacture

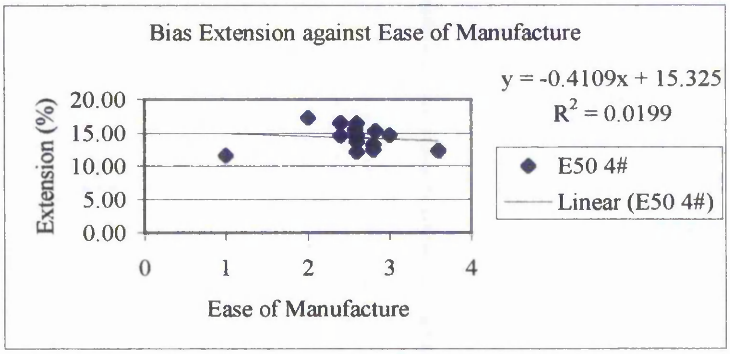
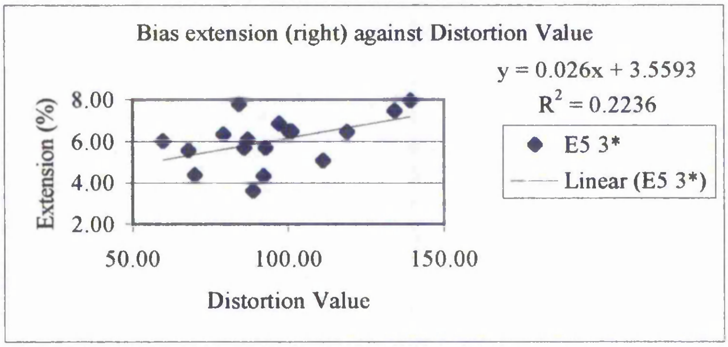
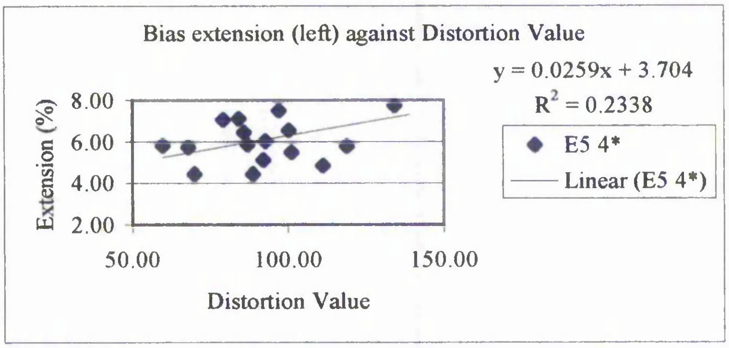


Figure 3.2.28 Bias Extension Parameters against Distortion Value (A-F)

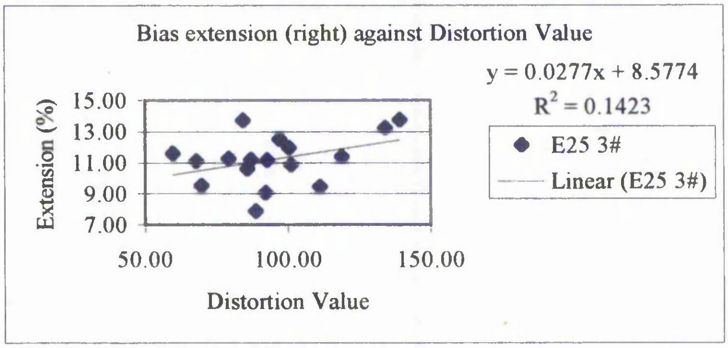
A) Right Bias Extension @ 5 gf/cm against Distortion Value



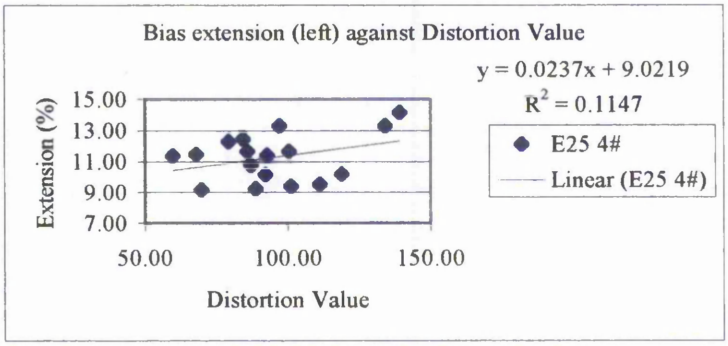
B) Left Bias Extension @ 5 gf/cm against Distortion Value



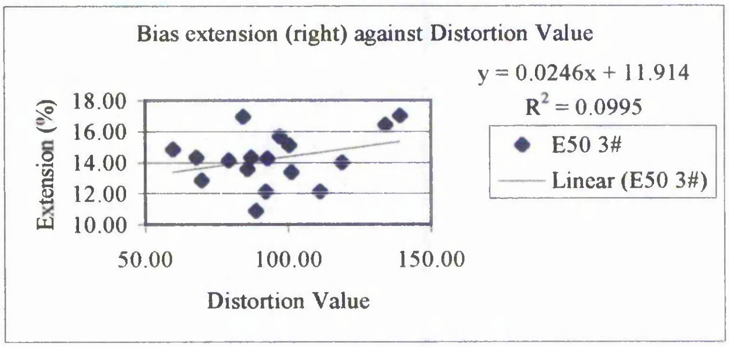
C) Right Bias Extension @ 25 gf/cm against Distortion Value



D) Left Bias Extension @ 25 gf/cm against Distortion Value



E) Right Bias Extension @ 50 gf/cm against Distortion Value



F) Left Bias Extension @ 50 gf/cm against Distortion Value

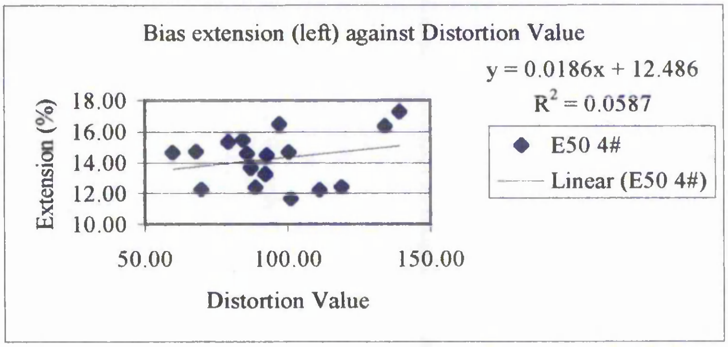
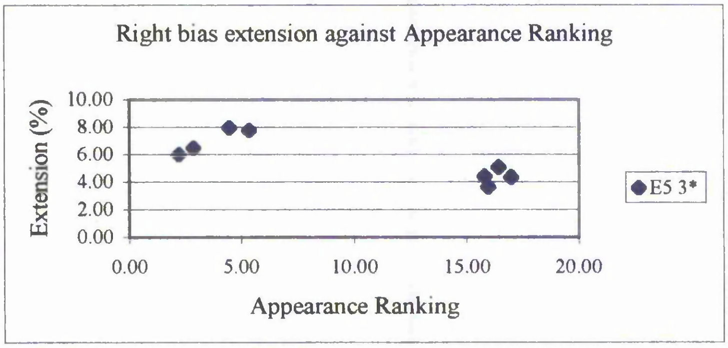
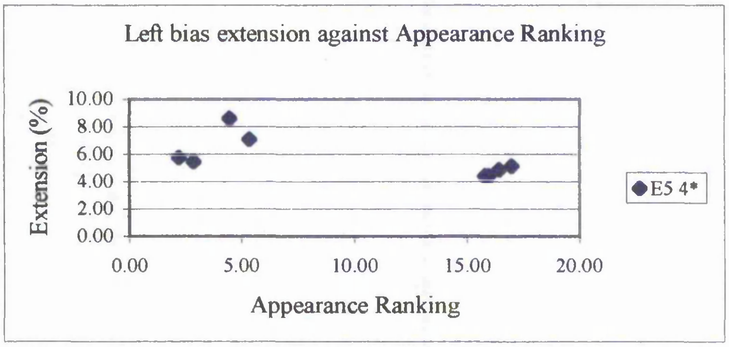


Figure 3.2.29 Bias Extension Parameters against Appearance Ranking (A-F)

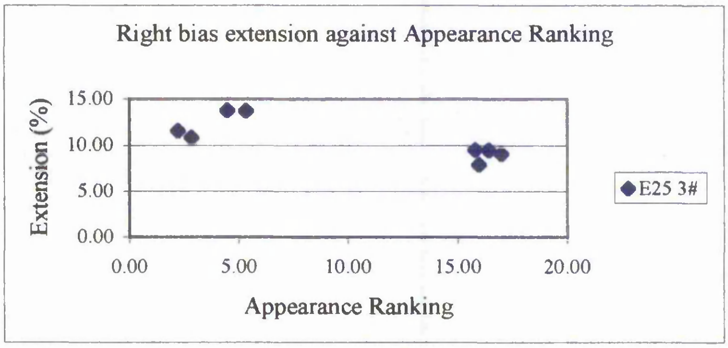
A) Right Bias Extension @ 5 gf/cm against Appearance Ranking



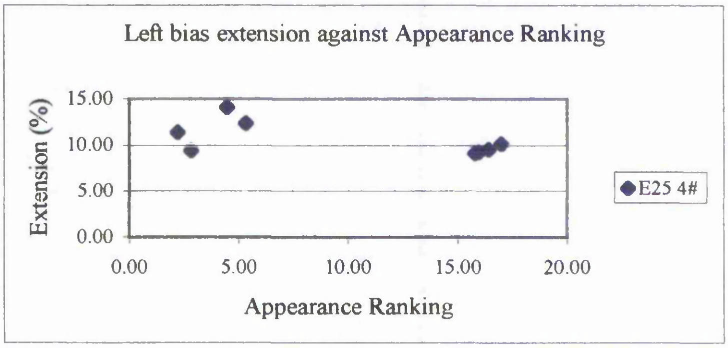
B) Left Bias Extension @ 5 gf/cm against Appearance Ranking



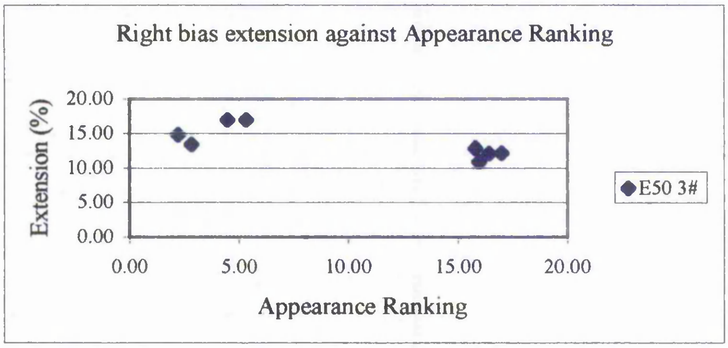
C) Right Bias Extension @ 25 gf/cm against Appearance Ranking



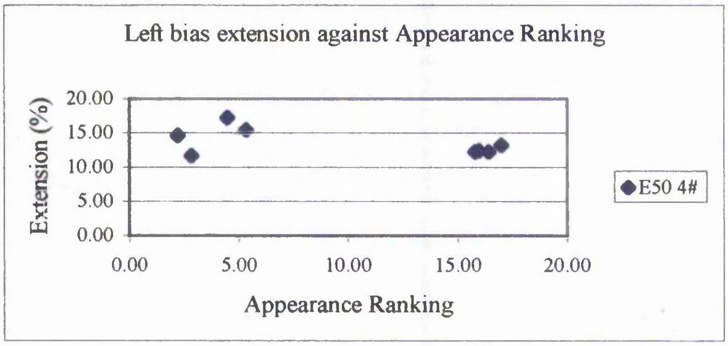
D) Left Bias Extension @ 25 gf/cm against Appearance Ranking



E) Right Bias Extension @ 50 gf/cm against Appearance Ranking



F) Left Bias Extension @ 50 gf/cm against Appearance Ranking



3.2.9.5 Drape

A trend was identified with respect to the changes in the drape coefficient results, where increases in the percentage weight reduction resulted in reductions in the drape coefficient (that is, the fabric becomes more flexible). This finding is consistent with the theory of the weight reduction process, which was designed to enable greater movement between the fibres and yarns in a fabric, and as a consequence provide a greater propensity to drape.

The test results for drape coefficient are not directly related to the amount of weight reduction each fabric has, as the fabric's initial characteristics are also very important. The drape properties of the Electra fabrics were the least affected, possibly due to their low initial results. The results for the Venus fabrics changed to the largest degree, V9 had a 23% lower result, possible due to the fabric as it was the only fabric containing basic-dyeable weft yarns.

The drape coefficient results were plotted against the ease of manufacture, and the resultant graph indicated a trend for a reduction in the drape coefficient results to coincide with increases in the difficulty in manufacturing. There was little difference between the results obtained when either face was uppermost. Drape explained 35% of the manufacturing problem.

Drape was not as good a predictor of the distortion parameter as of the manufacturing problem. The results did show a slight relationship, a reduction in the drape coefficient results coinciding with an increase in distortion value, which explained 22% of the distortion results.

The results of the investigation into appearance indicates that fabrics with large drape coefficient values (more rigid fabrics) are better in terms of appearance than the softer fabrics with more drape. This conclusion correlates with the previous results for bending, shear and extension. The graphs would suggest that this parameter is very important to the appearance variable.

Figure 3.2.30 Drape Visual

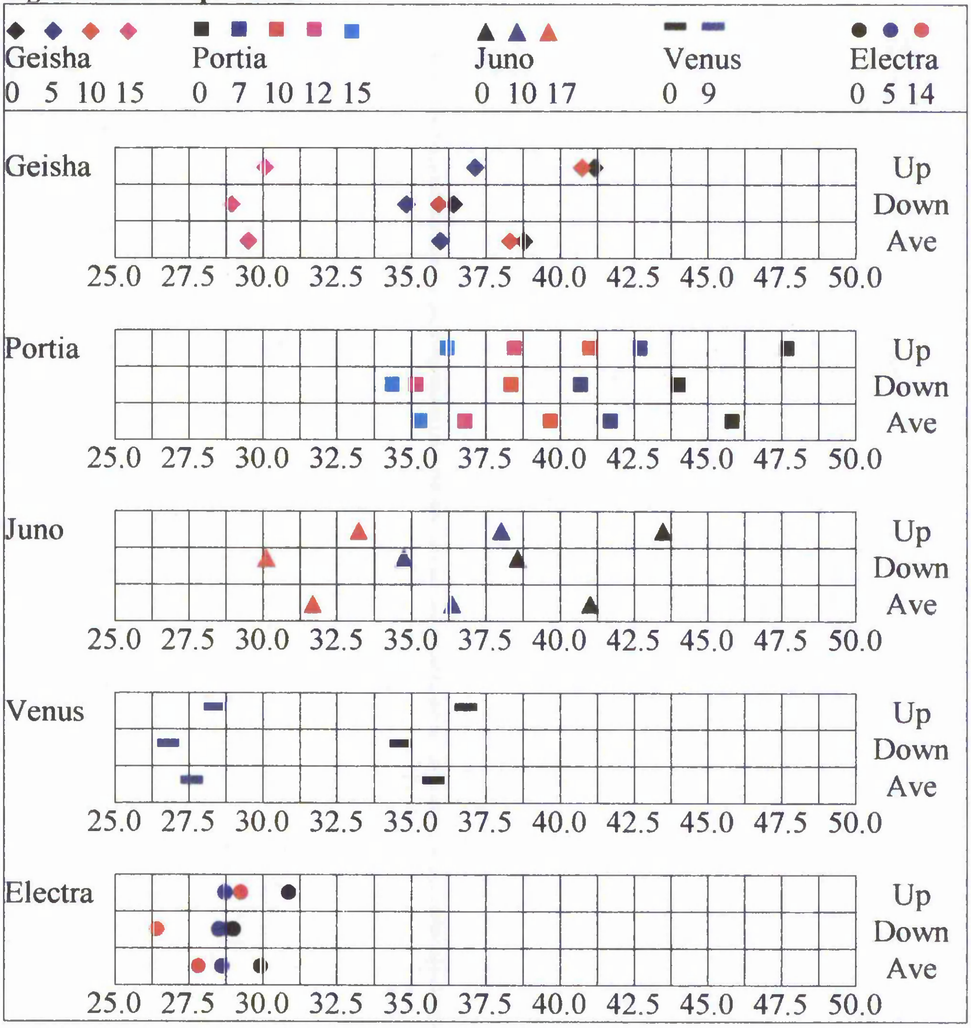
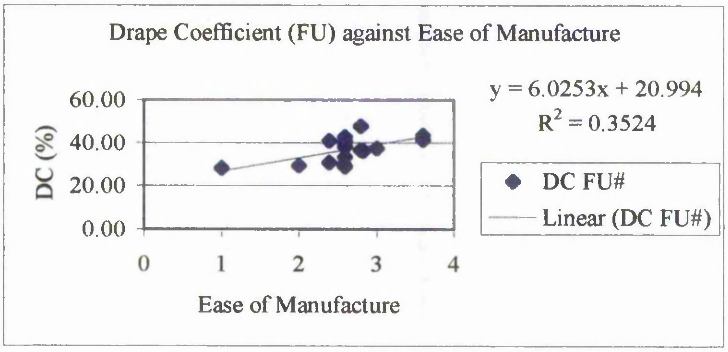


Figure 3.2.31 Drape Parameters against Ease of Manufacture (A-B)

A) Face-up Drape Coefficient against Ease of Manufacture



B) Face down Drape Coefficient against Ease of Manufacture

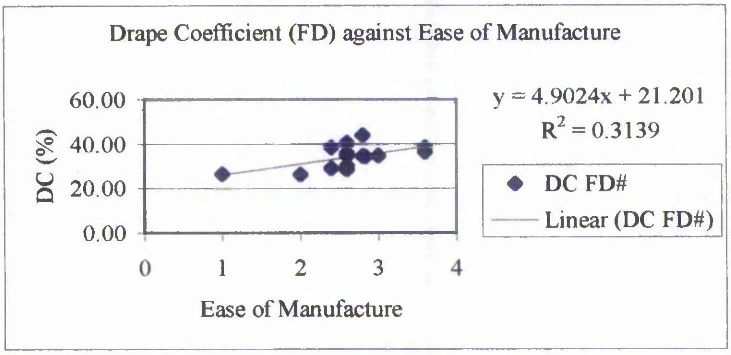
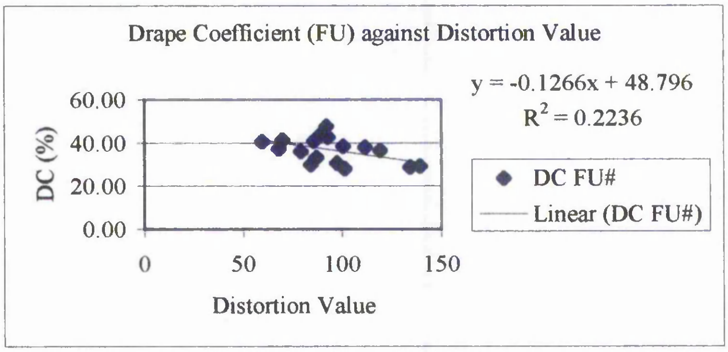


Figure 3.2.32 Drape Parameters against Distortion Value (A-B)

A) Face-up Drape Coefficient against Distortion Value



B) Face Down Drape Coefficient against Distortion Value

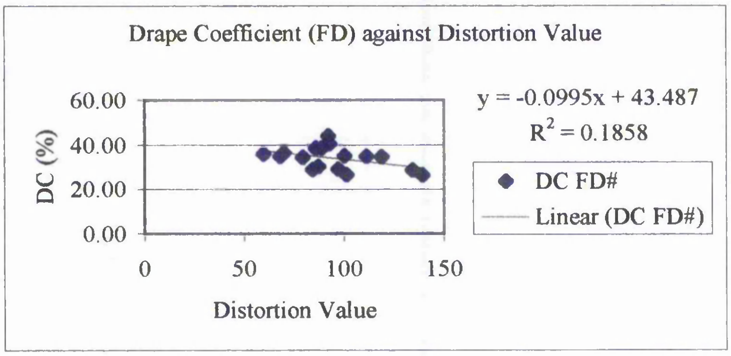
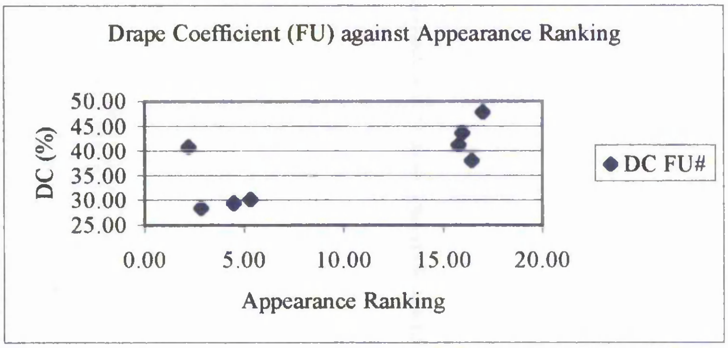
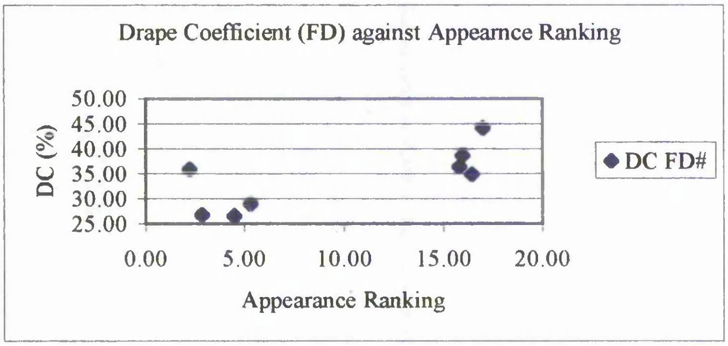


Figure 3.2.33 Drape Parameters against Appearance Ranking (A-B)

A) Face up Drape Coefficient against Appearance Ranking



B) Face Down Drape Coefficient against Appearance Ranking



3.2.9.6 Weight

The weight parameter was obviously very closely related to the weight reduction process; the higher the weight reduction percentage, the lower the weight per square metre of the fabric.

The percentage weight reduction as supplied by the fabric manufacturer did not necessarily represent the exact amount of weight lost by the fabric; a variation of 3% would be within tolerance. It was seen that this happened with the P 7 and P10 fabrics where the latter with a nominal 10% weight reduction, was actually heavier than the former which had only a nominal 7% weight reduction.

Weight is often linked to ease of manufacture where heavier fabrics are found to be easier to manufacture [7] and this finding was confirmed in this experiment. The weight variable explained 38% of the manufacturing problem. The positioning of

V9 was also noted for this parameter, as its results were not typical of the trend evident with the other fabrics.

The weight variable was not as good a predictor for distortion as it only explained 7% of the problem, which in statistical terms means it did not really contribute to predicting the problem. The results from the appearance investigation also suggested that lower weight fabrics produced garments of worse appearance, with the graphs suggesting a strong relationship.

Figure 3.2.34 Weight Visual

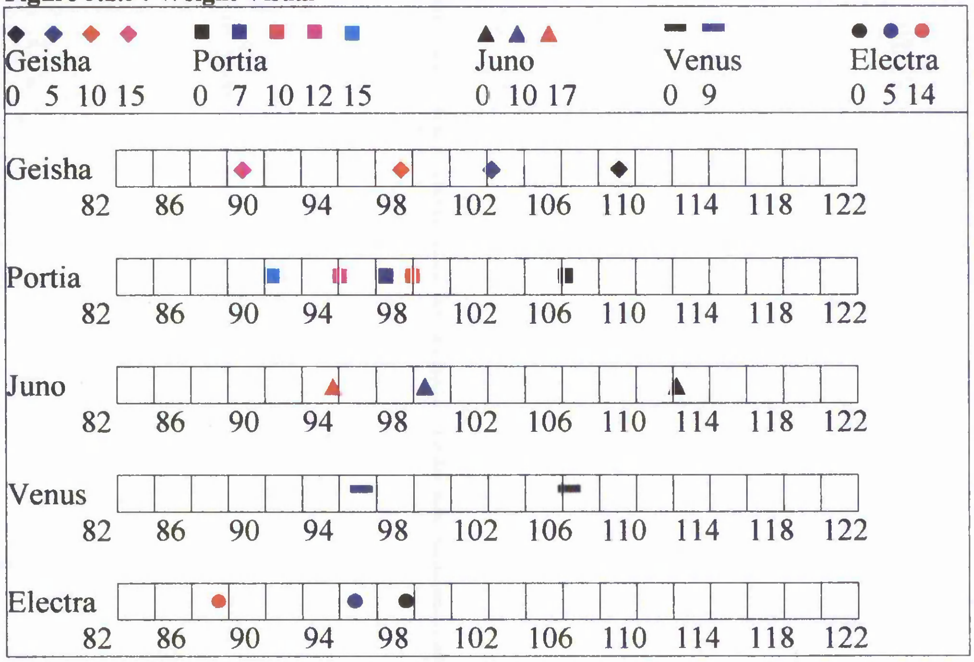


Figure 3.2.35 Weight against Ease of Manufacture

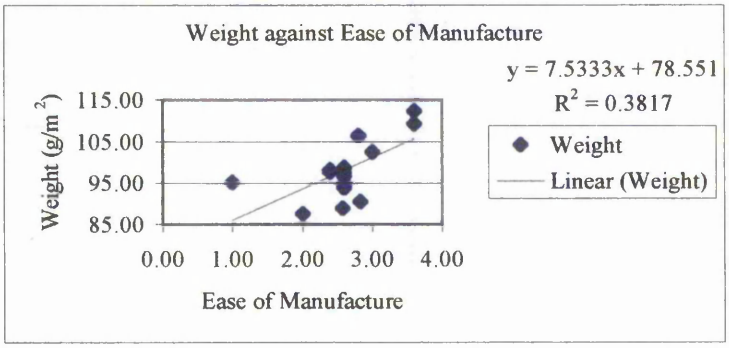


Figure 3.2.36 Weight against Distortion Value

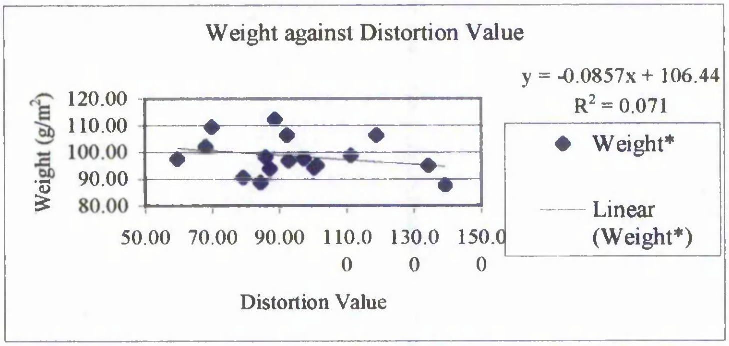
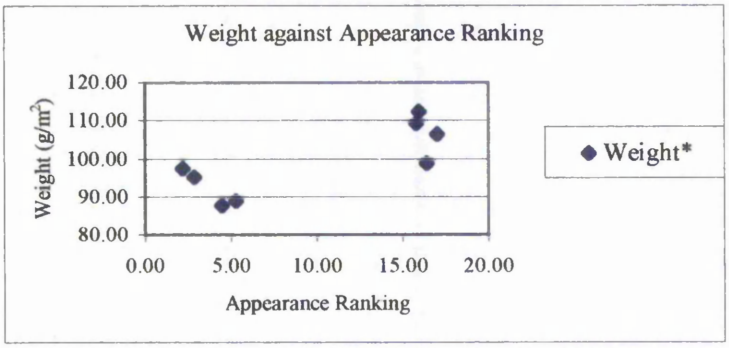


Figure 3.2.37 Weight against Appearance Ranking



3.2.9.7 Thickness

Results obtained from the compression meter are good indicators of handle and a predictor of problems for suiting fabrics [57]. Thickness was also found to be affected by the weight reduction technique when tested using the KES equipment [102]. However, these weight reduced polyester fabrics did not show such a straightforward trend. An increase in the weight reduction process reduced thickness for the Juno, Venus and Electra fabrics but not for Geisha or Portia fabrics. Related to this, an increase in the weight reduction process produced lower values in the surface thickness for Venus and Electra but not the other fabrics. As Venus and Electra were the problem fabrics, this could indicate a link with ease of manufacture but, as seen from the graphs, there was no relationship between the results and the problem variable. In addition, it is unlikely that such small differences would be detectable by hand.

There was also no real relationship with the actual thickness measurements and the distortion values. The best relationship with thickness (T100) was with appearance, which indicated that thicker fabrics produced garments with better appearance.

Figure 3.2.38 Thickness Visual

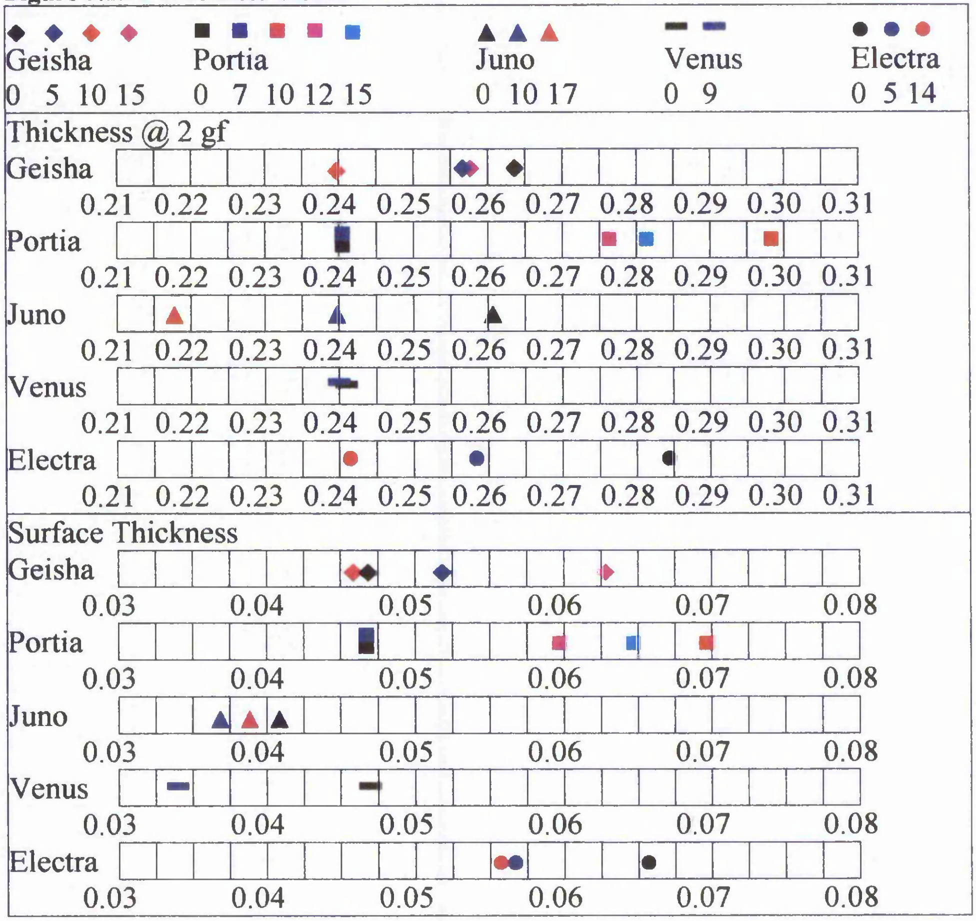
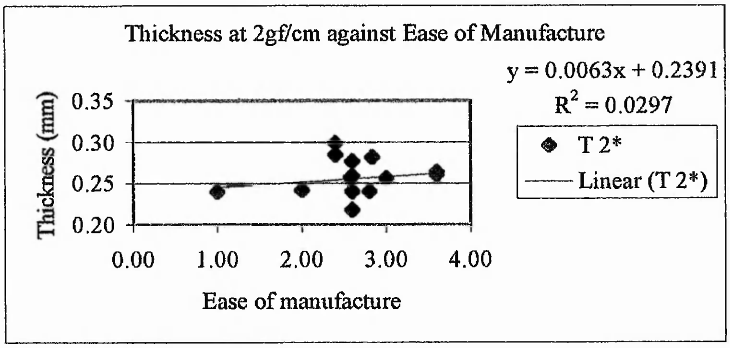
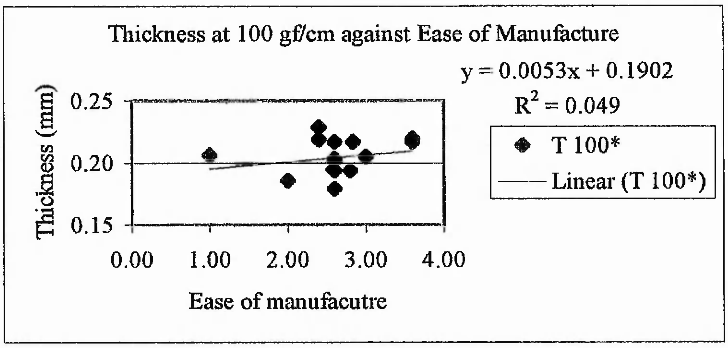


Figure 3.2.39 Thickness Parameters against Ease of manufacture (A-C)

A) Thickness at 2 gf/cm load against Ease of Manufacture



B) Thickness at 100 gf/cm load against Ease of Manufacture



C) Surface Thickness against Ease of Manufacture

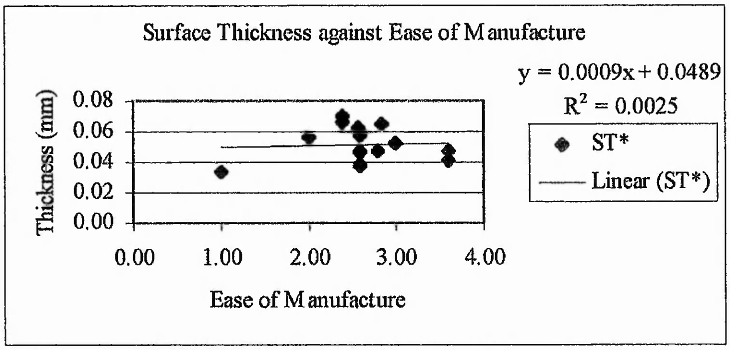
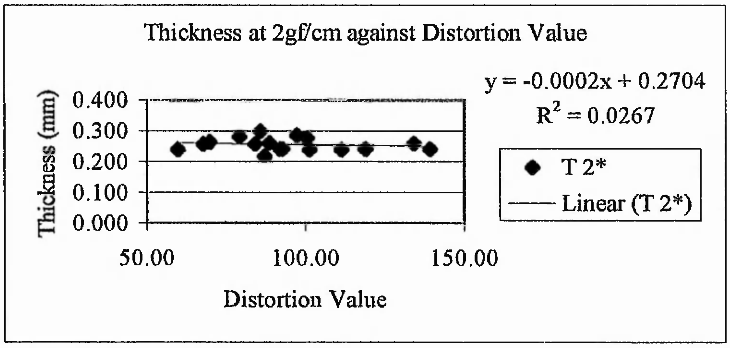
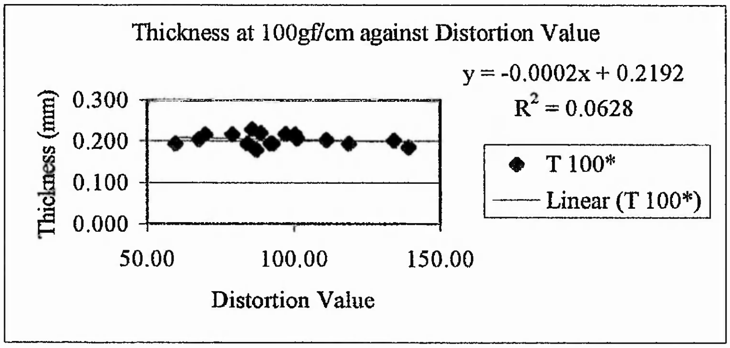


Figure 3.2.40 Thickness Parameters against Distortion Value (A-C)

A) Thickness at 2 gf/cm against Distortion Value



B) Thickness at 100 gf/cm against Distortion Value



C) Surface Thickness against Distortion Value

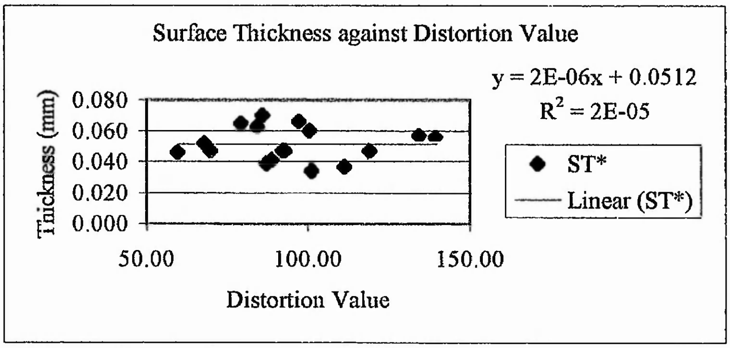
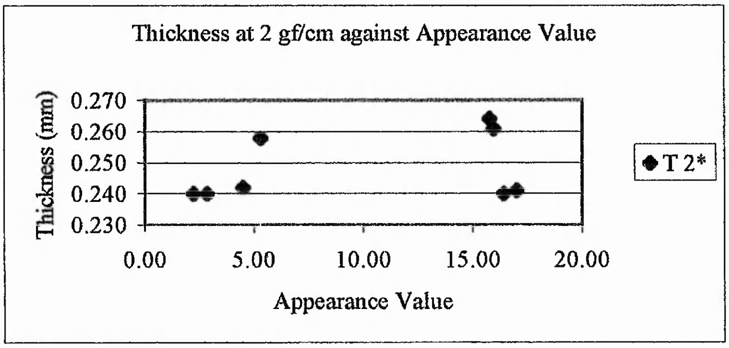
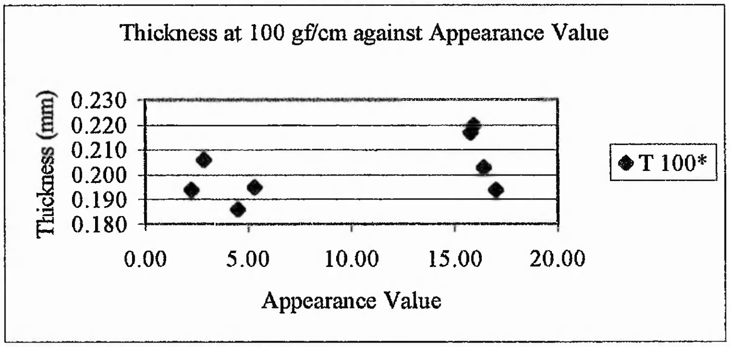


Figure 3.2.41 Thickness Parameters against Appearance Ranking (A-C)

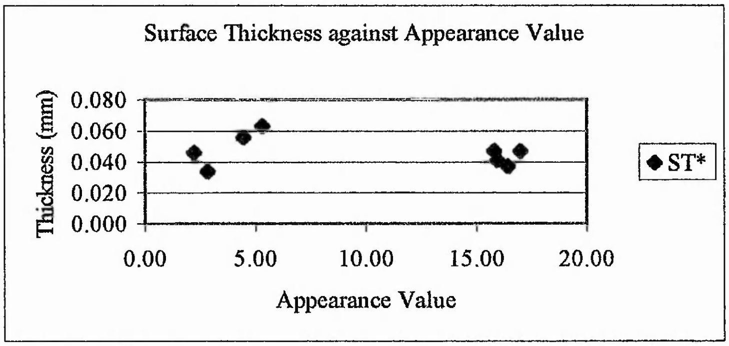
A) Thickness at 2gf/cm against Appearance Ranking



B) Thickness at 100 gf/cm against Appearance Ranking



C) Surface thickness against Appearance Ranking



3.2.9.8 Warp and Weft Extension

There was a relationship suggesting that an increase in the percentage weight reduction coincided with increasing extension results in the weft direction, although this was not the case for all fabrics. The results found from samples prepared in the warp direction did not follow a distinguishable trend; the fabrics were more stable in this direction and show less variation.

The results for the Venus fabrics were the most affected by the weight reduction process with an increase of 140% between V0 and V9 fabrics when measured at 100gf/cm. Juno was the second most affected. The Electra fabrics were the least modified by the finishing procedure, but the extension results were the highest for the Electra base fabric and also higher than any of the other fabric stories finished at equivalent weight reductions (5 and 14%). It is possible that the finishing process would not be able to modify these fabrics to such a great degree as the extension properties were already relatively high. Typically, fabrics with greater extension results also have greater problems in manufacture. The change in extension results for the Venus fabrics might indicate why V9 caused such problems in manufacturing. Whilst the Electra fabrics all had high extensions, this could have been due to extensible yarns; the yarns used in the Venus fabrics were not extensible as indicated by the V0 results. Thus, the changes in V9 are a result of weight reduction process and of destabilising the fabric structure, which would explain why the ease of manufacture grade for fabric V9 was worse than E14, even though E14 had large extension results.

However, when the graphs were plotted to represent ease of manufacture and extension it was seen that there was no simple relationship between the two. The extension results predicted more of the ease of manufacturing variable when tested in the weft direction at low loads. However, the results contradicted the normal assumption that an increase in extension increases problems in manufacture. It was noted that the V9 results could have been affecting the results, as with this parameter as well, they did not fall in line with the rest of the fabrics.

The warp direction of the extension tests explained a greater amount of the distortion problem than the weft, with 40% of the distortion results being explained by warp extension at 20 gf/cm. The weft direction results did not correlate with the problem but it is not clear why this is. However, the relationship with warp direction extension was expected, as too much extension is often linked to distortion of long seams, in this case causing the measurements to differ from those of the control.

There was no straightforward relationship between warp extension and appearance, but low results in the weft direction were linked to garments of better appearance. This trend was not repeated with bias extension results; no real difference was detected on the graphs.

Figure 3.2.42 Extension Visual

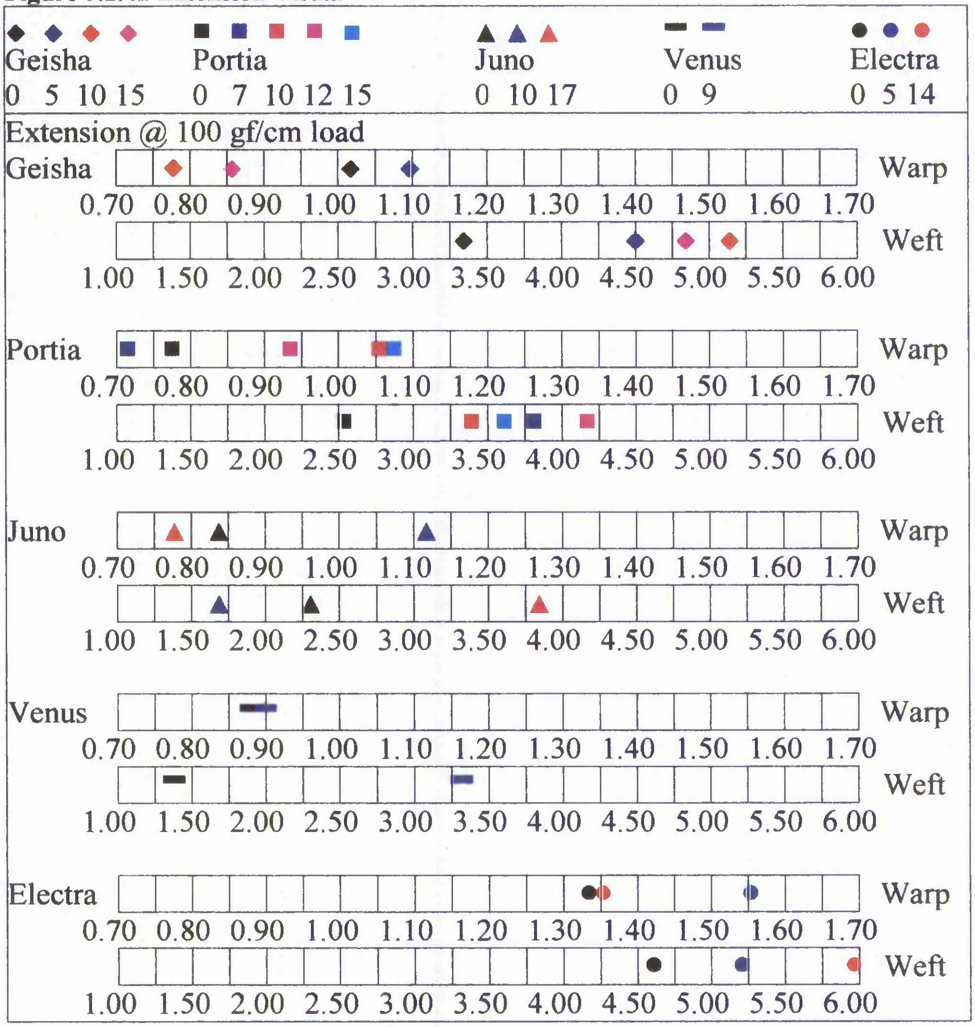
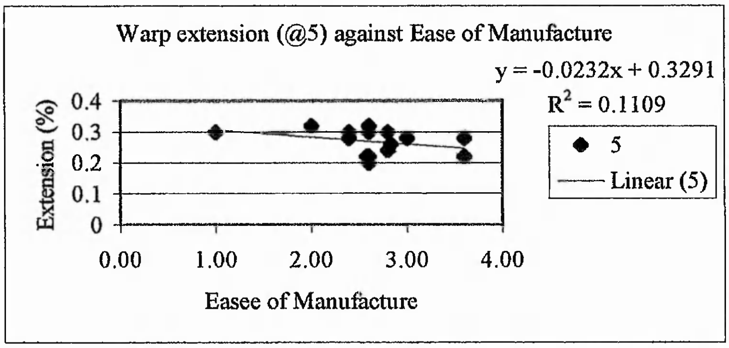
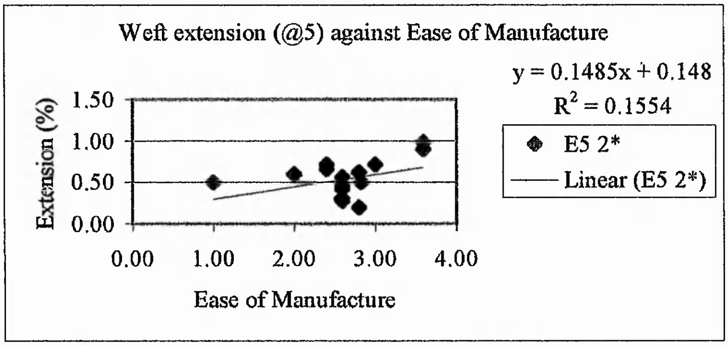


Figure 3.2.43 Extension Parameters against Ease of Manufacture(A-F)

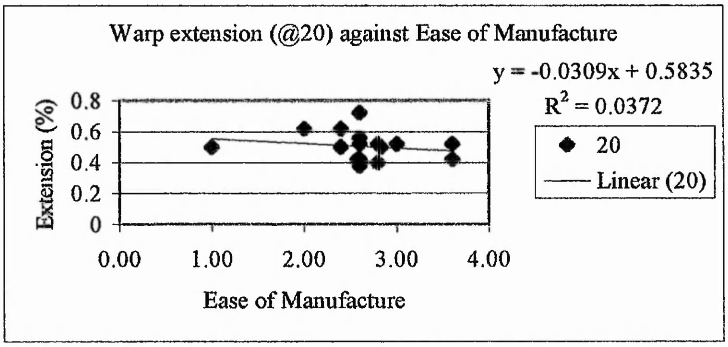
A) Warp extension @ 5 gf/cm against Ease of Manufacture



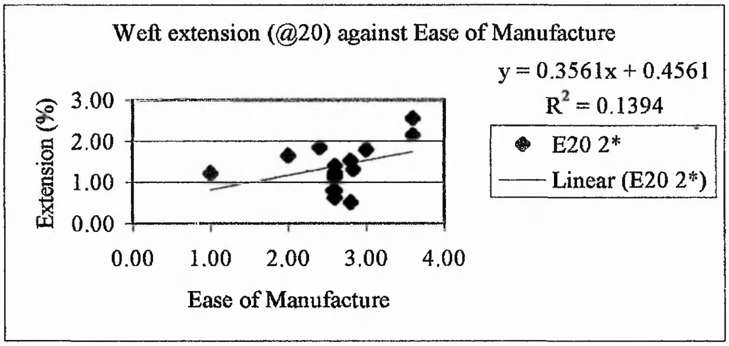
B) Weft extension at 5 gf/cm against Ease of Manufacture



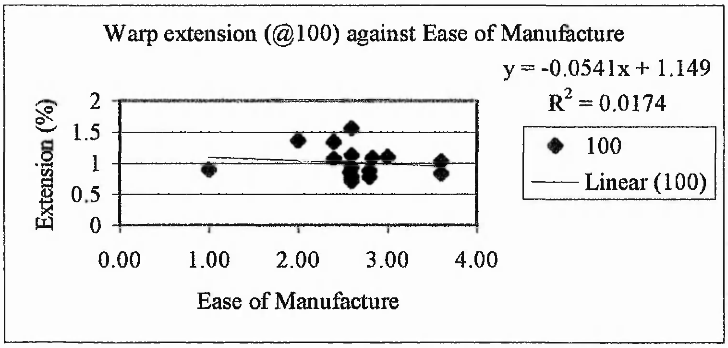
C) Warp extension at 20 gf/cm against Ease of Manufacture



D) Weft extension at 20 gf/cm against Ease of Manufacture



E) Warp extension at 100 gf/cm against Ease of Manufacture



F) Weft extension at 100 gf/cm against Ease of Manufacture

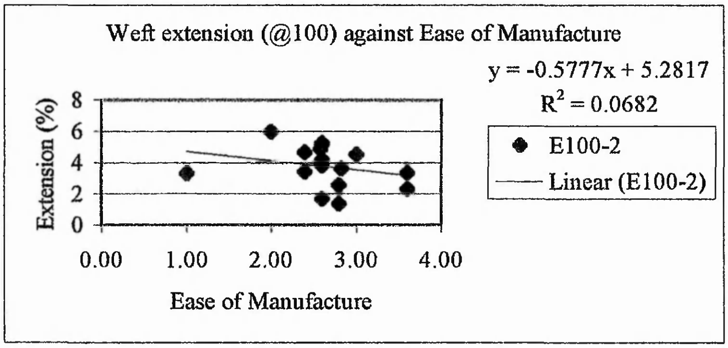
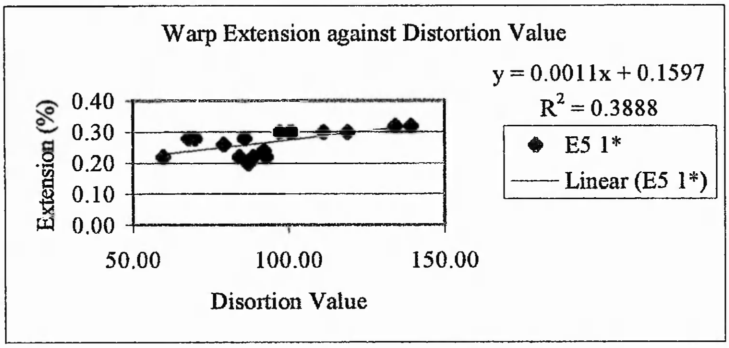
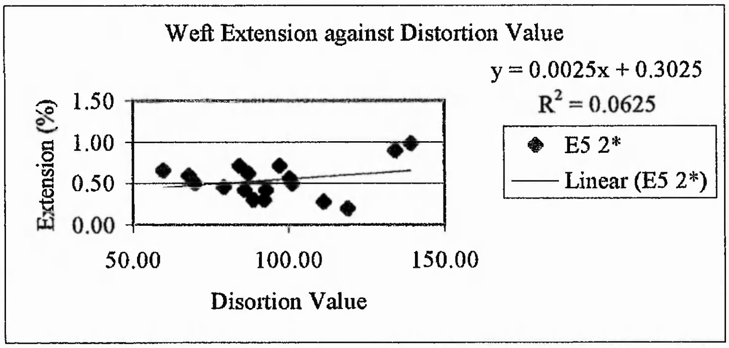


Figure 3.2.44 Extension Parameters against Distortion (A-F)

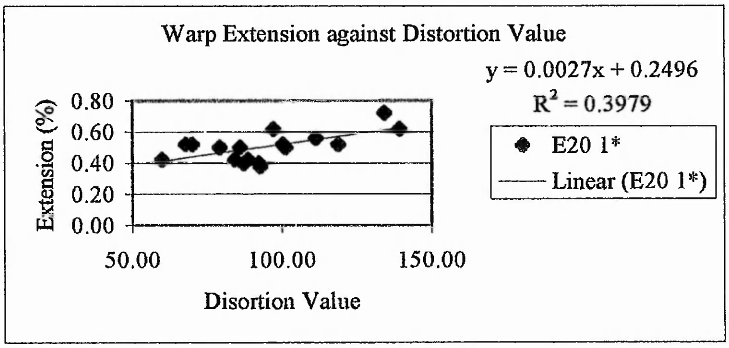
A) Warp extension at 5 gf/cm against distortion



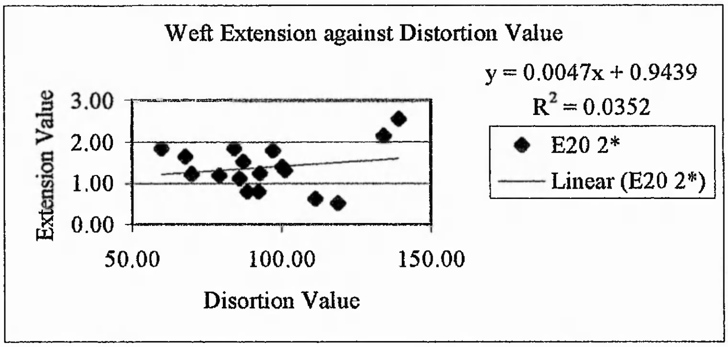
B) Weft extension at 5 gf/cm against distortion



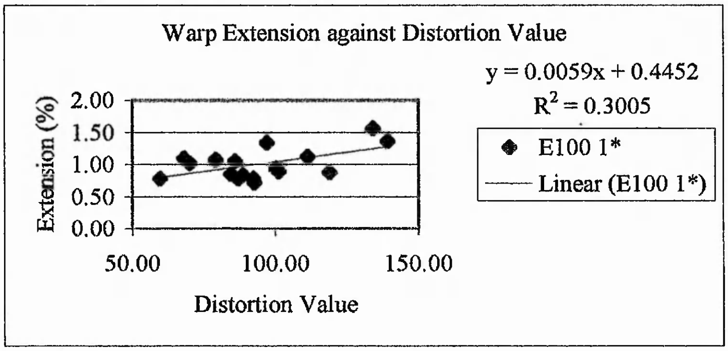
C)Warp extension at 20 gf/cm against distortion



D) Weft extension at 20 gf/cm against distortion



E) Warp extension at 100 gf/cm against distortion



F) Weft extension at 100 gf/cm against distortion

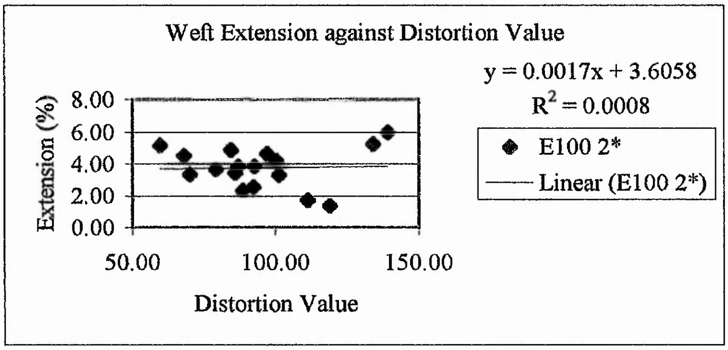
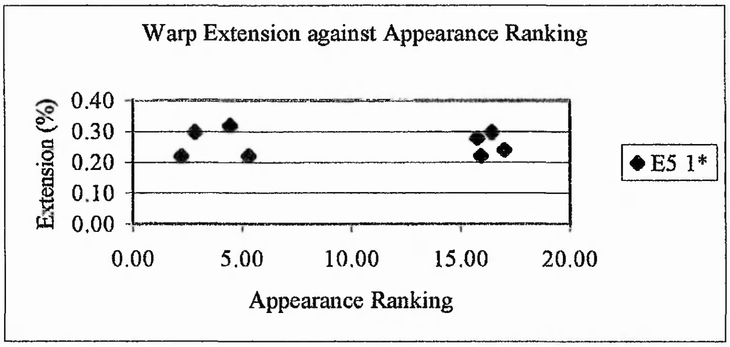
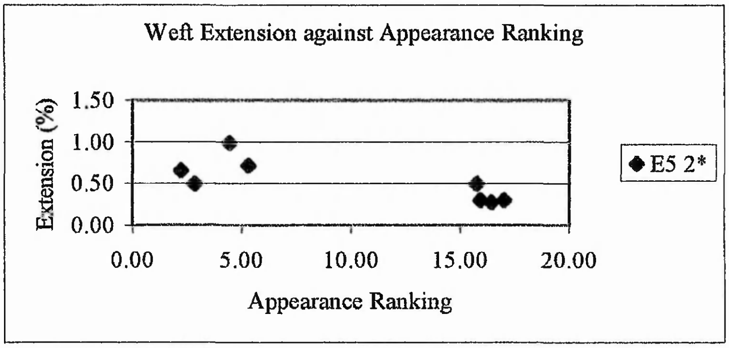


Figure 3.2.45 Extension Parameters against Appearance Ranking (A-F)

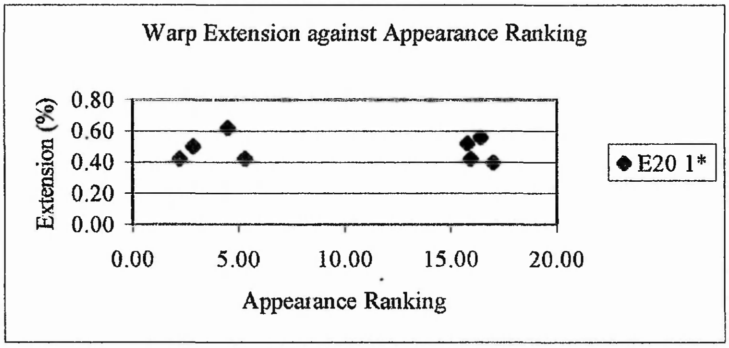
A) Warp extension at 5 gf/cm against Appearance Ranking



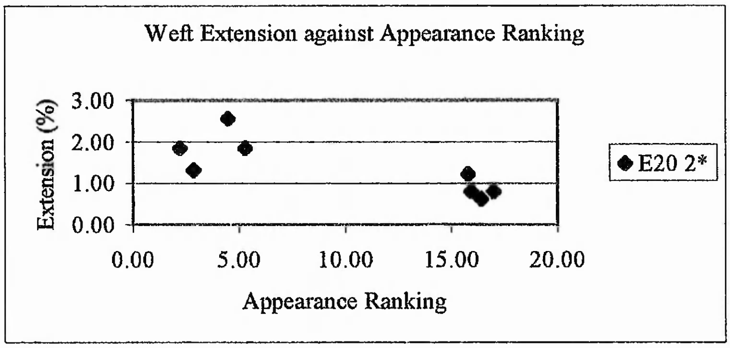
B) Weft extension at 5 gf/cm against Appearance Ranking



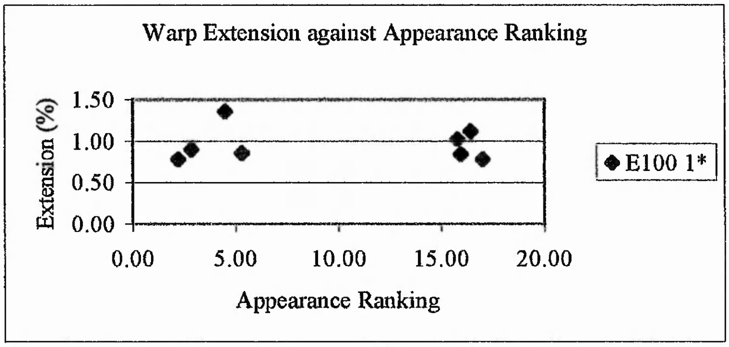
C) Warp extension at 20 gf/cm against Appearance Ranking



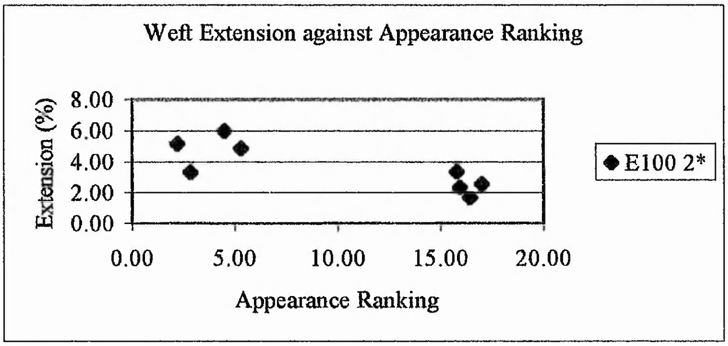
D) Weft extension at 20 gf/cm against Appearance Ranking



E) Warp extension at 100 gf/cm against Appearance Ranking



F) Weft extension at 100 gf/cm against Appearance Ranking



3.2.9.9 Changes in Ease of Manufacture

The graphs and correlation analysis indicated that each of the dependent test variables contributed to the change in the manufacturing grade, but that none of them explain it alone. The results can be summarised in the following manner: the Geisha, Portia and Juno stories were more stable than the Venus and Electra stories because the weight reduction process had no significant effect on any of the test parameters with low initial results. The Portia fabrics, for example, were significantly affected in the parameters of warp and bias bending, bias formability and shear, but initially the Portia base fabric had high results for all these parameters and additionally for weft formability and drape.

The Venus fabrics were severely affected by the finishing process in weft bending, bias formability and weft extension, and had low initial results in the parameters of warp bending, warp and weft formability, shear and weft extension. The weight reduction process did not significantly affect the Electra fabrics, but as the majority of its initial parameters were low, even small changes resulted in reductions in ease of manufacture. The dependent variables that were the most important in the prediction of the problem were right-direction shear rigidity, warp-direction extension, drape coefficient and weight. These were the main focus of the investigation for the multi-variate analysis.

3.2.9.10 Changes in Distortion Value

There was no simple direct relationship between the distortion value and the weight reduction process, although the effects of the weight reduction process did contribute to changes in the distortion value. The results of mechanical properties explain less of the distortion problem than they did of the ease of manufacture problem. However a number of variables were identified from the analysis that were suitable for further analysis using multi-variate techniques. Specifically, these were; warp-direction bending length, left-direction bias extension, drape and warp-direction extension.

3.2.9.11 Changes in Appearance Rankings

As stated previously, it was not possible to perform the same kind of analysis on the results of this experiment as it was for the others, nonetheless, some interesting conclusions were made. The experts preferred the appearance of the more stable fabrics, which was seen by the increase in ranking appearance of fabrics with low weight reduction percentages, high bending rigidity, formability, shear rigidity, drape coefficient and weight results. This should be taken in the context that all of these fabrics have typically low results for these parameters in comparison with the majority of apparel fabrics. Thus the results do not suggest that in general stiffer fabrics are preferred, just in the context of these very soft fabrics and just for the garment silhouette defined here. As the data in the experiment does not allow for in-depth analysis, the experiment will not be included in the multi-variate analysis.

3.2.10 Venus 9 Fabric

From the results of the single variable analysis, it was found that several of the graphs relating mechanical properties to ease of manufacture fabric for V9 did not follow the trends exhibited in the other fabrics; this was most pronounced in the shear and extension results. Hence, it was necessary to explore this anomaly in more depth before undertaking any further analysis.

3.2.10.1 Comparison with KES Tensile and Shear Parameters

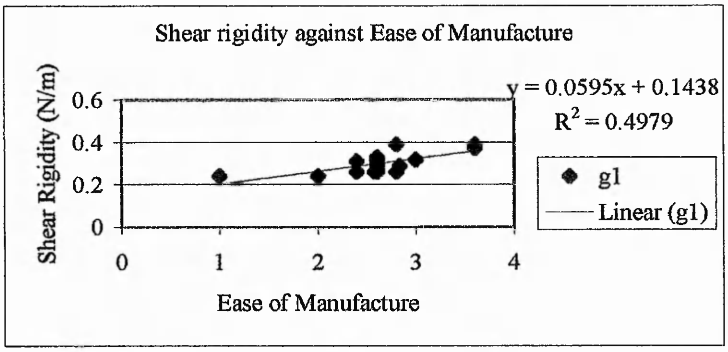
All of the fabrics were tested for extension and shear rigidity using the KES system to establish if the anomaly was due to inadequacies in the FAST modifications. It was hypothesised that the anomalies in V9 results were because this fabric was so easy to distort, and thus the results obtained from the FAST might not be an accurate representation of the actual fabric characteristics. This was particularly noticeable in the bias extension results; at low loads fabric V9 produced high extension results (greater than V0), however, as the loads increased, the difference was reduced and gradually reversed, resulting in fabric V0 producing results indicating it was more extensible than V9 at loads above 4 g/cm in the right bias direction and above 10 g/cm in the left bias direction. It was unlikely that the two extensibilities should vary to such a degree, unless this unusual nature of V9 was what actually caused its difficulty in manufacture. However, it was possible that as the fabric set did not contain any other fabrics of a similar nature to V9, that the discrepancies in the results were because of this difference and so it was also necessary to explore this possibility.

The vertical nature of the sample during the FAST extension tests was thought to be more of a disadvantage for some fabrics; notably those that distorted particularly easily. As the V9 fabric was particularly susceptible to a 'waisting effect' where the load was unevenly distributed across the fabric width, it was logical to assume that this affected the results in some manner. The Kawabata system has a horizontal apparatus, hence this gravity impact on the fabric samples would not be an influencing factor and thus it was planned to establish if the V9 fabric actually possessed more shear rigidity than V0 when its tendency to distortion was more adequately compensated for.

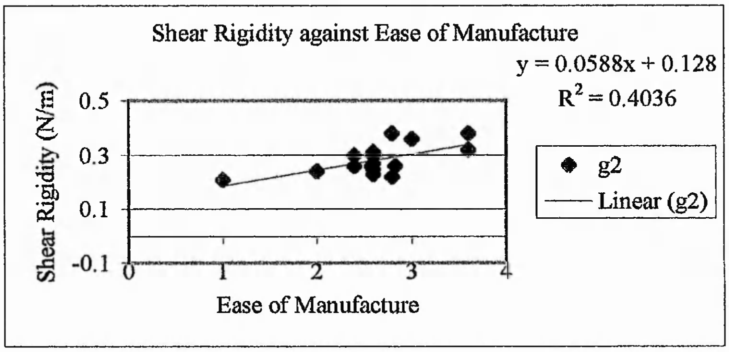
The results were not directly comparable because different techniques and loads were used to obtain them. The KES equipment assesses warp and weft extension at a load of 50 gf/cm (using the high sensitivity set-up), or 500 gf/cm (using the normal set-up) whereas the modified FAST assesses extension in 10 g load intervals up to a maximum load of 100 gf/cm. As the modified FAST method assessed extension at several loads, it was decided to compare the results to the KES both at 50 g/cm and 100 g/cm. The 50 g/cm load was used in the KES-F1 high sensitivity set-up and 100 g/cm was used because it was the normal parameter for comparison with the KES-F1. The KES shear results were assessed in the warp and weft direction; although the closest parameter measured by the FAST was the shear assessed in the bias direction at 5 gf/cm load. The results can be seen in the graphs below along with the associated linear regression equation and R^2 result. A comparison of the change of the mechanical properties associated with increasing the weight reduction percentage can be found in Appendix 4.

Figure 3.2.46 KES Shear Parameters against Ease of Manufacture (A-F)

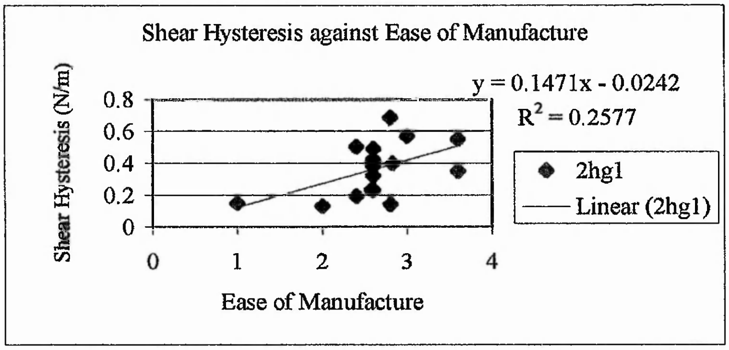
A) Warp shear rigidity against Ease of Manufacture



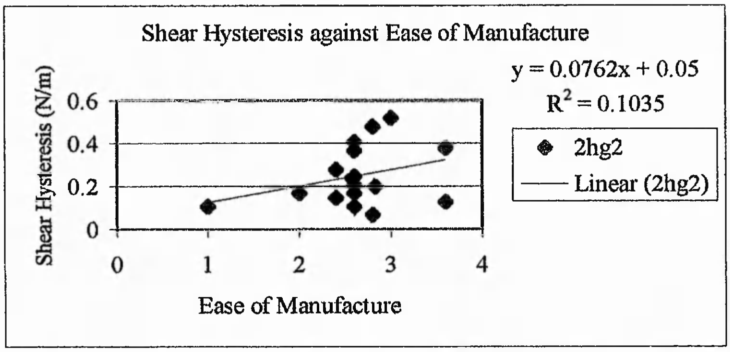
B) Weft shear rigidity against Ease of Manufacture



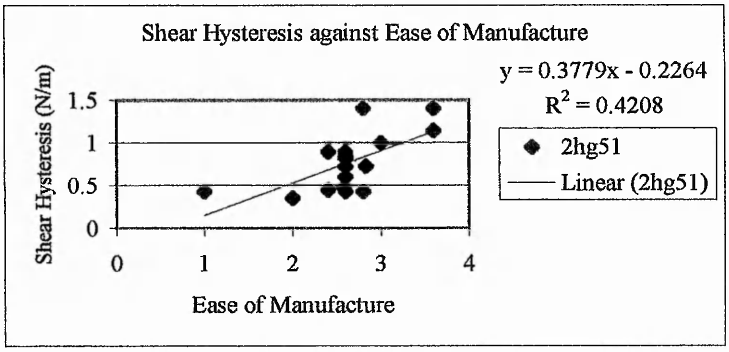
C) Warp shear hysteresis at 0.5° against Ease of Manufacture



D) Weft shear hysteresis at 0.5° against Ease of Manufacture



E) Warp shear hysteresis at 5° against Ease of Manufacture



F) Weft shear hysteresis at 5° against Ease of Manufacture

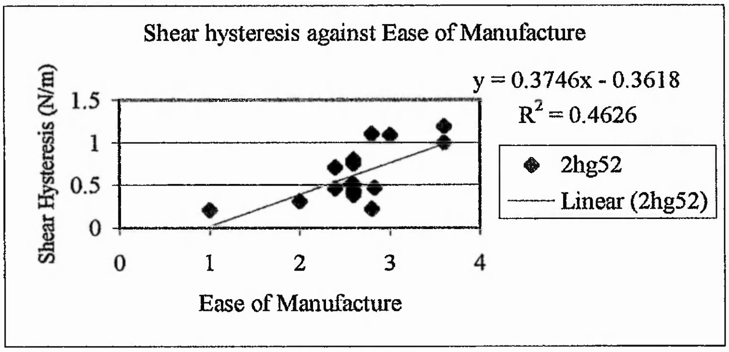
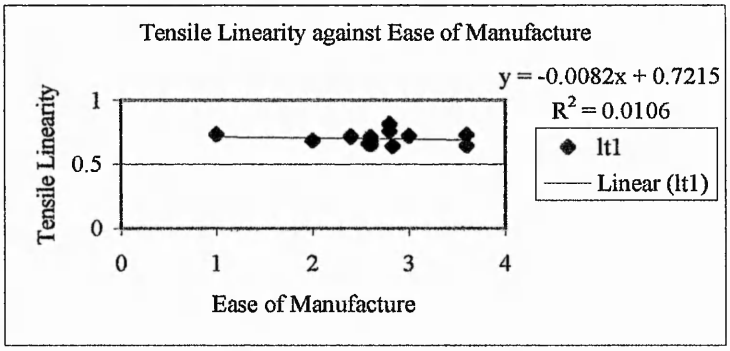
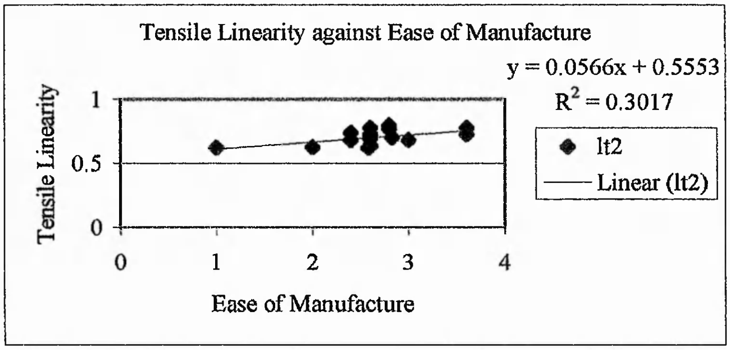


Figure 3.2.47 KES Tensile Parameters against Ease of Manufacture (A-H)

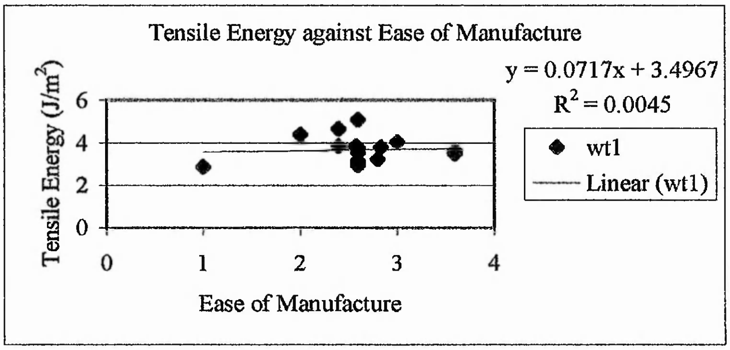
A) Warp tensile linearity against Ease of Manufacture



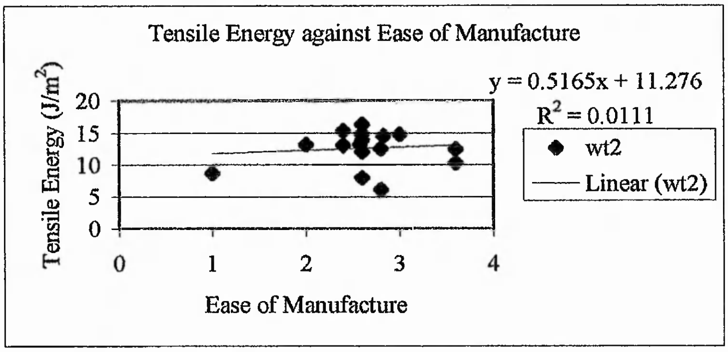
B) Weft tensile linearity against Ease of Manufacture



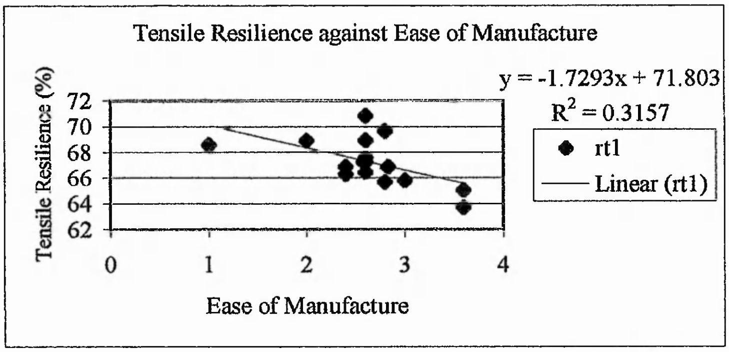
C) Warp tensile energy against Ease of Manufacture



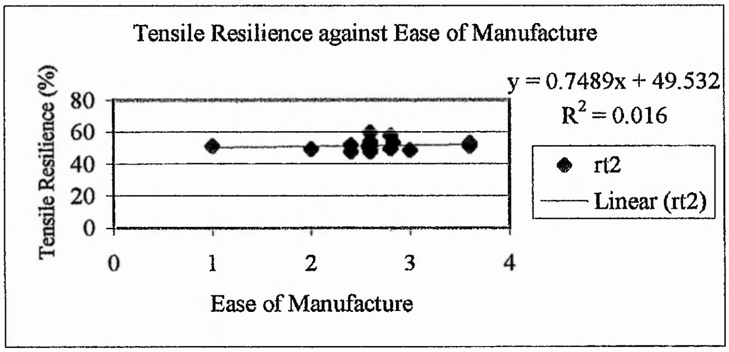
D) Weft tensile energy against Ease of Manufacture



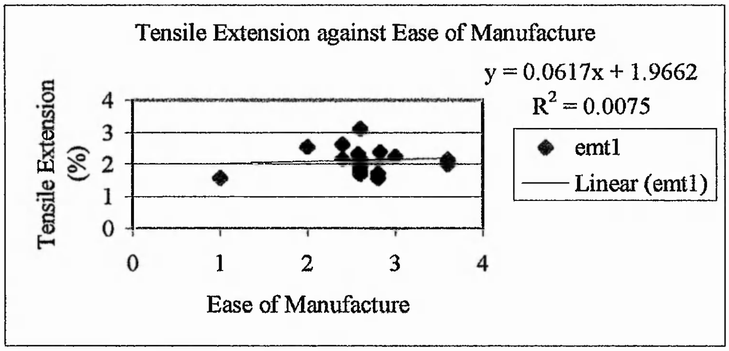
E) Warp tensile resilience against Ease of Manufacture



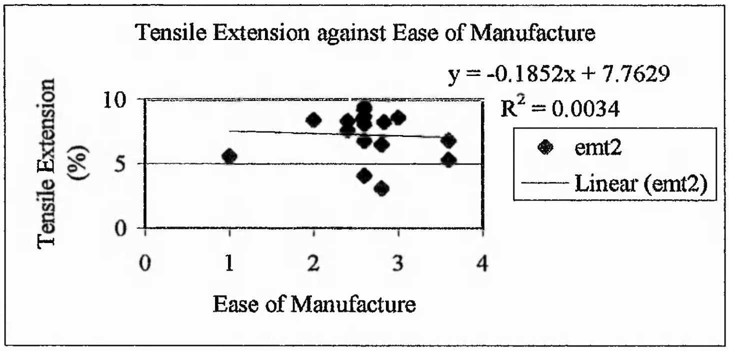
F) Weft tensile resilience against Ease of Manufacture



G) Warp tensile extension against Ease of Manufacture



H) Weft tensile extension against Ease of Manufacture



The graphical results for the KES parameters also indicated that the Venus 9 fabric produced results that were in some cases inconsistent with the other fabrics' results. However, the differences were much less than those given by the results from the FAST apparatus. This suggested that although the FAST equipment was in some way not fully representing the true nature of fabric V9, the fabric itself was distinct from the others.

3.2.10.2 Comparison of R^2 results with and without fabric V9 for Shear and Tensile Parameters

It was decided to establish the effect of removing the V9 fabric from the sample set, in order to test the hypothesis that a better prediction of the problem (more in line with that produced by the KES) might result from its withdrawal. It was extrapolated that if the equipment could not measure a fabric as easy to distort as V9, the addition of its results would alter the whole regression analysis. It was possible that more extreme modifications to the FAST might be necessary for the equipment to be suitable to test such a fabric, however the test method might still be valid for the majority of fabrics.

Two new parameters were included in this analysis: the ratio between the extension results from the two primary directions (αT). This has been described in (1.1.4.1); research suggests that large differences between the extension results found in the two primary yarn directions could cause difficulties in manufacturing when the areas of the garment require these directions to be sewn together [115]. This ratio was also calculated for the FAST extension results (αE100).

The other new parameter was the equivalent of αT for the shear parameters, using the above notation it has been called αG5 (FAST) and αg (KES-FB). This was added as for these garments both bias directions had to be sewn together on the centre back seam. The KES parameters that produced the highest R^2 results were g-1, 2hg5-1, 2hg5-2 and RT –1.

Table 3.2.24 Comparison of the effect of the removal of V9 between KES and FAST parameters

Manufacturing	KAWABATA		FAST	
SHEAR				
Complete set	g 1	50	G5 3	39
Without V9		*53*		*61*
Complete set	g 2	40	G5 4	21
Without V9		*35*		*65*
Complete set	αg	0	αG5	24
Without V9		*2*		*3*
Complete set	2hg 1	26		
Without V9		*17*		
Complete set	2hg 2	10		
Without V9		*4*		
Complete set	2hg5 1	42		
Without V9		*48*		
Complete set	2hg5 2	46		
Without V9		*46*		
EXTENSION				
Complete set	EMT 1	1	E100 1	2
Without V9		*7*		*10*
Complete set	EMT 2	0	E100 2	7
Without V9		*11*		*23*
Complete set	αT	2	αE100	3
Without V9		*3*		*8*
Complete set	LT 1	1	E50 1	2
Without V9		*0*		7
Complete set	LT 2	30	E50 2	10
Without V9		*20*		26
Complete set	WT 1	0	αE50	6
Without V9		*8*		14
Complete set	WT 2	1		
Without V9		*6*		
Complete set	RT 1	32		
Without V9		*39*		
Complete set	RT 2	2		
Without V9		*2*		

The results obtained using the FAST apparatus were more affected by the V9 fabric than those obtained using KES, and produced a better predictor of the problem without the V9. This suggests that the apparatus is less suitable for testing the full range of fabrics. However, it was interesting to note that without the V9 fabric, some very high regression coefficients were obtained. Indeed, they predicted the problem to a greater degree than the equivalent results from the KES parameters when V9 was omitted.

3.2.10.3 Comparison of R^2 results with and without fabric V9 for the other parameters

Although the previous analyses suggested that the extension and shear results were the ones most significantly effected by fabric V9, it was also interesting to assess the effect that the V9 fabric had on the other test parameters. The results can be seen below and show that the majority of the parameters were affected by the results from this fabric. For example, the parameters of bending rigidity and weight would predict more of the problem without fabric V9, whereas drape coefficient would be less able to predict the problem without the fabric.

The fabric manufacturing parameters were also included in this analysis, in order to establish if the basic properties of the fabric could aid in the prediction of the manufacturing problem, or could pinpoint why the Venus fabric behaved so differently. Not all of the fabric parameters could be used, as those such as warp denier and number of filaments were the same for all fabrics.

Table 3.2.25 The effect of the removal of V9 from the results of the other FAST parameters (A-G)

A) The effect of the removal of V9 on the bending parameters results

		Warp	Weft	Right Bias	Left Bias	Bias
Bending Rigidity	Complete set	30	10	19	18	19
	Without V9	*47*	*7*	*31*	*29*	*30*
Bending Length	Complete set	23	5	10	8	9
	Without V9	*31*	*2*	*18*	*14*	*16*

B) The effect of the removal of V9 on formability parameter results

Formability	Complete set	24	2	21	26	25
	Without V9	*20*	*16*	*15*	*15*	*16*

C) The effect of the removal of V9 on FAST extension parameters results

Load (gf/cm)		Warp	Weft
1	Complete set	0	7
	Without V9	*0*	*15*
2	Complete set	0	11
	Without V9	*2*	*23*
3	Complete set	13	14
	Without V9	*13*	*29*
4	Complete set	6	9
	Without V9	*10*	*25*
5	Complete set	11	9
	Without V9	*8*	*24*
10	Complete set	5	11
	Without V9	*7*	*25*
20	Complete set	4	10
	Without V9	*8*	*25*
30	Complete set	3	10
	Without V9	*8*	*26*
40	Complete set	2	10
	Without V9	*9*	*26*
50	Complete set	2	10
	Without V9	*7*	*26*
60	Complete set	2	9
	Without V9	*11*	*25*
70	Complete set	1	9
	Without V9	*8*	*25*
80	Complete set	2	8
	Without V9	*9*	*24*
90	Complete set	1	7
	Without V9	*7*	*24*
100	Complete set	2	7
	Without V9	*10*	*23*

D) The effect of the removal of V9 on FAST Bias Extension & Shear parameters results

Load (gf/cm)		Right Bias	Left Bias	Bias
Bias Extension				
1	Complete set	39	22	31
	Without V9	*45*	*43*	*46*
2	Complete set	41	21	32
	Without V9	*51*	*52*	*54*
3	Complete set	38	21	31
	Without V9	*54*	*56*	*58*
4	Complete set	37	19	29
	Without V9	*62*	*58*	*60*
5	Complete set	34	17	26
	Without V9	*56*	*58*	*60*
10	Complete set	29	13	22
	Without V9	*54*	*59*	*60*
15	Complete set	25	10	18
	Without V9	*53*	*58*	*59*
20	Complete set	22	8	15
	Without V9	*52*	*56*	*57*
25	Complete set	20	6	13
	Without V9	*51*	*55*	*56*
30	Complete set	19	5	12
	Without V9	*50*	*53*	*55*
35	Complete set	17	4	10
	Without V9	*49*	*51*	*53*
40	Complete set	15	3	9
	Without V9	*47*	*50*	*52*
45	Complete set	14	3	8
	Without V9	*46*	*48*	*51*
50	Complete set	13	2	7
	Without V9	*45*	*47*	*50*
Shear Rigidity				
1	Complete set	41	27	36
	Without V9	*50*	*43*	*50*
2	Complete set	44	28	28
	Without V9	*58*	*58*	*60*
3	Complete set	42	27	37
	Without V9	*61*	*62*	*64*
4	Complete set	41	24	35
	Without V9	*61*	*64*	*64*
5	Complete set	39	21	32
	Without V9	*61*	*65*	*65*

E) The effect of the removal of V9 on drape parameters results

		Face Up	Face Down
Drape	Complete set	35	33
	Without V9	*26*	*24*

F) The effect of the removal of V9 on weight parameters results

		Weight
Weight	Complete set	38
	Without V9	*62*

G) The effect of the removal of V9 on thickness parameters results

		T2	T100	ST
Thickness	Complete set	3	5	0
	Without V9	*0*	*13*	*16*

H) The effect of the removal of V9 on fabric parameters results

		Warp Ends*	Picks	Twist
Fabric	Complete set	29	9	11
Parameters	**Without V9**	*16*	*13*	*1*

* This parameter was used in the same format as the company (warp ends per fabric width)

A very interesting effect was noted during the analysis of the bias extension results without the inclusion of fabric V9. The analysis with fabric V9 had shown that the lower loads were better predictors of the problem; however, without fabric V9 all of the loads had similar R^2 values. This suggested that the results for V9 were more accurate at low loads and indicated that the discrepancies in the results from the FAST apparatus were most pronounced when measuring higher loads. It was possible that this was because the loads were tested as a sequence and therefore by the time the highest loads were measured, the sample had been vertically clamped for some time (approximately 1 minute).

This analysis indicated that the results obtained for this fabric did alter the predictive ability of the FAST apparatus. It was interesting to note that this single fabric had such a huge impact on the regression analysis. It suggested that the FAST was unsuitable for testing the fabrics that were at the extreme end of distortion; more specifically the bias extension (and therefore the shear results), but also the bending and weight parameters. The KES results also differed as a result of omitting fabric V9, but the differences would suggest that this was not due to inaccuracies in the testing procedure but rather to the differences one would encounter due to the removal of any fabric from a group. Hence, the removal of V9 from the results of the KES parameters only slightly altered their predictive ability; however its removal from the results of the FAST parameters produced a different selection of important parameters.

Notwithstanding this, the FAST results were not viewed as discouraging, instead they were assessed in the context of the fact that the KES equipment is significantly more expensive than the FAST; thus one expects some limitations to the range of fabrics that could be tested with FAST. The apparatus is suitable for testing the majority of these fabrics and able (even if in a less accurate manner than the KES) to predict the manufacturing problem in these fabrics, all are important achievements. Interestingly, the fabric parameters, especially warp ends, produced results that indicated that these simple properties could also be important in the analysis of manufacturing problems.

The fact that the distortion parameter was not affected by the V9 fabric also indicated that caution should be used in omitting the fabric from the overall results. The fabric did possess different characteristics to the others in the fabric set, yet it was also likely that the method of grading the manufacturing problem accentuated these differences. A grading of 1-5 (related to the hardest-to-easiest to manufacture) does have limitations, but many safeguards were used, and it was possible that although the fabric was worse than the others (the lowest of which was graded 2) it might not have warranted a grade 1. Had the fabric been graded a 1.5 or 1.75 then the differences in the mechanical parameters might not have distorted the graphs and predictive equations to the same degree. Also if there had been other fabrics that had been similarly graded it would have been easier to establish if the fabric was indeed an outlier. These potential drawbacks were realised prior to the experiment, but due to the subjective nature of the test, it was not practical to use a larger or more detailed grading system. As mentioned previously, the samples had been those commercially available, and thus the control of the fabric selection was less than ideal. If all the fabric stories had been available with the same amount of weight reduction percentages (0, 5, 10 and 15%, for example) there would have been a V5 fabric. This would have significantly increased the knowledge of V9 and thus probably resolved a great deal of the anomalies produced in this experiment.

However, as it was not possible to test any of these theories about fabric V9, the multi-variate analysis was commenced.

3.2.11 Multi-Variate Analysis of the Manufacturing Problem

The results obtained from the individual test parameters that had proved to have a strong linear relationship with the problem were used. These included those obtained from both the FAST as well from the Kawabata apparatus. This was in order to assess if there was a difference between the two methods in terms of the predictive ability of the extension and shear parameters. Two sets of data were used for the analysis, those including fabric V9 and those without.

3.2.11.1 Independence of Parameters

Prior to the analysis, the number of tests included was refined further as it was necessary to ensure that the test parameters were independent of each other. For example, bending length and weight per square metre parameters are used to establish the bending rigidity parameter, thus if bending rigidity results were used the weight results should not be, as they are already factored into the analysis and the results would not be valid. Also, as the range of loads for the extension test was devised to establish if a particular load would predict more of the problem than the others, it would not be valid to use more than one load for each direction. Ensuring the validity of the regression model is vital, and previous results published have not mentioned whether independence of parameters have been established or have simply assumed it [160]. Where the latter is the case, assumptions based on the analysis may be misleading. For example, if the analysis suggests that some parameters should be altered while keeping others stable; in order to improve the fabric, it is unlikely to be achievable if these parameters are dependent on each other.

A correlation matrix was calculated from those parameters that performed best in terms of the R^2 values to establish their dependence on each other. As well as ensuring the validity of the multiple regression, this procedure also reduced the number of parameters necessary to use in the model. These tables below illustrate that the chosen parameters were, in the main, not independent of each other. For example, for the data set including V9, both C1 and G2 3 could be used with warp ends, but C1 and G2 3 could not be used together.

Table 3.2.26 Independence of Variables (manufacturing problem) (A-B)

A) With Venus 9

	C 1	*G2 3*	*DC FU*	*Weight*	*Warp ends*	*G1*	*2hg52*	*rt1*
C 1	1.00							
G2 3	0.78	1.00						
DC FU	0.76	0.82	1.00					
Weight	0.71	0.86	0.66	1.00				
Warp ends	**0.39**	**0.52**	0.67	**0.18**	1.00			
gl	0.83	0.92	0.90	0.74	0.66	1.00		
2hg52	0.80	0.78	0.75	**0.64**	**0.64**	0.91	1.00	
rt1	**-0.62**	**-0.58**	**-0.50**	**-0.52**	**-0.36**	-0.73	-0.81	1.00

An allowance of 0.65 was made for the independence, this allowed the highly correlated factors to be removed; further reductions would, if necessary, be made during the multiple regression analysis.

B) Without Venus 9

	C 1	*G5 4*	*DC FU*	*Weight*	*E3 2*	*G1*	*2hg52*	*rt1*
C 1	1							
G5 4	0.67	1.00						
DC FU	0.78	0.73	1.00					
Weight	0.71	0.84	0.67	1.00				
E3 2	**-0.44**	-0.75	-0.80	-0.67	1.00			
gl	0.84	0.79	0.89	0.75	**-0.60**	1.00		
2hg5 2	0.80	0.66	0.71	**0.64**	**-0.36**	0.90	1.00	
rt1	**-0.61**	**-0.40**	**-0.47**	**-0.52**	**0.15**	-0.72	-0.81	1

An allowance of 0.65 was made for the independence, this allowed the highly correlated factors to be removed; further reductions would, if necessary, be made during the multiple regression analysis.

3.2.11.2 Multi-Variate Parameters

Various combinations of the above parameters were used in various regression models to find an optimum selection. The parameters of R2, adjusted R2, Anova and t-test were used to assess the combination, as described in the experimental methods chapter. An example of the results from the analysis and trials with the equation produced from the resultant coefficients can be seen below.

Table 3.2.27 An Example of the multivariate summary output using Shear Hysteresis at 5° and Weight (all fabrics)

Regression Statistics	
Multiple R	0.721
R Square	**0.520**
Adjusted R Square	**0.451**
Standard Error	0.426
Observations	17.000

ANOVA

	df	*SS*	*MS*	*F*	*Significance* F
Regression	2.000	2.747	1.373	7.579	**0.006**
Residual	14.000	2.537	0.181		
Total	16.000	5.283			

	Coefficients	*Standard Error*	*T Stat*	P-*value*	*Lower 95%*	*Upper 95%*
Intercept	**-0.423**	1.780	-0.238	0.816	-4.241	3.395
2hg5 2	**0.876**	0.436	2.007	**0.064**	-0.060	1.811
Weight	**0.025**	0.020	1.292	**0.217**	-0.017	0.068

Resultant Equation: Manufacturing Grade = -0.42 + (0.88 x 2hg5 2) + (0.03 x W)

As the grades given to the manufacturing problem increased when there were fewer problems in manufacture, and as both of the coefficients are positive, it was seen that large values of weft shear hysteresis (recovery from shear) and weight can be linked to the fabrics that manufacture with fewer problems. For example, the maximum values of weft hysteresis and weight obtained from these fabrics (1.19 N/m and 112 g/m^2 respectively) produced a manufacturing result of 4.0; the minimum values of weft hysteresis and weight (0.21 N/m and 88 g/m^2 respectively) produced a manufacturing grade of 2.40 when used in the above formula.

3.2.11.3 Combination of parameters

A) Using all fabrics

Table 3.2.28 Results from combination of parameters (all fabrics)

	R Square	Adjusted R Square	Anova	t-Test
2hg5 2 & Weight	0.52	0.45	0.01	0.06
				0.22
2hg5 2 & Warp Ends	0.48	0.41	0.01	0.04
				0.51
Weight & Warp Ends	**0.57**	**0.51**	**0.00**	**0.01**
				0.03
C1 & Warp Ends	0.37	0.28	0.04	0.19
				0.09
G2 3 & Warp Ends	0.49	0.41	0.01	0.04
				0.25
RT1 & G2 3	0.48	0.41	0.01	0.27
				0.05
RT 1 & DC FU	0.45	0.37	0.02	0.14
				0.09
RT1 & Weight	0.46	0.38	0.01	0.18
				0.07
RT1 & Warp Ends	0.45	0.37	0.02	0.07
				0.09
RT1 & C1	0.34	0.25	0.05	0.13
2hg5 2, Weight & Warp Ends	0.58	0.48	0.01	0.59
				0.10
				0.20
G1	0.50	0.46	0.00	0.00
Parameters in bold indicate the highest prediction of the problem.				

The analysis indicated that the best model for predicting ease of manufacture when the results of all the fabrics including V9 were used was the regression using weight and warp ends, as this had the largest R^2, adjusted R^2 and the lowest F significance and P-values. The regression explained 56% of the problem and the resultant equation is given below.

$$\text{Manufacturing Grade} = -5.59 + (0.04 \text{ x weight}) + (2.69\text{x}10^{-4} \text{ x warp ends}) \quad \ldots [18]$$

This indicates that these parameters were positively correlated with fabrics that would be easy to manufacture. It would seem from this formula that the addition of the warp ends parameter did not significantly affect the prediction (as it had such a small coefficient), but that the R^2 of the weight parameter alone only produced a value of 0.38. Thus, it was clear that although its coefficient was small, its effect was significant. If the minimum values of weight and warp ends achieved from these fabrics were inputted to this formula (88 g/m^2 and 13000 per 150 cm width respectively) a manufacturing grade of 1.4 was produced; the maximum values from these parameters (112 g/m^2 and 15000 per 150 cm width) achieved a manufacturing grade of only 3.0 when used in the formula. Thus, it was noted that this formula was predisposed to produce lower manufacturing grades; according to this formula, a fabric would need to have a weight of 130 g/m^2 and warp ends of 18000 to produce a high manufacturing grade of 4.5. The correlation between the predicted grades using the formula and the actual manufacturing grades is 0.75, which can be considered a very useful tool to the fabric mill as they would not need to invest in an objective measurement tool but would have a straightforward way in which to assess their fabrics. This is in agreement with research carried out by Nakata who stated that both hand values and mechanical parameters can be predicted from process variables, he included weight in his studies [146].

This regression does suggest that the fabric manufacturing company could possibly predict a lot of its potential problems by assessing two very straightforward parameters that they have immediate access to without specialist equipment, which is an interesting and cost effective possibility worth pursuing.

These parameters were very important in the design of the base fabric and the results of the analysis suggests that manufacturing problems could be linked to the stability of the original fabric before the weight reduction process takes place. The two fabric stories that presented the majority of the problems were Electra and Venus and these had fewer warp ends than the other fabric stories. This manufacturing detail produced an initial fabric that was easier to distort than the Portia, Geisha and Juno stories as there were fewer interlacings between the yarns. This, combined with the low initial weights of the Electra and Venus fabrics, provided a base fabric that could not withstand a high percentage of weight reduction. It was noted that the initial Portia fabric had a similar weight to that of the initial Venus but as it had a larger number of warp ends, it was not affected in the same manner as the Venus fabric. This illustrates that both parameters are required to predict the problems. This equation was a slight improvement over the individual highest parameter of G1 (which explained 50% of the problem).

The equation linking all the fabrics to G1 (KES shear rigidity parameter) was:

$$\text{Manufacturing Grade} = 0.11 + (8.36 \times G1) \qquad \ldots[19]$$

The shear parameters were predicted to be of great importance to the problem during the initial preparation of the experiment and modification to the FAST equipment. Previous research into mechanical parameters [1, 61, 102, 115, 122] together with an analysis of the manufacturing problem, suggested the link with shear rigidity. Thus the results for these fabrics were similar to findings for other types of fabrics and low shear rigidity (resistance to shear deformation) can be linked to manufacturing problems. This formula, although it was also predisposed to produce the lower manufacturing grades, produced a range slightly more centred than the above. The minimum shear rigidity obtained from these fabrics (0.24 N/m) produced a manufacturing grade of 2.1, whereas the maximum shear rigidity only produced a manufacturing grade of 3.4. A result for shear rigidity of 0.53 N/m would be required to produce a manufacturing grade of 4.5. The correlation exercise between the predicted and actual grades revealed a factor of 0.71, which was less than the above but indicated that the formula was also a useful measure of likely behaviour during manufacture.

ii) Without Fabric V9

Table 3.2.29 Results from combination of parameters (without V9)

	R Square	Adjusted R Square	Anova	t-Test
G5 4 & RT1	**0.75**	**0.72**	**0.00**	**0.00**
				0.03
Weight & Warp Ends	0.70	0.65	0.00	0.08
				0.00
RT1 & C1	0.44	0.35	0.02	0.10
				0.32
RT1 & DC FU	0.45	0.37	0.02	0.05
				0.25
RT1 & Weight	0.68	0.63	0.00	0.12
				0.00
E3 2 & G1	0.54	0.48	0.01	0.50
				0.02
E3 2 & 2HG5 2	0.56	0.49	0.00	0.10
				0.01
E3 2 & RT 1	0.60	0.53	0.00	0.02
				0.00
E3 2 & C1	0.41	0.32	0.00	0.14
				0.13
2HG5 2 & Weight	0.62	0.56	0.00	0.89
				0.01
Parameters in bold indicate the highest prediction of the problem.				

It is noteworthy that the results for the fabrics without V9 produced a much better prediction of the problem, the regression explaining 75% of the problem using G5 4 and RT 1. Interestingly the two parameters used were from the two different fabric objective measurement tools. The shear results from the FAST predicted more of the problem than those of the KES (when fabric V9 was not included in the selection), but the KES extension results predicted more of the problem than the FAST extension results both with and without V9. As the parameters are not independent of each other, the analysis could not be restricted to just one of the fabric objective measurement systems, and therefore the combination of FAST and KES produced not only the best predictor of the problem but the only valid one.

Thus a shear parameter was also important in the analysis without V9, but in this case, an extension parameter was also included. RT is a measure of tensile resilience and has been related by previous researcher to fabrics with good tailorability, with results of between 65-76% required as an optimum for suiting fabrics [115]. However, one would expect different results to be optimum for these type of fabrics in comparison to suiting fabrics, however, there has not been previous research regarding ease of manufacture using these type of fabrics. Tensile resilience has been negatively correlated with shear rigidity [103], thus these two parameters are both indicating that stiffer fabrics are easier to manufacture, and thus producing a similar result to equation 32 above, for fabrics including V9.

Manufacturing Grade = 6.86 + (0.07 x G5 4) - (0.08 x RT1) ...[20]

This formula produced a range that was the most evenly distributed over the grades of 1 to 5, the lowest grade (using the data from these fabrics) was 2.2 and the highest was 3.7. This low grade is produced when the minimum value for shear rigidity is used with the maximum value of tensile resilience (14.2 N/m and 70.9 % respectively); the highest grade resulted from inputting the maximum values for shear rigidity and the minimum value for tensile resilience (27.9 N/m and 63.7 % respectively). However, there are still limitations to this formula; for example, to produce the extreme ends of the scale, the formula requires results that would either not be achievable or would completely alter the nature of the fabrics. For example, to produce a manufacturing grade of 0.5, a shear rigidity result of 8 N/m and a tensile resilience of 86 % would be required. To produce a manufacturing grade of 4.5 a result for shear rigidity of 33 N/m and for tensile linearity of 59 % was necessary. Using the equation to establish the predicted manufacture grades and then correlating those with the actual grades produced a factor of 0.87, thus confirming that the removal of V9 increased the value of the equation. The weight and warp ends combination was also successful without fabric V9.

Manufacturing Grade = -3.34 + (0.04 x Weight) + ($1.34\text{x}10^{-4}$ x Warp Ends)...[21]

When the maximum values produced from these fabrics for weight and warp ends are inputted in this formula, a manufacturing grade of 3.2 is produced, whereas the minimum results of these parameters produced a grade of 1.9. Thus, this formula gives a very narrow range of possibilities with the results from the current fabrics. To achieve the extreme of 0.5, a weight of 65 g/m^2 and 9000 warp ends per 150 cm width would be required. It would be necessary to have results for weight of 135 g/m^2 and 18000 per 150 cm width to achieve the opposite extreme of 4.5. Interestingly the formula relating weight and warp ends, including V9, required similar results of a weight of 130 g/m^2 and warp ends of 18000 per 150 cm width, to achieve the 4.5 grading. The correlation factor found between the predicted and actual grades was 0.84, which although less than the formula involving G5 4 and RT1 was 0.09 better than the warp ends and weight formula when all the fabrics were used, thereby confirming the anomaly that this fabric's results produce

Further investigation is required to assess whether the inclusion of more fabrics would diminish the apparently unrelated nature of the V9 in terms of the mechanical properties. It is the opinion of the author that further modifications to the FAST apparatus would be required to accurately test fabrics of this nature, and that these modifications would require a complete reworking of the structure of the apparatus (for example: horizontal rather than vertical sample mounting, automatic rather than manual operation), which is beyond the scope of this thesis.

Thus for a wide variety of fabrics, the KES system was superior to the modified FAST, but as was seen in this case the simple measurements (such as weight and warp ends) can often compete with the complex. The individual results for the shear parameter generated by the two different instruments differed by only 6%. As this was the first attempt at measuring this type of fabric with the FAST, the overall results were very promising. The ideal manner in which to continue the research would be to enlarge the study with more fabrics to test and refine the models generated here, since it has been proven there is a link between manufacturing problems and mechanical properties for these fabrics.

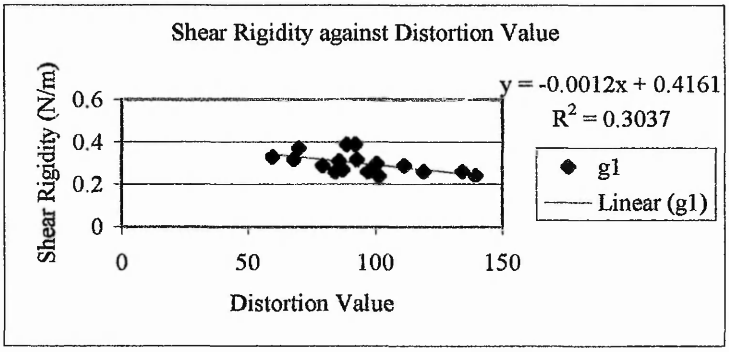
It was also not unrealistic to expect that there would be a narrower range of fabrics that could be assessed using the FAST than the KES, simply because of the manner of its modifications. However, the results without V9 were a very good prediction of the problem. An option for future research could be to try to reproduce the parameter of RT on the FAST apparatus.

3.2.12 Distortion Problem

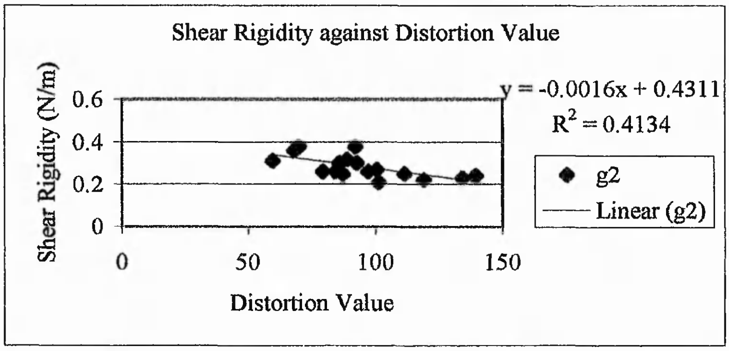
There was no indication in the graphs for the distortion parameter that the results of V9 were inconsistent with those found by the rest of the fabrics. The difference in the R^2 values was calculated, but no significant benefit was derived from removing the fabric. Thus, the analysis was performed on the complete fabric data set only, including the Kawabata parameters, for which the graphs are given below.

Figure 3.2.48 KES Shear Parameters against Distortion Value (A-F)

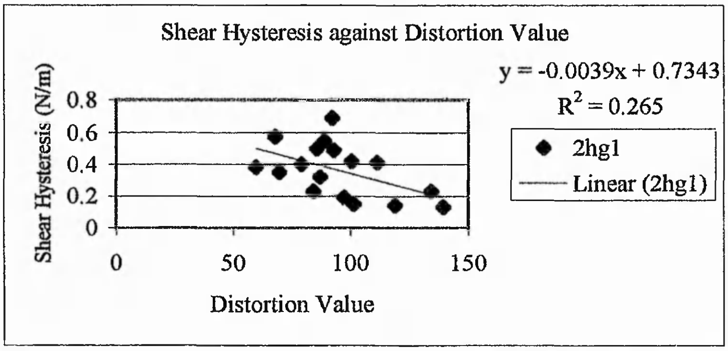
A) Warp shear rigidity against Distortion Value



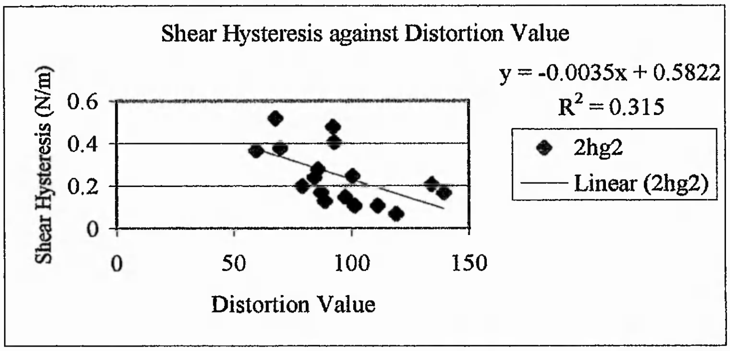
B) Weft shear rigidity against Distortion Value



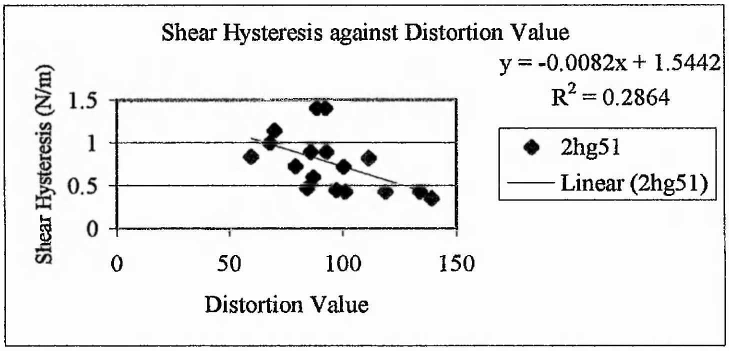
C) Warp shear hysteresis at 0.5° against Distortion Value



D) Weft shear hysteresis at 0.5° against Distortion Value



E) Warp shear hysteresis at 5° against Distortion Value



F) Weft shear hysteresis at 5° against Distortion Value

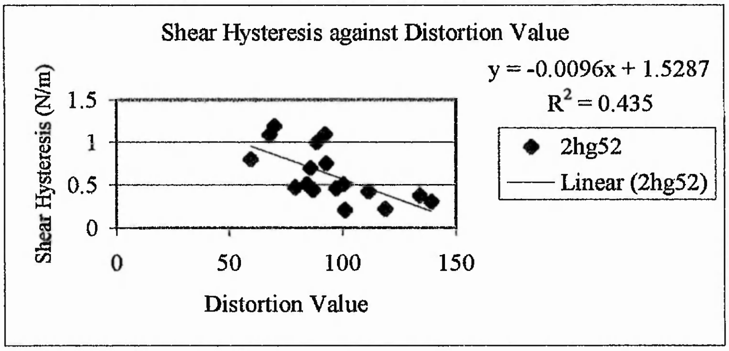
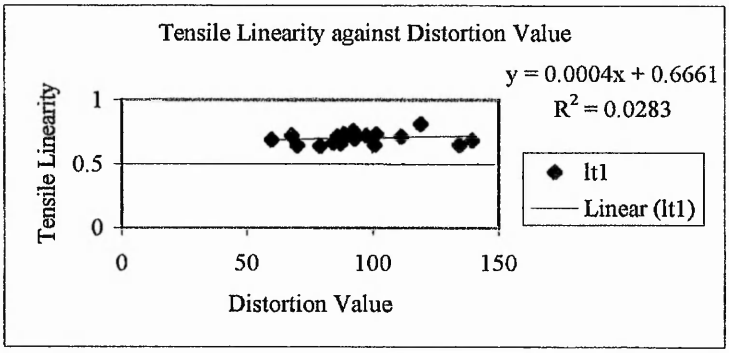
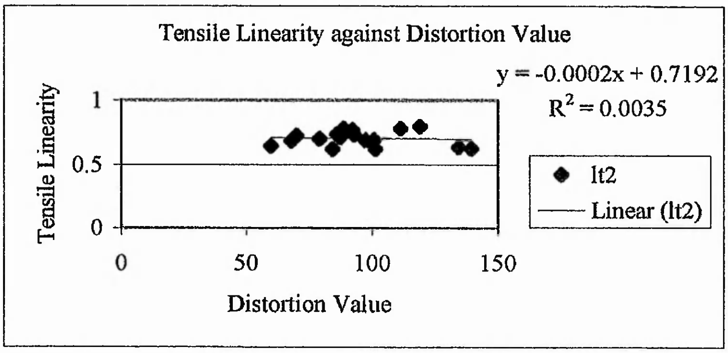


Figure 3.2.49 KES Tensile Parameters against Distortion Value(A-H)

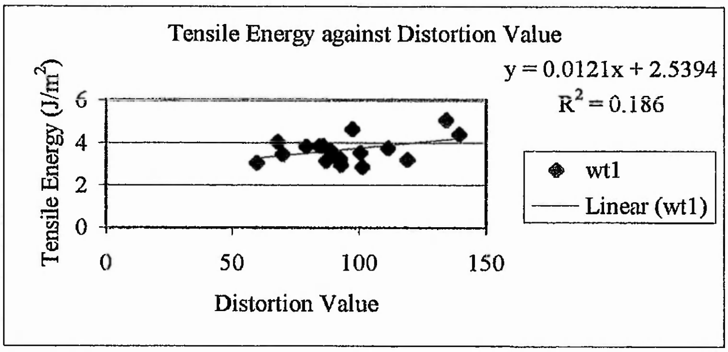
A) Warp tensile linearity against Distortion Value



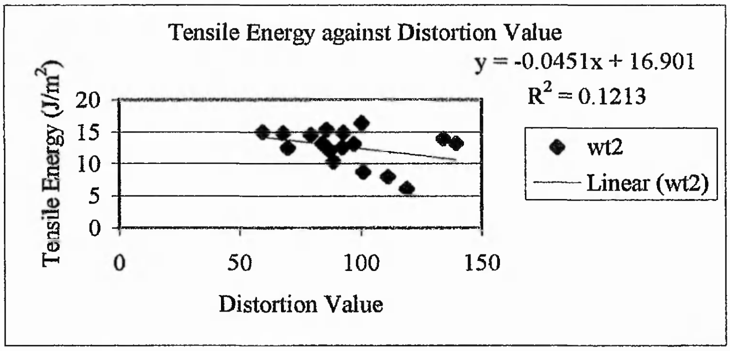
B) Weft tensile linearity against Distortion Value



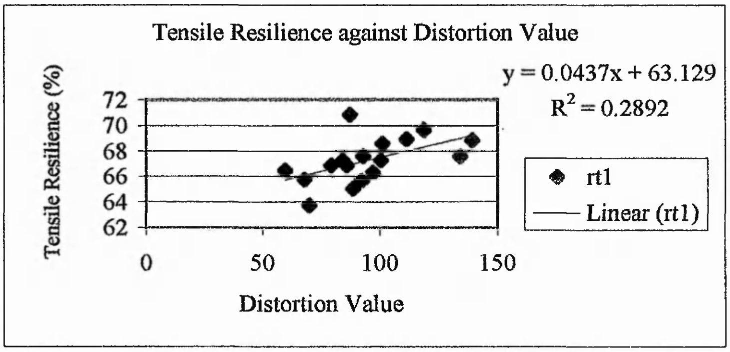
C) Warp tensile energy against Distortion Value



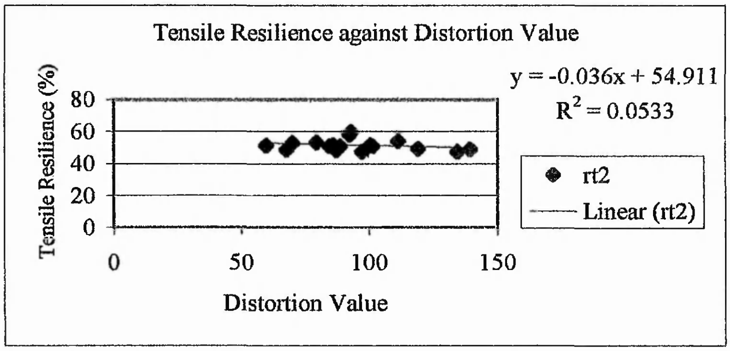
D) Weft tensile energy against Distortion Value



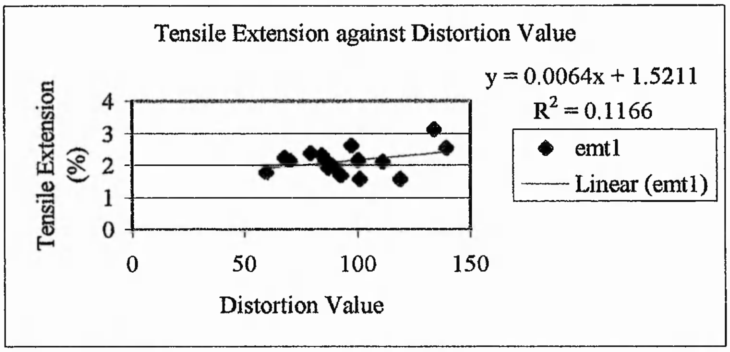
E) Warp tensile resilience against Distortion Value



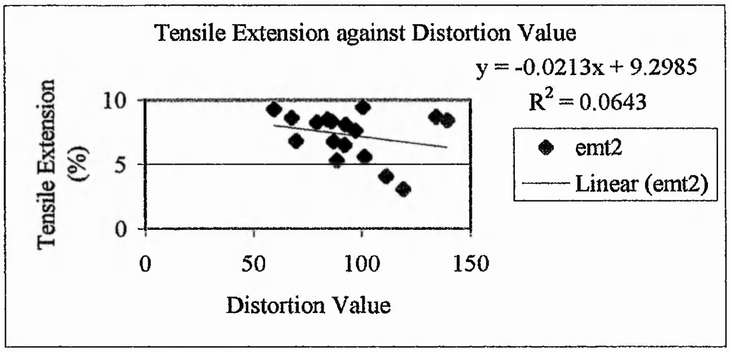
F) Weft tensile resilience against Distortion Value



G) Warp tensile extension against Distortion Value



H) Weft tensile extension against Distortion Value



The KES parameters that produced the largest predictive equations were: g2 (41%), 2 hg5 2 (44%), 2hg 2 (31%), rt1 (30%) and αT (28%). These would be used along with the FAST parameters previously established of: E1 4 (35%), C1 (21%) and E4 1 (44%), as well as the drape parameter (22%).

The distortion of garment dimensions can be considered similar to take into account fabric dropping. Guidelines have been established with regard to shear rigidity results that might predict the problem of dropping (table 1.2.2). Using the 2hg5 parameter on its own, 3 fabrics could be predicted to have problems with dropping (results less than 0.35 g/cm), those are, V0, V9 and E14. These fabrics were indeed amongst the worst in terms of distortion, however there were others that produced results in between these three, these are E5 and J10. Another parameter is also given that involves 2hg5 and weight parameters (100 x 2hg5/W). This was calculated using the results for the fabrics and the results indicate that all fabrics would have a problem with dropping, as all results were less than 3.8. Both were tested in a regression analysis where they produced a R^2 of 0.37 and 0.42; the former for the 2hg5 parameter singularly and the latter when it is used together with the weight parameter. Thus, it can be seen that although these measures of dropping were found useful previously they do not accurately predict the current problem using the guidelines given. The parameter of 2hg5 2 was selected for the multi-variate analysis as the weft direction shear hysteresis produced a higher correlation with the distortion problem than the average. In contrast, the weight parameter was not included in the subsequent analysis as it did not predict a high percentage of the problem.

3.2.12.1 Independence of Parameters

A correlation matrix was undertaken to establish if there were inter-relationships between these parameters. The results in the table below indicate that those parameters that were successful in predicting distortion values did not correlate with each other, and thus could be used successfully in a multiple regression formula.

Table 3.2.30 Independence of Variables (Distortion Problem)

	E4 1	E1 4	C 1	g2	2hg2	2hg52	RT1	αT	DC FU	Warp ends
E4 1	1.00									
E1 4	**0.63**	1.00								
C 1	-0.67	**-0.63**	1.00							
g2	**-0.47**	**-0.58**	0.78	1.00						
2hg2	**-0.33**	**-0.34**	**0.57**	0.83	1.00					
2hg52	**-0.47**	**-0.61**	0.80	0.98	0.79	1.00				
RT1	**0.16**	**0.32**	**-0.62**	-0.79	**-0.56**	-0.81	1.00			
αT	**0.13**	**0.04**	**-0.36**	-0.68	-0.84	-0.67	**0.58**	1.00		
DC FU	**-0.55**	-0.73	0.76	0.76	**0.54**	0.75	**-0.50**	**-0.34**	1.00	
Warp ends	**-0.48**	**-0.60**	**0.39**	**0.63**	**0.53**	**0.64**	**-0.36**	**-0.56**	0.67	1.00

An allowance of 0.65 was made for the independence, this allowed the highly correlated factors to be removed; further reductions would, if necessary, be made during the multiple regression analysis.

3.2.12.2 Combination of parameters

A process of assessing the best combination of the parameters was undertaken in a similar manner described earlier. The results can be seen in the table below.

Table 3.2.31 Results from the combination of parameters

A)

	R Square	Adjusted R Square	Anova	t-Test
Warp Ends & C1	0.55	0.49	0.00	0.00
				0.28
Warp Ends & E1 4	0.55	0.49	0.00	0.02
				0.29
Warp Ends & E4 1	**0.65**	**0.60**	**0.00**	**0.01**
				0.04
Warp Ends & 2hg5 2	0.58	0.52	0.00	0.04
				0.15
Warp Ends & 2hg 2	0.56	0.50	0.00	0.01
				0.24
Warp Ends & RT1	**0.61**	**0.55**	**0.00**	**0.00**
				0.09
Warp Ends & αT	0.57	0.51	0.00	0.01
				0.18
Warp Ends & g2	0.57	0.51	0.00	0.04
				0.18
C1 & E1 4	0.36	0.26	0.04	0.60
				0.09
C1 & RT1	0.31	0.22	0.03	0.15
				0.07
C1 & αT	0.38	0.29	0.03	0.15
				0.07
DC FU & E4 1	0.46	0.40	0.01	0.53
				0.03
DC FU & 2HG 2	0.36	0.26	0.05	0.36
				0.11
DC FU & RT1	0.35	0.25	0.05	0.29
				0.13
DC FU & αT	0.40	0.32	0.03	0.11
				0.06
E1 4 & E4 1	0.49	0.41	0.01	0.28
				0.07
E1 4 & 2hg5 2	0.49	0.42	0.01	0.24
				0.07
E1 4 & 2hg 2	0.50	0.42	0.01	0.04
				0.06
E1 4 & RT 1	0.48	0.41	0.01	0.04
				0.08

B)

	R Square	Adjusted R Square	Anova	t-Test
E1 4 & αT	**0.62**	**0.56**	**0.00**	**0.00**
				0.01
E1 4 & g2	0.48	0.41	0.01	0.19
				0.07
E4 1 & g2	0.58	0.52	0.01	0.03
				0.05
E4 1 & 2HG5 2	0.60	0.54	0.00	0.03
				0.04
E4 1 & 2HG 2	0.57	0.51	0.00	0.01
				0.06
E4 1 & RT 1	**0.63**	**0.58**	**0.00**	**0.00**
				0.02
E4 1 & αT	0.55	0.48	0.00	0.01
				0.09
G1 & 2HG 2	0.39	0.30	0.03	0.21
				0.18
G1 & αT	0.48	0.41	0.01	0.04
				0.05
2HG5 2 & αT	0.55	0.48	0.00	0.01
				0.08
2HG 2 & RT1	0.39	0.30	0.03	0.16
				0.22
2HG 2 & αT	0.36	0.27	0.04	0.20
				0.32
RT1 & αT	0.47	0.40	0.01	0.04
				0.05
Warp Ends, E4 1 & RT1	**0.74**	**0.68**	**0.00**	**0.04**
				0.02
				0.05
Warp Ends, E4 1 & E1 4	0.65	0.57	0.00	0.03
				0.08
				0.90
Warp Ends, E4 1 & αT	0.68	0.61	0.00	0.03
				0.05
				0.24
Warp Ends, RT1 & E1 4	0.62	0.54	0.00	0.04
				0.12
				0.37
Warp Ends, RT1 & αT	0.66	0.58	0.02	0.02
				0.10
				0.18
Warp Ends, E1 4 & αT	0.66	0.59	0.00	0.21
				0.09
				0.06

C)

	R Square	Adjusted R Square	Anova	t-Test
Warp Ends, E4 1, RT1 & E1 4	0.74	0.66	0.00	0.05
				0.04
				0.06
				0.82
Warp Ends, E4 1, RT1 & αT	0.77	0.70	0.00	0.08
				0.03
				0.05
				0.23
Parameters in bold indicate the highest prediction of the problem.				

The model with the best results used the parameters of warp ends, E4 1 and RT 1; this resulted in an optimum equation that predicted 74% of the problem.

$$\text{Distortion Value} = -119.7 + (-0.01 \times \text{Warp Ends}) + (318.69 \times \text{E4 1}) + (4.05 \times \text{RT1}) \qquad \ldots[22]$$

Thus again the warp ends proved to be very important and this regression model also used a mixture of results from the FAST and KES systems. Both of the parameters are related to extension in the warp direction, which would suggest that the majority of distortion was due to high extension. As the garments were cut on the bias, one would have thought that bias extension would have had more significance in the results, however that was not proven to be the case. The extension parameters were positively correlated with the distortion value (which increased with increasing distortion), thus small values coincide with fabrics with reduced distortion. The warp ends parameter was negatively correlated indicating that larger numbers of warp ends produced fabrics with less distortion.

Using this formula with the current results meant that with the smallest values of extension (0.2 % and 63.7 % for E4 1 and RT respectively) and the largest value for warp ends (15000 per 150 cm width) the predicted distortion value would be 52.0. Using the largest values of extension (0.3 % and 70.9%) and smallest values for warp ends (13000 per 150 cm width) the predicted distortion would be 133. These results compare favourably with the actual minimum of 60 and maximum of 140. The correlation between the predicted and actual distortion grades is 0.86, which can be considered significant.

It was interesting to note that the largest single factor in the equation was the warp end data, suggesting again that the fabric manufacturing company has a simple way in which to assess the quality of the finished products. Indeed the warp ends parameter could be used on its own, to predict the lower amount of 51%, but without the investment of new expensive equipment:

$$\text{Distortion Value} = 334 + (-0.017 \times \text{Warp Ends}) \qquad \ldots[23]$$

The distortion values obtained during this experiment had a range of 60 – 140. When the range of values for warp ends was inputted in the formula (13000 – 15000 per 150 cm width) the values for distortion were 118 and 85 respectively. In order to achieve the above distortion values the warp ends would have to range from 16498 – 11687 per 150 cm width. This correlation between the predicted and actual grades is 0.72, which can certainly be considered important for the fabric mill.

3.2.13 Conclusion

A number of conclusions may be drawn from this research. Firstly, the aim of modifying the FAST equipment in order to assess if it was suitable for testing these weight reduced fabrics: this was achieved as the results enabled differentiation of the fabrics and also a number of the modified parameters (those tested in the bias directions or the extension and shear results using the modified loads) were proven to predict the problems more conclusively than the initial FAST parameters. Further research is necessary to establish if these modifications are adequate or whether further work would be required to render the apparatus suitable for fabrics that distort very easily. However, the initial results confirmed that although some fabrics gave rise to difficulties, the apparatus is suitable for testing at a fraction of the price of the KES equipment and is a viable option for developing Fabric Objective Measurement guidelines.

The modification of the extension test using standard weights was successful, although doubt was cast on the technique of measuring so many loads due to the length of time the sample would be clamped vertically. This research has highlighted three loads that are the most informative (these are extension at 2, 3 and 4 g/cm, in all four directions), which could be used to limit impact on the fabric for future analysis. It would also be useful to assess the effect of measuring the higher loads without measuring the low loads beforehand, in order to compare the results obtained with both methods.

The weight reduction process was found to have different effects on fabrics depending on the fabrics' original characteristics. However, despite the difference in the degree of changes, all the fabrics were softened by the finishing process. This resulted in lower results for the drape coefficient, weight, shear and bending rigidity parameters. This is consistent with the findings of Matsudaira when measuring similar fabrics with the KES-FB equipment [102]. The results for these fabrics showed that the thickness parameters were not greatly affected by the weight reduction process, this is in contrast to the findings of previous researches [102, 152]. The extension results were found to increase with increasing weight reduction in the weft and bias directions.

Interesting results were found for the formability parameter due to the opposing changes in extension and bending rigidity (the former increased with increasing weight reduction percentage whereas the latter decreased). In the warp and bias directions the samples produced results that were lower as a result of weight reduction, whereas the samples in weft direction produced results that increased.

Thus, the information can be used to limit the weight reduction percentage for fabrics that have low initial results and for which the finishing process has a large effect on the mechanical properties of drape and shear, weft extension, formability and weight. Furthermore, it was seen that the fabrics tested fell into two distinct groups; the first comprised of the Portia, Juno and Geisha fabric stories. These fabrics were considered stable and could be finished to high percentage weight reductions (15%) because none of the fabrics that produced low results on the base fabrics were significantly effected by the weight reduction process. For example, the P15 produced the largest changes in the warp and bias directions for the FAST bending parameters and for the KES-FB measurements of shear, but because these parameters were initially high the subsequent reduction was not enough to destabilise the fabric.

The second group consists of the fabrics from the Venus and Electra stories, where the fabrics can be considered as not being able to withstand high weight reductions. The reason that the Electra story fabrics cannot withstand high weight reductions is that the results for drape, shear rigidity, weight were initially low, and the extension results were very high. The effect of the weight reduction process was minimal on this fabric, indeed for bending, formability, drape, FAST and KES shear and extension, the E14 fabric was amongst the least effected from its base fabric. If, given the initial base, the fabric story was more altered by the weight reduction process, it certainly would have been worse than the Venus fabrics.

However, the reason for the Venus fabric story being unable to withstand large weight reductions is that it showed the combination of having low initial results and being significantly affected by the weight reduction process. The largest difference was found on the weft extension parameter, where although the base fabric's results were not high, the large change is characteristic of the destabilisation that sometimes happens after weight reduction finishing. In addition to this, the V9 fabric was also among those fabrics most significantly altered from their base in the parameters of drape, weft bending and formability. Other results that were initially low included FAST and KES measurements of shear, drape coefficient and warp formability. The V9 fabric can be considered as the fabric most affected by the finishing process, possibly because it contained basic-dyeable weft yarns. It is likely that these absorbed more of the sodium hydroxide and were more susceptible to changes in structure, these conclusions are also consistent with the findings of previous research [153].

The experiment involving the manufacture, distortion and appearance of the garments was very informative and added a necessary focus to the investigation. It would not have been valid to perform statistical analysis on the information provided from different manufacturing sources with different equipment. However, the analysis was also restricted by several factors resulting from the fact that the fabrics were those commercially available, and hence each fabric story did not have the same sequence of weight reductions (for example 0, 5, 10, 15 percentage). This meant that the investigation could not be as in-depth as would otherwise be possible because not enough information was available. The colours of the fabrics were not the same, which presented difficulties when using the measurement booth to assess distortion and may also have had an effect on the grading for the appearance tests. This indicates the difficulties encountered with this type of research that is performed in conjunction with industry, where certain restrictions apply. Unless the complete material under investigation can be controlled and modified under laboratory conditions, there will be limits to the amount of data that can be obtained.

It was also decided that the analysis should be conducted according to valid statistical protocols, which meant not using variables that were closely related to each other. Some researchers assume independence [160], where the results produced might seem to predict more of the problem under investigation, and the method of analysis might suggest changes to the fabric that would be difficult or impossible to be achieved.

However despite these restrictions some very interesting conclusions can be reached. The parameters that individually predicted the largest amount of ease of manufacture were found to alter slightly depending on whether fabric V9 was or was not included. This fabric behaved differently from the other fabric stories. The KES measurements of shear (g1 and 2hg5 2) were important to both sets of analysis (with and without V9), however the specific FAST parameter alters between G2 3 (with V9) and G5 4 (without V9). However in both cases the shear parameters were extremely important in the prediction of the ease of manufacture. The two sets of analysis also indicated that weight, drape and warp bending length were important, with higher results for all correlating with fabrics that were easier to manufacture. The effect of the weight parameter was highly significant without V9.

This conclusion concurs with the hypothesis made at the beginning of the investigation that shear would be important. High values of shear rigidity resulted in fabrics that are easy to manufacture. Extension parameters also produced high correlation with this problem in both cases that is, with and without V9, and in particular the parameters of RT1 and E3 2 were important. The parameter of warp ends was only seen to contribute to the ease of manufacture problem for the analysis of the complete fabric set with V9.

Surprisingly, the formability parameter did not correlate very highly with the manufacturing variable, which does not agree with previous research [7], however this result was consistent with other findings [72]. The final models used the parameters of weight and warp ends (predicting 56% of the problem); KES - G1 (predicting 50% of the problem); FAST - G5 4 and KES - RT1 (predicting 75% of the problem) and FAST - G5 3 (66% of the problem). High correlation factors were found between the actual and predicted data with these equations, ranging from 0.71 to 0.87.

The results for the distortion problem indicated that the warp ends parameter was also important, used as a single variable it predicted 51% of the problem. When used together with the extension parameters of RT1 and E4 1 the formula predicted 74% of the problem. The extension parameters were positively correlated with the problem, indicating that fabrics with higher extension results would be more likely to produce distortion in garment measurements. The warp ends parameter was negatively correlated with the distortion problem, thus in a similar manner to the manufacturing problem, a fabric with higher number of warp ends will be liable to have less problems with distortion.

The results relating the mechanical properties and the appearance parameter were very interesting. Fabrics with low weight reduction percentages, and thus high bending rigidity, formability, shear rigidity, drape coefficient and weight results were preferred. High values of the above parameters indicate that the preferred fabrics were heavier and stiffer. The fabric that was considered the overall best in the ranking exercise that was carried out was P0, and the one considered worst was G10.

CHAPTER 4 –CONCLUSION

The large amount of data that was found during the research for this thesis was categorised in two main areas: the first and more important area explored was that of the effect of weight reduction on polyester fabrics. The second area of interest was the investigation into textile testing equipment.

The weight reduction process was found to have different effects on fabrics depending on the fabrics' original characteristics. However in all cases it softened the fabric, reducing the drape coefficient, bending and shear rigidity results, and increasing the weft extension results. The analysis allowed two groups of fabrics to be defined from the results of the initial base fabric and the manner in which the weight reduction affected it; these groups were those that could withstand high percentages of weight reduction and those that could not.

An experiment where samples of the fabrics were manufactured into garments allowed three variables to be correlated with the mechanical properties of each fabric. The variables used were ease of manufacture, distortion of garment dimensions and appearance of the final garment. Multiple regression analysis was carried out and the parameters of shear, weight, drape and warp bending length were found to be important in predicting difficulties in garment manufacture. To a lesser extent extension parameters were also important, but formability was not found to correlate with the manufacturing variables. This was very interesting as formability is traditionally found to be the most important variable for ease of manufacture. It would seem that as empirical data is found from more light-weight fabrics and from those that are relatively easy to distort, the distortion properties themselves (as measured by shear) have a more important role in the prediction of ease of manufacture than have those properties that are related to how easily a 2-dimensional fabric can create 3-dimensional forms.

The analysis also revealed that a combination of the weight and warp ends parameters could be used to predict manufacturing and distortion problems. As these were readily available to the fabric mill, they would prove an interesting and informative method of classifying their fabric. The equation relating to fabric distortion was greatly improved if extension parameters were included. It would be interesting to assess if the same simple parameters would also have such a high predictive ability when used in a greater range of fabrics. This could have huge implications for research if the technique could be proven valid when other fabrics are assessed.

The results relating the mechanical properties and the appearance variables were very interesting. Fabrics with low weight reduction percentages - and thus high bending rigidity, formability, shear rigidity, drape coefficient and weight results - were preferred. High values of the above parameters indicate that the preferred fabrics were heavier and stiffer. The technique of using photographs to assess visual aspects of garments was shown to be valid due to the close agreement of all assessors on the ranking order of the dresses.

The analyses of all of the three problem variables indicated that for the chosen garment silhouette the fabrics without the weight reduction finish were the most suitable. As we can link the increasing weight reduction percentage with increases in softness and ease of distortion of the fabric, we can also hypothesise that the length of the garment is fundamental. A shorter length dress might result in the preference of fabrics with a small percentage weight reduction. Furthermore, a simple blouse might be able to withstand a high percentage weight reduction and still rank highly in the three problem areas investigated, because its silhouette does not present as many problems as does the one measured here.

It is apparent that the context of fabric use is crucial, and to continue this work it would be beneficial to include garment silhouettes such as a shorter dress and blouse or skirt. Proper engineering of fabric samples from a number of bases greater than five, with weight reduction percentages of standardised amounts (0, 5, 10 and 15%), along with the use of the same colour for all fabrics (preferably white) would also be necessary.

In addition, it would be interesting to include fabrics with different fabric constructions, and also other techniques for increasing hand and drape such as micro-denier fabrics. It is probably the case that whilst similar equations could be used for different fabrics with the same end use, they would be changed according to the garment silhouette (in terms of its style and construction).

There is a great deal of further research than could and should be carried out in this area to fully understand the importance of mechanical parameters. However, what this research has proven is that the simple, yet accurate and effective FAST system of objective measurement should be included in any such investigations.

The research also explored the area of textile testing equipment during the investigation about drape and its measurement, and the modification of the FAST for the empirical research on the weight reduced polyester fabrics. A new method of measuring drape (the Kerrigan drape tester) was devised; this was quicker than the Cusick Drape meter used in the British Standard, but more accurate and repeatable than the Aldrich method, which was also investigated and modified. Several trials with numerous fabrics were made on the Kerrigan drape tester. A total of four modifications were produced, each of which improved the test. Consequently, results produced were repeatable, reproducible, accurate and correlated highly with those obtained by the Cusick method. The final modification enabled results to be produced that were quicker to obtain and as consistent as the Cusick method. The drawback was that it did not differentiate between fabrics to the same degree as the Cusick method and therefore may give rise to problems if similar fabrics are tested. However the idea of using a 20 cm square specimen, which had previously been proposed by Aldrich, was further developed and the data was encouraging. This small square sample would enable the test to be carried out on samples typical of those that would be given to buyers for the assessment of fabric, and would therefore provide an objective manner in which fabrics could be differentiated. The ideas for several further modifications, that were anticipated to advance the development of the instrument, were established; however, they were beyond the scope of this thesis.

The validity of measuring drape using a square sample, which had previously only been used by Aldrich, was extended and enhanced. Although the aim was to produce simple equipment that could bridge the gap between designers and technologists, the results showed that the test, although simple, did have the capability to provide valid data for the technologist as well. The work is by no means complete; collaboration with a mechanical engineer or interested company would be needed to take the basic idea through to a fully functioning proto-type. It would also be necessary to undertake further trials with fabrics that are more similar in terms of their drape properties in order to fully understand if the method is applicable or not.

In order to successfully measure weight reduced polyester fabrics with FAST equipment it was necessary to modify the method of test to complement the current procedure for suiting fabrics. This involved the use of different weights specifically designed for the FAST-3 instrument, and also the procedure of testing the samples in the bias directions for bending and formability parameters.

The extra extension results were possible because the new weights enabled measurements at below the 5 gf/cm minimum possible with the current FAST procedure, and also loads in between the 20 gf/cm and 100 gf/cm loads. This follows the procedure established by Kawabata that a lower weight is used when measuring thin dress fabric than when measuring suiting fabrics. The use of this new system was proven valid by the subsequent analysis. This part of the work was a fairly straightforward broadening of the measurement parameters of the FAST, but was vital to the research. In the future it would be perfectly feasible for the commercial equipment to be supplied with different weights for testing fabrics intended for different end uses. A parallel can be drawn with the Martindale abrasion equipment, which is supplied with 9 kPa weights for measuring apparel and 12 kPa for measuring furnishings fabrics.

The change to the sample preparation to include specimens cut on the bias was important because of the bias-cut nature of the end garment. This was a very interesting area of research as many more garments are being manufactured in this way and the fashion is for garments with large amounts of drape. The parameter of formability exhibited a large difference in its bias specimen results due to the weight reduction. Bending length and rigidity were also important but to a lesser extent. This shows that the addition of these specimens was valid and provided an additional indication about the nature of these fabrics. It is important to reflect changes in the fashion for particular types of fabrics in the tests and test methods used to assess them. As more fabrics are developed from totally new fibres or with new finishing techniques it is important that technologists question whether the existing test methods provide as much data as is possible. As a result of this research, it is the informed opinion of the author that the changes made to the FAST equipment would also be valid for other light-weight fabrics, specifically women's dress fabrics, that in contrast to suiting fabrics are relatively easy to distort. Future applications of the test could include garments that have relatively high degrees of drape due to other factors than bias-cutting, such as fabric construction (for example, satin weaves).

It was also proven that the FAST equipment could differentiate accurately between these types of fabrics, which had not been attempted previously. Although one fabric exhibited results that were not in keeping with the rest of the fabric set, these anomalies were in the majority confined to bias extension results measured at high loads. These were found to be of less importance than the lower loads in differentiating between the fabrics.

The FAST equipment does not have the sophistication to enable different set-ups due to fabric type, as does the KES-FB equipment. Despite this it can be used successfully to classify the mechanical properties of the majority of these lightweight, relatively easily distorted polyester fabrics. This is very important for future research into FOM, particularly in view of the much lower cost of the FAST compared to KES-FB. This research has shown that there is a good deal of potential viability for the FAST to have a role in many other areas than those for which it has previously been used.

The FAST, being much simpler in operation than the KES-FB, does have some drawbacks. The majority of these were evident in the FAST – 3 tensile-meter, such as the vertical position of the samples (leading to waisting and uneven load application across the sample width) and the manual implementation of the load. These were contributing factors to the anomalies found with the V9 fabric. It would be interesting to re-evaluate the fabrics in the future if such modifications could be made. However, even if it could only measure a smaller range of fabrics (and it is likely that the difference would not be great), the reductions in price and complexity would still probably persuade most industrial quality managers to chose the FAST rather than the KES. This alone should warrant more research into using the FAST.

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APPENDICES

Appendix 1 – Comparison of Measurements from Pattern and Control Fabrics

	Pattern	Control Fabric	Difference
Centre Front:	121.1	121.87	0.77
Right Side:	105.9	106.27	0.37
Left Side:	105.8	106.40	0.65
Centre Back:	126.7	127.47	0.77
Bustline:	50.2	47.4	-2.80
Waistline:	49.2	46.8	-2.40
Sleeve Circumference (R)	34.9	34.3	0.60
Sleeve Height (1) (R)	21	21.2	0.20
Sleeve Height (2) (R)	8.9	7.00	-1.90
Sleeve Circumference (L)	34.9	34.3	-0.60
Sleeve Height (1) (L)	21	21.1	0.10
Sleeve Height (2) (L)	8.9	6.95	-1.95
Right Dart	13.7	13.1	-0.60
Seam to R Dart	8.4	8.2	-0.20
Left Dart	13.4	13.1	-0.30
Seam to L Dart	8.5	7.6	-0.90
Front Hem	72.3	73.0	0.70
Back R Hem	38.8	38.50	-0.30
Back L Hem	38.8	38.43	-0.37
Right Shoulder (front)	9.9	10.2	0.30
Left Shoulder (front)	9.9	9.9	0.00
Front Neckline	30.2	27.40	-2.80
Back Neckline R	13.8	11.5	-2.30
Back Neckline L	13.8	11.8	-2.00

Appendix 2 - Results of Grades during Appearance Experiment

Hang	Grade		Actual	Range	
G 0 Q1	4.00		**4.00**	3-5	
G 5 R1	3.22	3.33	3.28	2-4	2-4
G 10 A1	1.67		**1.67**	1-3	
G 15 T1	2.22		2.22	1-3	
P 0 M	4.00		**4.00**	3-5	
P 7 N	3.28		3.28	2-4	
P 10 O1	2.94	3.06	3.00	1-4	1-5
P 12 B	2.89		2.89	2-4	
P 15 P1	2.28		2.28	1-4	
J 0 X	3.89		**3.89***	3-5	
J 10 Y1	3.83	4.17	**4.00**	3-5	3-5
J 17 Z	2.94		2.94	2-4	
V 0 I1	2.72		2.72	1-4	
V 9 J1	1.44		**1.44**	1-3	
E 0 U1	1.89		**1.89**	1-4	
E 5 V1	2.83		3.89	1-5	
E 14 W	2.06		**2.06**	1-3	

* The choice of J0 rather than E5 was because the smaller range indicated that the assessors were more consistent in their preference of the garment.

Puckering	Grade		Actual	Range	
G 0 Q1	4.33		**4.33**	3-5	
G 5 R1	2.83	2.83	2.83	2-4	2-5
G 10 A1	1.61		**1.61**	1-4	
G 15 T1	1.89		**1.89**	1-4	
P 0 M	4.22		**4.22**	3-5	
P 7 N	2.72		2.72	1-5	
P 10 O1	3.17	3.06	3.11	2-4	2-5
P 12 B	2.94		2.94	2-4	
P 15 P1	2.50		2.50	1-4	
J 0 X	4.28		**4.28**	3-5	
J 10 Y1	4.00	4.11	4.06	3-5	3-5
J 17 Z	2.67		2.67	1-4	
V 0 I1	2.94		2.94	1-4	
V 9 J1	1.67		**1.67**	1-4	
E 0 U1	1.94		**1.94**	1-3	
E 5 V1	2.78		**4.28**	1-5	
E 14 W	1.94		1.94	1-3	

Levelness of Hem	Grade		Actual	Range	
G 0 Q1	3.72		**3.72**	3-5	
G 5 R1	3.00	3.06	3.03	2-5	2-4
G 10 A1	1.72		**1.72**	1-3	
G 15 T1	1.72		**1.72**	1-3	
P 0 M	3.83		**3.83**	3-5	
P 7 N	3.11		3.11	2-4	
P 10 O1	2.28	2.44	2.36	1-3	1-4
P 12 B	3.00		3.00	2-4	
P 15 P1	2.50		2.50	1-4	
J 0 X	3.67		**3.67***	3-5	
J 10 Y1	3.78	3.94	**3.86**	2-5	3-5
J 17 Z	2.83		2.83	2-4	
V 0 I1	2.06		2.06	1-4	
V 9 J1	1.83		**1.83**	1-4	
E 0 U1	1.44		**1.44**	1-3	
E 5 V1	2.78		3.67	1-4	
E 14 W	2.28		2.28	1-3	

* The choice of J0 rather than E5 was because the smaller range indicated that the assessors were more consistent in their preference of the garment.

Overall Appearance	Grade		Actual	Range	
G 0 Q1	3.72		**3.72**	2-5	
G 5 R1	3.06	3.11	3.08	2-4	2-4
G 10 A1	1.33		**1.33**	1-3	
G 15 T1	1.89		**1.89**	1-3	
P 0 M	4.11		**4.11**	3-5	
P 7 N	2.78		2.78	1-4	
P 10 O1	2.61	2.78	2.69	2-3	1-4
P 12 B	2.83		2.83	2-4	
P 15 P1	2.33		2.33	1-4	
J 0 X	3.67		**3.67**	2-4	
J 10 Y1	3.61	4.06	**3.83**	3-5	2-5
J 17 Z	2.56		2.56	2-4	
V 0 I1	2.50		2.50	1-4	
V 9 J1	1.22		**1.22**	1-2	
E 0 U1	1.67		**1.67**	1-3	
E 5 V1	2.67		3.67	1-5	
E 14 W	1.89		1.89	1-3	

* The choice of J0 rather than E5 was because the smaller range indicated that the assessors were more consistent in their preference of the garment.

Appendix 3 – Percentage Change of FAST results due to Weight Reduction

Fabric:	C 1*	% change	C 2*	% change	C 3#	% change	C 4#	% change	B 1*	% change	B 2*	% change
Geisha 0	18.200		11.700		13.050		13.150		6.463		1.717	
Geisha 5	16.750	**-8%**	11.550	**-1%**	12.200	**-7%**	12.500	**-5%**	4.720	**-27%**	1.547	**-10%**
Geisha 10	17.600	**-3%**	11.300	**-3%**	12.750	**-2%**	13.050	**-1%**	5.216	**-19%**	1.380	**-20%**
Geisha 15	16.450	**-10%**	11.100	**-5%**	11.550	**-11%**	11.550	**-12%**	3.885	**-40%**	1.194	**-30%**
Portia 0	18.550		14.200		13.800		13.850		6.664		2.989	
Portia 7	18.050	**-3%**	13.300	**-6%**	13.250	**-4%**	13.500	**-3%**	5.581	**-16%**	2.233	**-25%**
Portia 10	16.550	**-11%**	13.850	**-2%**	13.000	**-6%**	12.750	**-8%**	4.367	**-34%**	2.560	**-14%**
Portia 12	16.150	**-13%**	13.500	**-5%**	12.350	**-11%**	12.550	**-9%**	3.895	**-42%**	2.275	**-24%**
Portia 15	15.500	**-16%**	13.417	**-6%**	11.850	**-14%**	12.150	**-12%**	3.310	**-50%**	2.147	**-28%**
Juno 0	18.100		12.800		13.100		13.050		6.535		2.311	
Juno 10	15.950	**-12%**	13.000	**2%**	12.650	**-3%**	12.800	**-2%**	3.932	**-40%**	2.129	**-8%**
Juno 17	16.050	**-11%**	11.550	**-10%**	11.750	**-10%**	12.200	**-7%**	3.805	**-42%**	1.418	**-39%**
Venus 0	16.600		13.850		13.400		13.700		4.774		2.773	
Venus 9	16.250	**-2%**	11.600	**-16%**	12.400	**-7%**	12.600	**-8%**	4.007	**-16%**	1.458	**-47%**
Electra 0	16.550		11.450		12.150		12.400		4.348		1.440	
Electra 5	15.650	**-5%**	11.100	**-3%**	11.800	**-3%**	11.850	**-4%**	3.573	**-18%**	1.275	**-11%**
Electra 14	15.950	**-4%**	10.900	**-5%**	11.600	**-5%**	12.000	**-3%**	3.490	**-20%**	1.114	**-23%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	B 3#	**% change**	B 4#	**% change**	F 1*	**% change**	F 2*	**% change**	F 3#	**% change**	F 4#	**% change**
Geisha 0	2.383		2.438		0.106		0.084		0.684		0.640	
Geisha 5	1.824	**-23%**	1.962	**-20%**	0.077	**-27%**	0.112	**33%**	0.563	**-18%**	0.635	**-1%**
Geisha 10	1.983	**-17%**	2.126	**-13%**	0.071	**-33%**	0.111	**32%**	0.634	**-7%**	0.668	**4%**
Geisha 15	1.345	**-44%**	1.345	**-45%**	0.053	**-50%**	0.091	**8%**	0.454	**-34%**	0.410	**-36%**
Portia 0	2.744		2.774		0.073		0.102		0.732		0.782	
Portia 7	2.208	**-20%**	2.335	**-16%**	0.061	**-16%**	0.125	**22%**	0.682	**-7%**	0.715	**-9%**
Portia 10	2.117	**-23%**	1.997	**-28%**	0.065	**-10%**	0.122	**20%**	0.593	**-19%**	0.590	**-25%**
Portia 12	1.742	**-37%**	1.828	**-34%**	0.058	**-20%**	0.130	**28%**	0.540	**-26%**	0.530	**-32%**
Portia 15	1.479	**-46%**	1.594	**-43%**	0.054	**-25%**	0.108	**6%**	0.411	**-44%**	0.471	**-40%**
Juno 0	2.478		2.449		0.089		0.079		0.594		0.658	
Juno 10	1.961	**-21%**	2.032	**-17%**	0.070	**-22%**	0.052	**-34%**	0.494	**-17%**	0.536	**-18%**
Juno 17	1.493	**-40%**	1.671	**-32%**	0.052	**-42%**	0.087	**10%**	0.438	**-26%**	0.468	**-29%**
Venus 0	2.511		2.684		0.071		0.060		0.721		0.686	
Venus 9	1.780	**-29%**	1.868	**-30%**	0.055	**-24%**	0.081	**35%**	0.443	**-39%**	0.417	**-39%**
Electra 0	1.720		1.829		0.095		0.106		0.555		0.605	
Electra 5	1.532	**-11%**	1.551	**-15%**	0.097	**3%**	0.109	**3%**	0.502	**-9%**	0.491	**-19%**
Electra 14	1.342	**-22%**	1.486	**-19%**	0.071	**-25%**	0.120	**13%**	0.446	**-20%**	0.468	**-23%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	G1 3#	**% change**	G1 4#	**% change**	G2 3#	**% change**	G2 4#	**% change**	G3 3#	**% change**	G3 4#	**% change**
Geisha 0	14.759		13.920		19.180		18.051		22.439		21.520	
Geisha 5	12.129	**-18%**	12.895	**-7%**	14.701	**-23%**	14.527	**-20%**	17.277	**-23%**	16.652	**-23%**
Geisha 10	10.381	**-30%**	11.667	**-16%**	13.342	**-30%**	14.029	**-22%**	15.660	**-30%**	16.211	**-25%**
Geisha 15	7.249	**-51%**	7.853	**-44%**	9.590	**-50%**	10.863	**-40%**	11.683	**-48%**	13.050	**-39%**
Portia 0	16.858		13.172		20.234		16.187		22.952		18.840	
Portia 7	12.500	**-26%**	12.010	**-9%**	14.789	**-27%**	13.639	**-16%**	17.037	**-26%**	16.000	**-15%**
Portia 10	11.036	**-35%**	9.646	**-27%**	14.029	**-31%**	12.153	**-25%**	16.652	**-27%**	14.661	**-22%**
Portia 12	9.280	**-45%**	8.566	**-35%**	12.094	**-40%**	11.580	**-28%**	14.319	**-38%**	14.154	**-25%**
Portia 15	8.333	**-51%**	8.059	**-39%**	11.690	**-42%**	10.628	**-34%**	14.488	**-37%**	13.004	**-31%**
Juno 0	17.927		14.583		23.016		18.459		27.125		21.563	
Juno 10	13.172	**-27%**	15.705	**8%**	16.046	**-30%**	17.536	**-5%**	18.872	**-30%**	19.785	**-8%**
Juno 17	9.620	**-46%**	10.180	**-30%**	12.742	**-45%**	13.246	**-28%**	15.397	**-43%**	15.839	**-27%**
Venus 0	9.722		10.560		12.399		13.792		14.603		16.356	
Venus 9	7.853	**-19%**	9.423	**-11%**	10.815	**-13%**	13.128	**-5%**	13.731	**-6%**	16.070	**-2%**
Electra 0	8.813		7.903		11.746		10.403		13.887		12.432	
Electra 5	7.424	**-16%**	6.652	**-16%**	10.061	**-14%**	9.323	**-10%**	12.391	**-11%**	11.652	**-6%**
Electra 14	6.756	**-23%**	5.518	**-30%**	9.264	**-21%**	8.076	**-22%**	11.452	**-18%**	10.299	**-17%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	G4 3#	% change	G4 4#	% change	G5 3*	% change	G5 4*	% change	DC FU#	% change	DC FD#	% change
Geisha 0	25.415		24.648		27.864		27.489		41.25		36.50	
Geisha 5	19.778	-22%	19.235	-22%	21.971	-21%	21.285	-23%	37.22	-10%	34.90	-4%
Geisha 10	18.371	-28%	18.938	-23%	20.365	-27%	21.138	-23%	40.83	-1%	35.99	-1%
Geisha 15	13.856	-45%	15.280	-38%	15.758	-43%	17.268	-37%	30.14	-27%	29.02	-20%
Portia 0	25.861		21.576		28.249		23.821		47.84		44.14	
Portia 7	19.235	-26%	18.302	-15%	21.509	-24%	20.298	-15%	42.86	-10%	40.85	-7%
Portia 10	19.235	-26%	16.972	-21%	21.585	-24%	18.978	-20%	41.16	-14%	38.49	-13%
Portia 12	16.684	-35%	16.515	-23%	18.862	-33%	18.746	-21%	38.61	-19%	35.30	-20%
Portia 15	17.150	-34%	15.473	-28%	19.338	-32%	17.316	-27%	36.36	-24%	34.49	-22%
Juno 0	30.914		24.941		33.805		27.613		43.57		38.64	
Juno 10	21.800	-29%	22.708	-9%	24.229	-28%	25.123	-9%	38.09	-13%	34.83	-10%
Juno 17	17.945	-42%	18.440	-26%	20.164	-40%	20.827	-25%	33.30	-24%	30.18	-22%
Venus 0	16.914		18.793		18.978		21.211		36.85		34.66	
Venus 9	16.350	-3%	19.464	4%	18.862	-1%	22.372	5%	28.39	-23%	26.81	-23%
Electra 0	16.135		14.469		17.924		16.303		30.99		29.13	
Electra 5	14.642	-9%	13.882	-4%	16.434	-8%	15.819	-3%	28.84	-7%	28.65	-2%
Electra 14	13.525	-16%	12.397	-14%	15.376	-14%	14.234	-13%	29.38	-5%	26.54	-9%
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	Weight*	**% change**	T 2*	**% change**	T 100*	**% change**	ST*	**% change**
Geisha 0	109.29		0.264		0.217		0.047	
Geisha 5	102.38	**-6%**	0.257	**-3%**	0.205	**-6%**	0.052	**11%**
Geisha 10	97.53	**-11%**	0.240	**-9%**	0.194	**-11%**	0.046	**-2%**
Geisha 15	88.97	**-19%**	0.258	**-2%**	0.195	**-10%**	0.063	**34%**
Portia 0	106.43		0.241		0.194		0.047	
Portia 7	96.75	**-9%**	0.241	**0%**	0.194	**0%**	0.047	**0%**
Portia 10	98.21	**-8%**	0.299	**24%**	0.229	**18%**	0.070	**49%**
Portia 12	94.27	**-11%**	0.277	**15%**	0.217	**12%**	0.060	**28%**
Portia 15	90.62	**-15%**	0.282	**17%**	0.217	**12%**	0.065	**38%**
Juno 0	112.35		0.261		0.220		0.041	
Juno 10	98.77	**-12%**	0.240	**-8%**	0.203	**-8%**	0.037	**-10%**
Juno 17	93.81	**-17%**	0.218	**-16%**	0.179	**-19%**	0.039	**-5%**
Venus 0	106.39		0.241		0.194		0.047	
Venus 9	95.19	**-11%**	0.240	**0%**	0.206	**6%**	0.034	**-28%**
Electra 0	97.78		0.285		0.219		0.066	
Electra 5	95.03	**-3%**	0.259	**-9%**	0.202	**-8%**	0.057	**-14%**
Electra 14	87.66	**-10%**	0.242	**-15%**	0.186	**-15%**	0.056	**-15%**
Percentage difference calculated from 0% weight reduction for each fabric base								

Fabric:	E1 1#	**% change**	E1 2#	**% change**	E2 1#	**% change**	E2 2#	**% change**	E3 1#	**% change**	E3 2#	**% change**
Geisha 0	0.20		0.20		0.20		0.30		0.20		0.32	
Geisha 5	0.18	**-10%**	0.20	**0%**	0.20	**0%**	0.30	**0%**	0.20	**0%**	0.40	**25%**
Geisha 10	0.16	**-20%**	0.20	**0%**	0.20	**0%**	0.30	**0%**	0.20	**0%**	0.42	**31%**
Geisha 15	0.12	**-40%**	0.22	**10%**	0.16	**-20%**	0.4	**33%**	0.2	**0%**	0.52	**63%**
Portia 0	0.16		0.18		0.20		0.20		0.20		0.22	
Portia 7	0.16	**0%**	0.18	**0%**	0.18	**-10%**	0.26	**30%**	0.20	**0%**	0.32	**45%**
Portia 10	0.16	**0%**	0.2	**11%**	0.2	**0%**	0.24	**20%**	0.2	**0%**	0.32	**45%**
Portia 12	0.18	**13%**	0.26	**44%**	0.20	**0%**	0.34	**70%**	0.24	**20%**	0.40	**82%**
Portia 15	0.16	**0%**	0.16	**-11%**	0.2	**0%**	0.26	**30%**	0.22	**10%**	0.3	**36%**
Juno 0	0.14		0.18		0.20		0.20		0.20		0.24	
Juno 10	0.18	**29%**	0.14	**-22%**	0.2	**0%**	0.16	**-20%**	0.22	**10%**	0.22	**-8%**
Juno 17	0.14	**0%**	0.22	**22%**	0.20	**0%**	0.32	**60%**	0.20	**0%**	0.42	**75%**
Venus 0	0.20		0.10		0.20		0.20		0.20		0.20	
Venus 9	0.18	**-10%**	0.2	**100%**	0.2	**0%**	0.3	**50%**	0.22	**10%**	0.38	**90%**
Electra 0	0.12		0.22		0.2		0.4		0.22		0.52	
Electra 5	0.20	**67%**	0.30	**36%**	0.20	**0%**	0.42	**5%**	0.24	**9%**	0.60	**15%**
Electra 14	0.20	**67%**	0.30	**36%**	0.20	**0%**	0.48	**20%**	0.22	**0%**	0.64	**23%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	E4 1#	% change	E4 2#	% change	**E5 1***	% change	**E5 2***	% change	E10 1#	% change	E10 2#	% change
Geisha 0	0.22		0.40		0.28		0.50		0.38		0.80	
Geisha 5	0.24	**9%**	0.50	**25%**	0.28	**0%**	0.60	**20%**	0.38	**0%**	1.02	**28%**
Geisha 10	0.20	**-9%**	0.52	**30%**	0.22	**-21%**	0.66	**32%**	0.30	**-21%**	1.12	**40%**
Geisha 15	0.22	**0%**	0.62	**55%**	0.22	**-21%**	0.72	**44%**	0.32	**-16%**	1.16	**45%**
Portia 0	0.20		0.26		0.24		0.30		0.30		0.48	
Portia 7	0.22	**10%**	0.38	**46%**	0.22	**-8%**	0.42	**40%**	0.32	**7%**	0.74	**54%**
Portia 10	0.22	**10%**	0.36	**38%**	0.28	**17%**	0.42	**40%**	0.38	**27%**	0.7	**46%**
Portia 12	0.26	**30%**	0.50	**92%**	0.30	**25%**	0.56	**87%**	0.42	**40%**	0.88	**83%**
Portia 15	0.26	**30%**	0.36	**38%**	0.26	**8%**	0.46	**53%**	0.36	**20%**	0.76	**58%**
Juno 0	0.22		0.30		0.22		0.30		0.32		0.50	
Juno 10	0.26	**18%**	0.26	**-13%**	0.3	**36%**	0.28	**-7%**	0.4	**25%**	0.44	**-12%**
Juno 17	0.20	**-9%**	0.52	**73%**	0.20	**-9%**	0.62	**107%**	0.30	**-6%**	1.00	**100%**
Venus 0	0.22		0.20		0.30		0.20		0.38		0.32	
Venus 9	0.24	**9%**	0.42	**110%**	0.3	**0%**	0.5	**150%**	0.38	**0%**	0.86	**169%**
Electra 0	0.24		0.62		0.3		0.72		0.44		1.2	
Electra 5	0.30	**25%**	0.74	**19%**	0.32	**7%**	0.90	**25%**	0.50	**14%**	1.40	**17%**
Electra 14	0.28	**17%**	0.80	**29%**	0.32	**7%**	0.98	**36%**	0.42	**-5%**	1.62	**35%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	**E20 1***	**% change**	**E20 2***	**% change**	E30 1#	**% change**	E30 2#	**% change**	E40 3#	**% change**	E40 4#	**% change**
Geisha 0	0.52		1.22		0.62		1.60		0.72		1.90	
Geisha 5	0.52	**0%**	1.66	**36%**	0.62	**0%**	2.18	**36%**	0.70	**-3%**	2.60	**37%**
Geisha 10	0.42	**-19%**	1.84	**51%**	0.46	**-26%**	2.44	**53%**	0.54	**-25%**	2.94	**55%**
Geisha 15	0.42	**-19%**	1.84	**51%**	0.5	**-19%**	2.42	**51%**	0.58	**-19%**	2.86	**51%**
Portia 0	0.40		0.80		0.50		1.08		0.54		1.30	
Portia 7	0.38	**-5%**	1.24	**55%**	0.42	**-16%**	1.62	**50%**	0.52	**-4%**	2.00	**54%**
Portia 10	0.5	**25%**	1.12	**40%**	0.6	**20%**	1.5	**39%**	0.7	**30%**	1.84	**42%**
Portia 12	0.52	**30%**	1.40	**75%**	0.62	**24%**	1.88	**74%**	0.68	**26%**	2.28	**75%**
Portia 15	0.5	**25%**	1.2	**50%**	0.62	**24%**	1.62	**50%**	0.72	**33%**	1.96	**51%**
Juno 0	0.42		0.80		0.50		1.00		0.56		1.20	
Juno 10	0.56	**33%**	0.64	**-20%**	0.66	**32%**	0.82	**-18%**	0.74	**32%**	0.96	**-20%**
Juno 17	0.40	**-5%**	1.52	**90%**	0.50	**0%**	1.96	**96%**	0.52	**-7%**	2.34	**95%**
Venus 0	0.52		0.52		0.54		0.64		0.62		0.78	
Venus 9	0.5	**-4%**	1.32	**154%**	0.58	**7%**	1.72	**169%**	0.64	**3%**	2.06	**164%**
Electra 0	0.62		1.8		0.74		2.32		0.86		2.72	
Electra 5	0.72	**16%**	2.16	**20%**	0.86	**16%**	2.76	**19%**	1.02	**19%**	3.26	**20%**
Electra 14	0.62	**0%**	2.56	**42%**	0.76	**3%**	3.26	**41%**	0.88	**2%**	3.82	**40%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	E50 1#	**% change**	E50 2#	**% change**	**ratio**	**% change**	E60 1#	**% change**	E60 2#	**% change**
Geisha 0	0.78		2.16		0.361		0.82		2.46	
Geisha 5	0.80	**3%**	2.98	**38%**	0.268	**-26%**	0.84	**2%**	3.34	**36%**
Geisha 10	0.58	**-26%**	3.40	**57%**	0.171	**-53%**	0.64	**-22%**	3.80	**54%**
Geisha 15	0.62	**-21%**	3.3	**53%**	0.188	**-48%**	0.68	**-17%**	3.64	**48%**
Portia 0	0.60		1.58		0.380		0.64		1.80	
Portia 7	0.52	**-13%**	2.38	**51%**	0.218	**-42%**	0.56	**-13%**	2.68	**49%**
Portia 10	0.76	**27%**	2.16	**37%**	0.352	**-7%**	0.84	**31%**	2.4	**33%**
Portia 12	0.72	**20%**	2.64	**67%**	0.273	**-28%**	0.80	**25%**	2.98	**66%**
Portia 15	0.78	**30%**	2.3	**46%**	0.339	**-11%**	0.84	**31%**	2.62	**46%**
Juno 0	0.64		1.40		0.457		0.66		1.60	
Juno 10	0.82	**28%**	1.1	**-21%**	0.745	**63%**	0.88	**33%**	1.26	**-21%**
Juno 17	0.60	**-6%**	2.66	**90%**	0.226	**-51%**	0.64	**-3%**	2.94	**84%**
Venus 0	0.72		0.90		0.800		0.72		1.02	
Venus 9	0.7	**-3%**	2.36	**162%**	0.297	**-63%**	0.74	**3%**	2.6	**155%**
Electra 0	0.96		3.14		0.306		1.06		3.48	
Electra 5	1.14	**19%**	3.68	**17%**	0.310	**1%**	1.24	**17%**	4.08	**17%**
Electra 14	0.98	**2%**	4.32	**38%**	0.227	**-26%**	1.06	**0%**	4.72	**36%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	E70 1#	**% change**	E70 2#	**% change**	E80 1#	**% change**	E80 2#	**% change**	E90 1#	**% change**	E90 2#	**% change**
Geisha 0	0.90		2.68		0.92		2.92		1.00		3.16	
Geisha 5	0.92	**2%**	3.66	**37%**	1.00	**9%**	3.96	**36%**	1.04	**4%**	4.26	**35%**
Geisha 10	0.66	**-27%**	4.18	**56%**	0.70	**-24%**	4.50	**54%**	0.74	**-26%**	4.82	**53%**
Geisha 15	0.72	**-20%**	4	**49%**	0.76	**-17%**	4.3	**47%**	0.82	**-18%**	4.6	**46%**
Portia 0	0.68		2.00		0.70		2.20		0.76		2.38	
Portia 7	0.62	**-9%**	2.98	**49%**	0.62	**-11%**	3.26	**48%**	0.62	**-18%**	3.58	**50%**
Portia 10	0.9	**32%**	2.7	**35%**	0.94	**34%**	2.94	**34%**	1	**32%**	3.18	**34%**
Portia 12	0.82	**21%**	3.32	**66%**	0.90	**29%**	3.60	**64%**	0.92	**21%**	3.92	**65%**
Portia 15	0.88	**29%**	2.86	**43%**	0.98	**40%**	3.14	**43%**	0.98	**29%**	3.38	**42%**
Juno 0	0.74		1.80		0.76		1.96		0.82		2.10	
Juno 10	0.94	**27%**	1.38	**-23%**	1	**32%**	1.48	**-24%**	1.04	**27%**	1.6	**-24%**
Juno 17	0.68	**-8%**	3.18	**77%**	0.70	**-8%**	3.46	**77%**	0.76	**-7%**	3.66	**74%**
Venus 0	0.74		1.10		0.82		1.20		0.82		1.28	
Venus 9	0.78	**5%**	2.8	**155%**	0.82	**0%**	2.96	**147%**	0.84	**2%**	3.14	**145%**
Electra 0	1.14		3.82		1.22		4.1		1.28		4.38	
Electra 5	1.34	**18%**	4.38	**15%**	1.44	**18%**	4.72	**15%**	1.50	**17%**	5.00	**14%**
Electra 14	1.14	**0%**	5.06	**32%**	1.22	**0%**	5.42	**32%**	1.28	**0%**	5.72	**31%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	**E100 1***	**% change**	**E100 2***	**% change**	**ratio**	**% change**	E1 3#	**% change**	E1 4#	**% change**
Geisha 0	1.02		3.36		0.304		1.66		1.76	
Geisha 5	1.10	**8%**	4.52	**35%**	0.243	**-20%**	2.02	**22%**	1.90	**8%**
Geisha 10	0.78	**-24%**	5.16	**54%**	0.151	**-50%**	2.36	**42%**	2.10	**19%**
Geisha 15	0.86	**-16%**	4.86	**45%**	0.177	**-42%**	3.38	**104%**	3.12	**77%**
Portia 0	0.78		2.56		0.305		1.45		1.86	
Portia 7	0.72	**-8%**	3.84	**50%**	0.188	**-38%**	1.96	**35%**	2.04	**10%**
Portia 10	1.06	**36%**	3.42	**34%**	0.310	**2%**	2.22	**53%**	2.54	**37%**
Portia 12	0.94	**21%**	4.20	**64%**	0.224	**-27%**	2.64	**82%**	2.86	**54%**
Portia 15	1.08	**38%**	3.64	**42%**	0.297	**-3%**	2.94	**102%**	3.04	**63%**
Juno 0	0.84		2.32		0.362		1.37		1.68	
Juno 10	1.12	**33%**	1.7	**-27%**	0.659	**82%**	1.86	**36%**	1.56	**-7%**
Juno 17	0.78	**-7%**	3.86	**66%**	0.202	**-44%**	2.55	**86%**	2.41	**43%**
Venus 0	0.88		1.38		0.638		2.52		2.32	
Venus 9	0.9	**2%**	3.32	**141%**	0.271	**-57%**	3.12	**24%**	2.6	**12%**
Electra 0	1.34		4.64		0.289		2.78		3.1	
Electra 5	1.56	**16%**	5.24	**13%**	0.298	**3%**	3.30	**19%**	3.68	**19%**
Electra 14	1.36	**1%**	6.00	**29%**	0.227	**-22%**	3.63	**30%**	4.44	**43%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	E2 3#	% change	E2 4#	% change	E3 3#	% change	E3 4#	% change	E4 3#	% change	E4 4#	% change
Geisha 0	2.56		2.72		3.28		3.42		3.86		3.98	
Geisha 5	3.34	**30%**	3.38	**24%**	4.26	**30%**	4.42	**29%**	4.96	**28%**	5.10	**28%**
Geisha 10	3.68	**44%**	3.50	**29%**	4.70	**43%**	4.54	**33%**	5.34	**38%**	5.18	**30%**
Geisha 15	5.12	**100%**	4.52	**66%**	6.3	**92%**	5.64	**65%**	7.08	**83%**	6.42	**61%**
Portia 0	2.43		3.03		3.21		3.91		3.79		4.55	
Portia 7	3.32	**37%**	3.60	**19%**	4.32	**35%**	4.60	**18%**	5.10	**34%**	5.36	**18%**
Portia 10	3.5	**44%**	4.04	**33%**	4.42	**38%**	5.02	**28%**	5.1	**34%**	5.78	**27%**
Portia 12	4.06	**67%**	4.24	**40%**	5.14	**60%**	5.20	**33%**	5.88	**55%**	5.94	**31%**
Portia 15	4.2	**73%**	4.62	**52%**	5.08	**58%**	5.66	**45%**	5.72	**51%**	6.34	**39%**
Juno 0	2.13		2.66		2.71		3.41		3.17		3.93	
Juno 10	3.06	**43%**	2.8	**5%**	3.9	**44%**	3.72	**9%**	4.5	**42%**	4.32	**10%**
Juno 17	3.85	**81%**	3.71	**39%**	4.78	**76%**	4.65	**36%**	5.47	**72%**	5.32	**35%**
Venus 0	3.96		3.56		5.04		4.50		5.80		5.22	
Venus 9	4.54	**15%**	3.74	**5%**	5.36	**6%**	4.58	**2%**	6	**3%**	5.04	**-3%**
Electra 0	4.18		4.72		5.3		5.92		6.08		6.78	
Electra 5	4.88	**17%**	5.27	**12%**	5.94	**12%**	6.32	**7%**	6.70	**10%**	7.07	**4%**
Electra 14	5.30	**27%**	6.08	**29%**	6.43	**21%**	7.15	**21%**	7.25	**19%**	7.91	**17%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	**E5 3***	% change	**E5 4***	% change	E10 3#	% change	E10 4#	% change	E15 3#	% change	E15 4#	% change
Geisha 0	4.40		4.46		6.20		6.12		7.56		7.36	
Geisha 5	5.58	**27%**	5.76	**29%**	7.62	**23%**	7.92	**29%**	9.04	**20%**	9.40	**28%**
Geisha 10	6.02	**37%**	5.80	**30%**	8.14	**31%**	7.90	**29%**	9.58	**27%**	9.30	**26%**
Geisha 15	7.78	**77%**	7.1	**59%**	10.14	**64%**	9.12	**49%**	11.6	**53%**	10.5	**43%**
Portia 0	4.34		5.15		6.05		6.96		7.27		8.27	
Portia 7	5.70	**31%**	6.04	**17%**	7.82	**29%**	8.12	**17%**	9.18	**26%**	9.50	**15%**
Portia 10	5.68	**31%**	6.46	**26%**	7.5	**24%**	8.42	**21%**	8.82	**21%**	9.82	**19%**
Portia 12	6.50	**50%**	6.54	**27%**	8.60	**42%**	8.46	**22%**	9.98	**37%**	9.74	**18%**
Portia 15	6.34	**46%**	7.08	**38%**	8.18	**35%**	9.08	**30%**	9.44	**30%**	10.44	**26%**
Juno 0	3.63		4.44		5.13		6.16		6.24		7.39	
Juno 10	5.06	**40%**	4.88	**10%**	6.72	**31%**	6.68	**8%**	7.86	**26%**	7.88	**7%**
Juno 17	6.08	**68%**	5.89	**33%**	8.03	**57%**	7.76	**26%**	9.35	**50%**	9.02	**22%**
Venus 0	6.46		5.78		8.50		7.58		9.78		8.68	
Venus 9	6.5	**1%**	5.48	**-5%**	8.22	**-3%**	6.98	**-8%**	9.34	**-4%**	8	**-8%**
Electra 0	6.84		7.52		9		9.78		10.44		11.3	
Electra 5	7.46	**9%**	7.75	**3%**	9.60	**7%**	9.92	**1%**	11.10	**6%**	11.33	**0%**
Electra 14	7.97	**17%**	8.61	**15%**	10.21	**13%**	10.76	**10%**	11.73	**12%**	12.18	**8%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	E20 3#	**% change**	E20 4#	**% change**	E25 3#	**% change**	E25 4#	**% change**	E30 3#	**% change**	E30 4#	**% change**
Geisha 0	8.62		8.32		9.52		9.16		10.28		9.90	
Geisha 5	10.12	**17%**	10.52	**26%**	11.08	**16%**	11.44	**25%**	11.84	**15%**	12.26	**24%**
Geisha 10	10.72	**24%**	10.42	**25%**	11.62	**22%**	11.38	**24%**	12.44	**21%**	12.20	**23%**
Geisha 15	12.74	**48%**	11.58	**39%**	13.72	**44%**	12.42	**36%**	14.48	**41%**	13.2	**33%**
Portia 0	8.26		9.29		9.09		10.15		9.79		10.89	
Portia 7	10.24	**24%**	10.54	**13%**	11.18	**23%**	11.42	**13%**	11.94	**22%**	12.16	**12%**
Portia 10	9.8	**19%**	10.8	**16%**	10.62	**17%**	11.66	**15%**	11.36	**16%**	12.38	**14%**
Portia 12	11.06	**34%**	10.80	**16%**	11.96	**32%**	11.66	**15%**	12.76	**30%**	12.40	**14%**
Portia 15	10.42	**26%**	11.42	**23%**	11.24	**24%**	12.3	**21%**	11.92	**22%**	13.04	**20%**
Juno 0	7.15		8.39		7.92		9.24		8.61		9.99	
Juno 10	8.76	**22%**	8.76	**4%**	9.48	**20%**	9.52	**3%**	10.14	**18%**	10.16	**2%**
Juno 17	10.39	**45%**	10.00	**19%**	11.23	**42%**	10.79	**17%**	11.97	**39%**	11.49	**15%**
Venus 0	10.68		9.54		11.42		10.20		12.08		10.76	
Venus 9	10.16	**-5%**	8.76	**-8%**	10.88	**-5%**	9.4	**-8%**	11.52	**-5%**	9.96	**-7%**
Electra 0	11.58		12.38		12.5		13.32		13.22		14.06	
Electra 5	12.28	**6%**	12.40	**0%**	13.22	**6%**	13.30	**0%**	14.02	**6%**	14.05	**0%**
Electra 14	12.85	**11%**	13.25	**7%**	13.78	**10%**	14.15	**6%**	14.57	**10%**	14.92	**6%**

Percentage difference calculated from 0% weight reduction for each fabric base

Fabric:	E35 3#	**% change**	E35 4#	**% change**	E40 3#	**% change**	E40 4#	**% change**	E45 3#	**% change**	E45 4#	**% change**
Geisha 0	11.04		10.56		11.72		11.18		12.32		11.74	
Geisha 5	12.56	**14%**	12.96	**23%**	13.22	**13%**	13.60	**22%**	13.78	**12%**	14.16	**21%**
Geisha 10	13.12	**19%**	12.88	**22%**	13.76	**17%**	13.52	**21%**	14.36	**17%**	14.10	**20%**
Geisha 15	15.2	**38%**	13.82	**31%**	15.8	**35%**	14.42	**29%**	16.4	**33%**	14.94	**27%**
Portia 0	10.45		11.58		11.05		12.19		11.59		12.77	
Portia 7	12.60	**21%**	12.82	**11%**	13.20	**19%**	13.44	**10%**	13.74	**19%**	13.98	**9%**
Portia 10	12	**15%**	13.02	**12%**	12.58	**14%**	13.6	**12%**	13.08	**13%**	14.14	**11%**
Portia 12	13.40	**28%**	13.04	**13%**	14.00	**27%**	13.62	**12%**	14.56	**26%**	14.22	**11%**
Portia 15	12.6	**21%**	13.7	**18%**	13.14	**19%**	14.3	**17%**	13.68	**18%**	14.84	**16%**
Juno 0	9.22		10.67		9.82		11.29		10.39		11.87	
Juno 10	10.68	**16%**	10.76	**1%**	11.22	**14%**	11.3	**0%**	11.68	**12%**	11.8	**-1%**
Juno 17	12.66	**37%**	12.09	**13%**	13.22	**35%**	12.65	**12%**	13.83	**33%**	13.19	**11%**
Venus 0	12.62		11.28		13.10		11.68		13.54		12.08	
Venus 9	12.04	**-5%**	10.44	**-7%**	12.5	**-5%**	10.88	**-7%**	13	**-4%**	11.3	**-6%**
Electra 0	13.96		14.72		14.56		15.38		15.16		16	
Electra 5	14.72	**5%**	14.72	**0%**	15.34	**5%**	15.28	**-1%**	15.90	**5%**	15.87	**-1%**
Electra 14	15.26	**9%**	15.57	**6%**	15.87	**9%**	16.19	**5%**	16.44	**8%**	16.73	**5%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	E50 3#	% change	E50 4#	% change	Manufacturing Grade		Total Distortion		Appearance rank	
Geisha 0	12.88		12.28		3.6		69.90		15	
Geisha 5	14.34	**11%**	14.72	**20%**	3	**-17%**	67.90	**-3%**	13	**-13%**
Geisha 10	14.84	**15%**	14.66	**19%**	2.6	**-28%**	59.60	**-15%**	1	**-93%**
Geisha 15	16.96	**32%**	15.46	**26%**	2.58	**-28%**	84.30	**21%**	3	**-80%**
Portia 0	12.14		13.29		2.8		92.20		17	
Portia 7	14.26	**17%**	14.50	**9%**	2.6	**-7%**	92.80	**1%**	11	**-35%**
Portia 10	13.6	**12%**	14.62	**10%**	2.4	**-14%**	85.90	**-7%**	12	**-29%**
Portia 12	15.14	**25%**	14.68	**10%**	2.6	**-7%**	100.50	**9%**	7	**-59%**
Portia 15	14.14	**16%**	15.36	**16%**	2.83	**1%**	79.20	**-14%**	6	**-65%**
Juno 0	10.89		12.41		3.6		88.70		14	
Juno 10	12.12	**11%**	12.24	**-1%**	2.6	**-28%**	111.30	**25%**	16	**14%**
Juno 17	14.33	**32%**	13.65	**10%**	2.6	**-28%**	87.20	**-2%**	8	**-43%**
Venus 0	14.02		12.46		2.8		119.00		10	
Venus 9	13.4	**-4%**	11.68	**-6%**	1	**-64%**	101.20	**-15%**	2	**-80%**
Electra 0	15.68		16.5		2.4		97.20		5	
Electra 5	16.44	**5%**	16.40	**-1%**	2.6	**8%**	134.20	**38%**	9	**80%**
Electra 14	17.01	**9%**	17.29	**5%**	2	**-17%**	139.30	**43%**	4	**-20%**
Percentage difference calculated from 0% weight reduction for each fabric base										

Appendix 4 Percentage Change in KES-FB1 Results due to Weight Reduction

Fabric:	g1	**% change**	G2	**% change**	ratio g1/2	**% change**
Geisha 0	0.37		0.38		1.027	
Geisha 5	0.32	**-14%**	0.36	**-5%**	1.125	**10%**
Geisha 10	0.33	**-11%**	0.31	**-18%**	0.939	**-9%**
Geisha 15	0.26	**-30%**	0.26	**-32%**	1.000	**-3%**
Portia 0	0.39		0.38		0.974	
Portia 7	0.32	**-18%**	0.3	**-21%**	0.938	**-4%**
Portia 10	0.31	**-21%**	0.3	**-21%**	0.968	**-1%**
Portia 12	0.3	**-23%**	0.27	**-29%**	0.900	**-8%**
Portia 15	0.29	**-26%**	0.62	**63%**	2.138	**119%**
Juno 0	0.39		0.32		0.821	
Juno 10	0.29	**-26%**	0.25	**-22%**	0.862	**5%**
Juno 17	0.27	**-31%**	0.25	**-22%**	0.926	**13%**
Venus 0	0.26		0.22		0.846	
Venus 9	0.24	**-8%**	0.21	**-5%**	0.875	**3%**
Electra 0	0.26		0.26		1.000	
Electra 5	0.26	**0%**	0.23	**-12%**	0.885	**-12%**
Electra 14	0.24	**-8%**	0.24	**-8%**	1.000	**0%**
Percentage difference calculated from 0% weight reduction for each fabric base						

Fabric:	2hg1	**% change**	2hg2	**% change**	2hg51	**% change**	2hg52	**% change**
Geisha 0	0.35		0.38		1.14		1.19	
Geisha 5	0.57	**63%**	0.52	**37%**	1	**-12%**	1.09	**-8%**
Geisha 10	0.38	**9%**	0.37	**-3%**	0.84	**-26%**	0.8	**-33%**
Geisha 15	0.23	**-34%**	0.24	**-37%**	0.47	**-59%**	0.51	**-57%**
Portia 0	0.69		0.48		1.41		1.1	
Portia 7	0.49	**-29%**	0.41	**-15%**	0.89	**-37%**	0.75	**-32%**
Portia 10	0.5	**-28%**	0.28	**-42%**	0.89	**-37%**	0.7	**-36%**
Portia 12	0.42	**-39%**	0.25	**-48%**	0.72	**-49%**	0.51	**-54%**
Portia 15	0.4	**-42%**	0.2	**-58%**	0.73	**-48%**	0.47	**-57%**
Juno 0	0.55		0.13		1.41		1	
Juno 10	0.41	**-25%**	0.11	**-15%**	0.82	**-42%**	0.42	**-58%**
Juno 17	0.32	**-42%**	0.17	**31%**	0.6	**-57%**	0.44	**-56%**
Venus 0	0.14		0.07		0.43		0.22	
Venus 9	0.15	**7%**	0.11	**57%**	0.43	**0%**	0.21	**-5%**
Electra 0	0.19		0.15		0.45		0.46	
Electra 5	0.23	**21%**	0.21	**40%**	0.43	**-4%**	0.38	**-17%**
Electra 14	0.13	**-32%**	0.17	**13%**	0.35	**-22%**	0.31	**-33%**
Percentage difference calculated from 0% weight reduction for each fabric base								

Fabric:	lt1	**% change**	lt2	**% change**	Wt1	**% change**	wt2	**% change**	rt1	**% change**	rt2	**% change**
Geisha 0	0.647		0.727		3.48		12.44		63.7		52.85	
Geisha 5	0.724	**12%**	0.684	**-6%**	4.06	**17%**	14.72	**18%**	65.8	**3%**	48.5	**-8%**
Geisha 10	0.69	**7%**	0.645	**-11%**	3.06	**-12%**	14.98	**20%**	66.5	**4%**	51.45	**-3%**
Geisha 15	0.663	**2%**	0.622	**-14%**	3.85	**11%**	13.25	**7%**	67.25	**6%**	51.05	**-3%**
Portia 0	0.756		0.77		3.23		12.53		65.7		57.9	
Portia 7	0.697	**-8%**	0.733	**-5%**	2.95	**-9%**	14.85	**19%**	67.6	**3%**	59.85	**3%**
Portia 10	0.715	**-5%**	0.739	**-4%**	3.85	**19%**	15.38	**23%**	66.9	**2%**	51.85	**-10%**
Portia 12	0.653	**-14%**	0.693	**-10%**	3.54	**10%**	16.42	**31%**	67.25	**2%**	51.7	**-11%**
Portia 15	0.641	**-15%**	0.705	**-8%**	3.81	**18%**	14.56	**16%**	66.9	**2%**	53.05	**-8%**
Juno 0	0.73		0.781		3.64		10.39		65.05		50.85	
Juno 10	0.715	**-2%**	0.782	**0%**	3.76	**3%**	7.99	**-23%**	68.95	**6%**	54	**6%**
Juno 17	0.659	**-10%**	0.711	**-9%**	3.17	**-13%**	12.12	**17%**	70.85	**9%**	48.3	**-5%**
Venus 0	0.815		0.8		3.22		6.13		69.65		49.3	
Venus 9	0.733	**-10%**	0.622	**-22%**	2.88	**-11%**	8.75	**43%**	68.6	**-2%**	50.8	**3%**
Electra 0	0.721		0.688		4.66		13.12		66.3		47.55	
Electra 5	0.652	**-10%**	0.637	**-7%**	5.09	**9%**	13.9	**6%**	67.6	**2%**	47.3	**-1%**
Electra 14	0.686	**-5%**	0.628	**-9%**	4.39	**-6%**	13.21	**1%**	68.9	**4%**	49.15	**3%**
Percentage difference calculated from 0% weight reduction for each fabric base												

Fabric:	emt1	**% change**	emt2	**% change**	ratio emt1/2	
Geisha 0	2.16		6.85		3.171	
Geisha 5	2.25	**4%**	8.61	**26%**	3.827	**21%**
Geisha 10	1.79	**-17%**	9.29	**36%**	5.190	**64%**
Geisha 15	2.33	**8%**	8.54	**25%**	3.665	**16%**
Portia 0	1.72		6.51		3.785	
Portia 7	1.7	**-1%**	8.1	**24%**	4.765	**26%**
Portia 10	2.17	**26%**	8.33	**28%**	3.839	**1%**
Portia 12	2.17	**26%**	9.48	**46%**	4.369	**15%**
Portia 15	2.38	**38%**	8.27	**27%**	3.475	**-8%**
Juno 0	2		5.33		2.665	
Juno 10	2.11	**5%**	4.09	**-23%**	1.938	**-27%**
Juno 17	1.93	**-4%**	6.82	**28%**	3.534	**33%**
Venus 0	1.58		3.08		1.949	
Venus 9	1.58	**0%**	5.64	**83%**	3.570	**83%**
Electra 0	2.62		7.63		2.912	
Electra 5	3.13	**19%**	8.72	**14%**	2.786	**-4%**
Electra 14	2.56	**-2%**	8.42	**10%**	3.289	**13%**
Percentage difference calculated from 0% weight reduction for each fabric base						

Appendix 5 – Previous Publication: An Investigation into Polyester Fabrics Using Objective Measurement

Conference paper presented in the Fibres to Finished Fabrics Conference, 1999
The Textile Institute,
7-8 December 1999,
Prestbury, Cheshire,
England.

An Investigation into Polyester Fabrics Using Objective Measurement

Judith Kerrigan & George A. F. Roberts

ABSTRACT

The aim of this work is to establish whether weight reduced polyester fabrics can be assessed using a modified version of the FAST (Fabric Assurance by Simple Testing). A further aim is to determine whether the results can be used to provide a link between the weight reduction process and the fabric's subsequent performance during clothing manufacture.

Weight reduction is a chemical process that erodes the surface of polyester fibres. It is used as a finishing technique to reduce friction between the fibres and yarns and therefore improves the fabric handle by increasing drape and reducing stiffness. The factors controlling the percentage weight reduction are the concentration of sodium hydroxide, the temperature, and the time of reaction. However there is a limit to the amount of weight reduction a fabric can undergo without significantly effecting its use in manufacture, by making the fabric too soft. This point is currently established by trial and error and from previous experience; it is hoped that the research will be able to provide a more scientific method for establishing the limits of the weight reduction process, taking into account the properties of the base fabric.

A number of tests were required in order to characterise the fabric fully; a modified version of the FAST was used together with the British Standard method of assessing drape. The FAST system is a Fabric Objective Measurement technique that uses measurements of thickness, bending, extension and dimensional stability to provide information on how a fabric will perform during manufacture. The FAST was

developed for fabrics with a suiting end use and therefore the parameters measured and the guidelines developed to predict manufacturing problems had to be altered. The test methods and samples were modified to be more appropriate to the nature of weight-reduced polyester fabrics that were for a lingerie end use. The modifications also took into account the garment silhouette that tended to exhibit problems; that is a bias-cut full-length dress.

The parameter that required the greatest modification was that of extension. A new weight system was developed that allowed a greater variation in the loads applied to the samples. Bias cut samples were included in the new extension method to provide more information about shear properties (albeit at smaller loads than the warp and weft), and the method of testing bending was also extended to include bias cut samples. This allowed more information to be gained about the fabric in ways relevant to its bias cut end use.

1 THE WEIGHT REDUCTION PROCESS

The term weight reduced is given to a polyester fabric when, as part of its finishing process, the fabric is treated with sodium hydroxide; this erodes the surface of the fibres. The process was patented by Hall and Whinfield in 1952 and subsequently used by DuPont in 1958 [1]. A picture of untreated and treated fibres can be found in the appendices.

1.1 Process Variables

The factors controlling the percentage weight reduction are the concentration of sodium hydroxide, the temperature, and the time of hydrolysis. Several researchers have found that temperature has a larger effect that the concentration of alkali, which in turn has a greater effect than the time of hydrolysis on the weight loss incurred by the fabric [1, 2] [3]. Dave and colleagues found that weight loss increases linearly with treatment time but non-linearly with alkali concentration and reaction temperature [2].

Houser found that the effect of the treatment depends on the base characteristics of the fabric [1]. Bright fibres with round cross-sections lose weight more slowly than delustred types with multi-lobal cross-sections; this could be due to the presence of the delustrent and/or the larger surface area. Samples appear to lose weight faster after texturing, also cationic dyeable yarns react very rapidly and the weight lost is difficult to control. Hsieh found that a short hydrolysis time (10-30 mins) actually increased fabric weight and thickness slightly [3].

1.2 Effect of Process

It has been found that weight reduced polyester provides a handle closer to silk than untreated polyester [4-6] [7]. Matsudaira and Matsui used discriminant analysis and found that the Hari (anti-drape stiffness) and Shinayakasa (flexibility with a soft feel) of the polyester fabrics were similar to that of silk after the weight reduction stage [8]. The weight reduction process does this by reducing bending and shear rigidity, thickness and mass [8]. Dave and colleagues found that a weight loss of 7% decreases the flexural rigidity results to half the original value [2].

It is also noteworthy that the process increases the comfort of the fabrics. It does not alter the low moisture regain of polyester, as the reaction is limited to the surface of the fibre, but although the fibre is still considered hydrophobic, the hydrolysis does enhance its moisture–related properties. An increase is found in the amount of water retained after immersion, and the wicking height and the water-drop-absorbency time decreases [9].

The technique reduces friction between the fibres and yarns which increases drape and reduces stiffness, thereby improving the fabric handle. Gorrafa states that this is due to greater fabric matrix freedom as well as the reduction in denier [10]. This agrees with the research of Matsudaira and Kawabata [4-6] who postulated that the improvement in handle of the treated polyester fabrics was due to the process introducing an effective gap between the warp and weft yarns at their crossover points. This is likened to the sericen removal of silk

	Silk	Polyester	Weight reduced Polyester
Effective gap	6.6	0.0	2.5

Although the weight reduction process introduces a small effective gap in the polyester fabric it also destabilises the weave structure which the sericen removal of silk does not do. There is therefore a limit of weight reduction that can be applied to polyester, however standards of between 20-25% exist in Japan [5].

Gorrafa stated that although each fabric should be considered separately in terms of its processing conditions and optimum weight loss, some generalisations can be made. For example, woven fabrics for blouse/shirt/dress type end uses have an optimum weight loss of between 15-17% [10]. He stated that a weight reduction of more than 25% yields lighter fabrics with only marginal additional suppleness, his theory was that the only the minimum level of weight loss that is detectable in an improvement in fabric qualities should be used.

2 THE FAST

FAST was developed as an Objective Measurement System by the Commonwealth Scientific Industrial Research Organisation (CSIRO) and introduced in 1989. The instruments were developed to provide data on fabric tailorability; it is not intended to predict handle properties. The order of the parameters listed in the data control sheet is the order of importance found by CSIRO for suiting fabrics with good tailorability properties. A list of these properties can be found in the appendices.

The FAST has been favourably compared with the other Objective Measurement System of KES-F (Kawabata Evaluation System for Fabrics). Barndt has stated that he found the FAST system a better predictor of tailoring difficulties than the KES [11]. Shishoo reports that "the FAST is much cheaper, simpler and more robust than the KES-F system, and hence perhaps more suited to an industrial environment [12]. The FAST was developed to assess the mechanical properties of suiting end use fabrics, traditionally wool fabrics. Numerous articles have been written about the instruments use in assessing the effects of the finishing process on wool fabrics [13] [14-16]. Other areas where research has been developed include garment appearance [17, 18], shirting fabrics [19-22], non-woven fabrics [23] and pattern development [24].

3 THE PROBLEM

As the weight reduction process destabilises the weave structure, there are limits to amount of treatment a fabric can undergo without causing problems in manufacture. The fabric manufacturer in question currently established the limits of the weight reduction process by trial and error and from previous experience. However they were interested in finding a more scientific method for establishing these limits, taking into account the properties of the base fabric. All the fabrics tested were for a lingerie end use. Five different bases were used and commercial samples with varying amounts of weight reduction were tested, details of which can be found in the appendices.

It was noted that where complaints were received from garment manufacturers it was usually when the fabrics were used for full-length bias-cut nightdresses. As the equipment used in the manufacturing process would have an effect on whether a particular fabric was a problem, it was decided to conduct an independent manufacturing trial. A pattern was chosen to represent the bias cut silhouette. The seventeen polyester fabrics were all cut using a vacuum-cutting table to minimise any differences due to cutting and handling. They were then produced into dresses using the specifications found in the appendices.

An experienced machinist gave each fabric a grade from 1 to 5 depending on how it manufactured (1 hardest and 5 easiest). Each operation was given a grade as well as the overall performance of the fabric and the average was quoted.

4 MODIFICATIONS TO THE FAST

An initial set of fabrics with a wide variety of weight reductions and base fabrics, separate from the above investigation, were used to refine the modifications. The number of test parameters was greatly increased from the normal FAST procedures; this was in order to gain as much data as possible about the fabrics. It was decided to include parameters that were not normally used and establish statistically whether they were relevant, after all the data was collated, in order to reduce the data to a more manageable set. This follows the suggestion of other researchers that as many properties as possible should be tested initially and then reduced once those that are relevant have been established [25] [26] [27].

4.1 Procedural

The first modification that was made to the test methods was to increase the number of samples tested from three to five. The differences between these fabrics may be quite small and it was felt that there would be more confidence in the results with a larger data set. The next alteration was to add bias samples to the bending and extension tests, this is because the end garment was cut on the bias and therefore the bias directions relate to the warp and weft of a regular cut garment. It is not normal practise to measure bending in the bias direction, however Cooper stated that bending measurements taken in the two principle directions are often insufficient to fully define a fabric's bending properties; different types of variation can exist in the other directions for fabrics with similar warp and weft bending rigidities [28].

Bias samples are used in the standard extension method but only at low loads to provide the shear information, however with the modified procedure bias extension was measured at a series of loads. These changes allowed the formability in the bias directions to be assessed, Waesterberg used this method to establish the making up properties of wool [29].

Where the bias directions were included in the range of parameters measured (bending, formability, and shear/extension), they were calculated separately for each bias direction as well as the overall average. This was because all of the fabrics were satin weaves with an un-balanced weave structure. This could alter the properties between the bias samples, especially in extension. As such it was decided to assess the results separately, before the averages, to ensure no important data was lost.

The shear parameter was also slightly modified instead of simply using the formula at 5gf/cm; loads up to and including 5 grams were used. The equation had to be slightly modified to take into account the different forces of gravity that each load would incur. ?

The initial tests showed that both of the stability parameters (RS & HE) and the thickness measurements after steaming (STR) could be omitted from the group of tests. This is because the results for all the fabrics were so similar that no trends would be able to be established,

4.2 Equipment

In order to be able to test the samples at a variety of loads a new weight system was required. The standard technique for assessing the extension properties for the warp and weft directions is to measure the extension at 100 gf/cm width, (loads of 5 and 20 gf/cm width are also measured but for use in the formability formula). It was reasoned that 100 gf/cm might not be appropriate for these fabrics, so different loads with increments of 10 grams were used in order to achieve a clearer picture of the fabric characteristics.

The bias samples were tested in a similar manner, however a 5 gram increment was used and the parameter was only measured up to 50 gf/cm. This was because there is a fixed extension that can be recorded on the FAST equipment. Initial tests showed that, for some of the fabrics, extensions in the bias directions would exceed this limit if loads of greater than 50 gf/cm were used.

It was also decided that because research has shown that there is often more difference between fabrics at lower loads [30], initial increments of 1 gram be used up to 5 grams.

A number of trials were undertaken to establish how to change the loading system of the FAST – 2 Extension Meter. Various platforms were tried for the loading of balance weights but it was decided that the new weights should be in the form of rings with the same central hole dimensions as the standard FAST weights. This ensured that the weights were the correct distance from the central pivot that dictated the load exerted on the sample. Different widths and thicknesses enabled the load variations to be achieved. This allowed a data sheet to be produced for each of the fabrics, an example of which can be found in the appendices.

4.3 Repeat tests to assess the accuracy of the test

Due to the changes made to the standard extension test method and the different nature of the fabric to be tests, it was necessary to establish the accuracy and repeatability of the modifications.

Four fabrics were chosen at random from the group and three sets of tests were performed on them. The preparation and testing of each set were done on different days. The results were analysed using an Anova technique in order to calculate whether the results obtained on the three days differed significantly, results at all of the loads were assessed [31]. At the 0.01 level, 92% of the results (for the different loads and fabrics) showed no difference. Thus we can say for the majority of data points the evidence supports the assumption that there is no difference between results from the same fabric when prepared and tested on different days.

It was also decided to assess the reproducibility of the results by re-testing the three sets of samples. The results were assessed using a t-test for paired comparisons. Due to the nature of the tests it was appropriate to establish if the results from the second testing of the samples would be larger than the first . Only nine out of the 168 pairs (5%) showed a statistical increase in the second extension results, thus it can be seen that the same sample can be measured on different occasions without significantly altering the results, provided sufficient time for recovery has elapsed. In this case three weeks had passed, though it is likely that recovery would have been completed much more quickly.

It also points to the fact that those data points in the initial repeatability exercise that were statistically different from each other were probably due to actual differences within the fabric rather than any inaccuracy in the tests. If the initial results showed differences between the samples measured on the three occasions but the repeats of these sets individually agreed with the originals, it is likely that the results were a correct representation of the fabric and that the fabric had variations. The high percentage weight reduction of these fabrics could attribute to larger differences within fabric than one would normally expect.

Confidence intervals as a percentage of the mean were established from the initial fifteen samples for the four fabrics in both directions, and the averages for all the fabrics at each load were calculated. The right bias had lower confidence intervals than the left bias, indicating less variation in the results, however the difference was not statistically significant.

5 RESULTS

A method of visually interpreting the data was required. The FAST control chart could not be used because of the modified and additional parameters. However a similar chart format was developed, no limits were identified and the range was set to encompass the results obtained. It provided a useful means for comparison, an example of the chart with some of the results for the base fabrics can be found in the appendices.

5.1 The base fabrics

It was hoped that these results would help to pinpoint parameters that could indicate when a fabric might have problems in manufacturing. In order to compare the base fabrics one must have an idea of the manner in which the weight reduction process affects the different fabric stories. It was not straightforward to compare the fabrics as they do not all have the same percentage weight reductions (due to their commercial nature), however broad generalisations could be made. A graph of the manufacturing grades for all the fabrics can be found in the appendices.

Geisha, Portia and Juno were all considered fairly stable fabrics, they had high initial grades which were gradually reduced as the percentage weight reduction increased. The Electra fabric had the lowest initial grade, however as the weight reduction process did not alter the fabric as much as the above group it was also considered stable, but its inherent properties were more liable to cause problems in manufacturing. The Venus fabric was the most affected by the weight reduction with fabric V9 (Venus at 9%) having the lowest grade.

Thus it was noted that Venus and Electra fabrics were the ones that presented the most problems. Interpretation of the base fabrics chart (appendix 6) suggests reasons why, both fabrics had low results for the shear rigidity and drape coefficient parameters, the Electra fabric being the lowest of the two. The Electra fabric also had low bending rigidity in all directions whereas Venus was only low in the warp direction. The formability results were low for the Venus fabrics in warp and weft and low for the Electra fabrics in bias directions.

This indicates that both fabrics are liable for problems in manufacturing as the fabrics are very soft and too easy to distort. The fact that the Electra fabrics produced high extension results slightly compensates for the low results in the other parameters. It suggests that a great deal of its flexibility was due to the warp and weft threads, whereas for the Venus fabrics it was more due to distortion between the threads.

5.2 The effects of the weight reduction process

5.2.1 Bending

An increase in the percentage weight reduction leads to a general reduction in the bending results, (both bending length and rigidity) in all four directions tested. An example of the changes in results for bending rigidity can be found in the appendix. The bias results did not differ between the directions tested and therefore it was sufficient to use the average. The actual test results were not related to the amount of weight reduction; they were very dependent on the fabric's initial characteristics.

However it was not the amount of change in bending that was important; the Portia fabrics showed the largest changes, especially notable in the warp and bias directions. This would no doubt contribute to the reduction in its manufacturing grade, however as the initial untreated fabric was quite stiff, this increase in flexibility does not make fabric P15 (Portia at 15%) a particular problem in manufacture. The Electra fabrics presented the least amount of changes due to the weight reduction process, however they have the lowest results in all directions, this accounts for their difficulties in manufacturing.

There was less percentage difference in the weft directions for Geisha, Portia and Juno (from the initial base fabric) than in the warp and bias directions. The Venus fabrics and, to a lesser extent Electra fabrics, show a greater reduction in the bending rigidity results in the weft direction than the other directions. As these were the problem fabrics, this suggests that weft direction bending might be an important parameter to predict manufacturing problems. A pairwise plot of manufacturing grade against weft bending did not show a straightforward relationship, nor did the plots of warp and bias bending. This suggests that although bending rigidity is undoubtedly a factor in ease of manufacturing, it is in combination with other parameters.

5.2.2 Formability

There was a general trend for formability to decrease as percent weight reduction increases, this was found in all the directions except weft which showed an overall increase in the formability results with increasing weight reduction. An increase in formability would result from an increase in extension or bending rigidity. Generally extension increases with weight reduction percentage, however bending rigidity decreases. Thus for the weft direction the increase in extension must have been more significant than the reduction in bending rigidity, conversely for the other directions.

There were no major differences in the results for the bias two directions for formability; an average could therefore be used. Examples of the formability graphs can be found in the appendices.

The graphs show that in the warp direction shows that the Electra fabrics have high results and the Venus fabrics have low, as both these fabrics have problems in manufacturing this poses some interesting points. The high results for the Electra fabrics were due to their high extension values. As stated earlier this seems to compensate for the low results in the bending, shear and bias formability values. The low results for warp (and bias) formability for the Venus fabrics contributes with the bending and shear results to give V9 the lowest manufacturing grade. Thus is was noted that there were different combinations of the mechanical properties that cause contribute to problems in manufacture.

The Geisha fabrics were the most affected fabric in the warp direction and were moderately affected in the bias directions, the Portia fabrics were the most affected in the bias directions, these reduction in formability would contribute to the reduction in their manufacturing grades.

Formability in suiting fabrics is very related to ease of manufacture, with low results indicating problems. There was not such a straightforward relationship with these fabrics. The warp and bias direction results did suggest a relationship with lower formability values increasing the difficulty of manufacture, but it was not significant.

5.2.3 Shear

There was a general trend for shear rigidity to reduce as the weight reduction percentage increased at all loads, examples of the graphs using one of the loads can be found in the appendix. The shear results showed a slight difference in the results obtained from the different directions, the right bias produced results that varied more than direction the left bias. This difference was statistically assessed, but was not found to be significant, this would indicate that the average could be used.

The shear properties of Electra and Venus fabrics were the least affected by the weight reduction process, however their results were lower than the other fabrics at similar weight reductions. Geisha and Portia were the most affected with up to 50% reduction in shear rigidity at 15% weight reduction from the initial base fabric results.

No simple relationship with ease of manufacture however a general increase in difficulty was found with reduced shear rigidity values.

5.2.4 Drape

The general trend was for the drape coefficient to be reduced (fabric becomes more flexible) as the weight reduction percentage is increased.

The actual test results were not related to the amount of weight reduction but were very dependent of the fabric's initial characteristics. The drape properties of the Electra fabrics were the least affected, due to their low initial status. The results for the Venus fabrics were the most changed 23% reduction at V9).

Plotting the drape coefficient against the ease of manufacturing showed a general trend of reduction in drape coefficient increasing the difficulty in manufacturing.

5.2.5 Weight

The weight parameter is obviously very related to the weight reduction process, the higher the weight reduction percentage the lower the weight per square meter of the fabric is.

The percentage weight reduction as supplied by the fabric manufacturer does not necessarily represent the exact amount of weight lost by the fabric; a variation of 3%

would be within tolerance. It is seen that this has happened with the P10 (Portia at 10%) fabric that actually being heavier than the P7 (Portia at 7%) fabric.

Weight is often linked to ease of manufacture with heavier fabrics being easier. However in this case, although there was a general trend, there was no simple relationship.

5.2.6 Thickness

The results obtained from the compression meter were good measures of handle for suiting fabrics, however these weight reduced polyester fabrics showed no relationships with thickness. The fabrics were all very similar and there was no trend toward the thinner fabrics being the ones with high weight reductions.

There was also no relationship with the actual thickness measurements and ease of manufacture.

5.2.7 Extension

There was a general trend towards an increase in the extension results with increasing percentage weight reduction in the weft direction, although this was not a simple relationship. The results in the warp direction do not follow a distinguishable trend, the fabrics seem to be more stable in this direction and show less variation. It was noted earlier that the weft direction parameters seem to be more important than the warp direction.

The results for the Venus fabrics were the most affected by the weight reduction process with an increase of 140% at V9 from the base fabric when measured at 100gf/cm, Juno was the second most affected. The Electra fabrics changed the least, however the extension results were still the highest for fabrics with equivalent weight reductions. Although for the Electra fabrics the high extensions seem to reduce the problems in manufacture, this is due to being high prior to the finishing process, typically high extensions increase problems in manufacture. The increase in the extension results for the Juno and Venus fabrics are likely to reduce their manufacturing grades.

There was no simple relationship between the extension results and ease of manufacture.

5.2.8 Changes in manufacturing grade

Each of the test parameters contribute to the change in the manufacturing grade, however none of them explain it alone. In a further study a statistical relationship will be investigated in order to define this more decisively. At present the overall effect of the weight reduction process on the ease of manufacture will be judged from a combination of the initial results of the test parameters and how significantly they have been affected by the finishing.

Thus it can be summarised that Geisha, Portia and Juno were more stable than Venus and Electra because none of the test parameters with low initial results were significantly effected by the weight reduction process. The Portia fabrics, for example, were significantly affected in parameters of warp and bias bending, bias formability and shear, but initially it had high results for warp and bias bending, weft and bias formability, drape and shear.

The Venus fabrics were severely affected by the finishing process in weft bending, bias formability and weft extension, and had low initial results in the parameters of warp bending, warp and weft formability, shear and weft extension. The Electra fabrics were not significantly affected by the weight reduction process, however the majority of its initial parameters were low.

6 CONCLUSION

It has been shown that the modifications to the FAST equipment have provided data that can distinguish between the fabrics tested. Trends of low bending, drape and shear were identified, for the untreated fabrics, in order to determine those fabrics that will not withstand high weight reductions. The effects of the weight reduction process were also identified as reductions in resistance to bending and shear, lower drape coefficients and formability results and increases in fabric extension.

The results to date show that it is not possible to identify potential problems in manufacture from a consideration of the results of a single parameter. An indication can be obtained from the properties of the base fabric and there is a generalised reduction in manufacturing grade with increase in the percentage weight reduction. However all the fabrics do not show the same changes in the test parameters with increasing weight reductions, thus the effects of the process on each fabric type must also be assessed.

The problem fabrics do have some similarities; they tend to have low resistance to bending and shear, and low drape coefficients. However compensation can be found if the untreated fabric has large results for formability and extension, these indicate greater flexibility of the threads rather than distortion between them.

7 FURTHER WORK

This research is part of a larger investigation for a PhD, further statistical analysis of the data will be performed to assess which parameters are the most important and then model these in an equation to predict the ease of manufacturing grade. Data on the dropping factor will also be included by assessing the changes in dress dimensions using a 3-d measuring booth. Due to the constraints of time and size of paper they were not included here.

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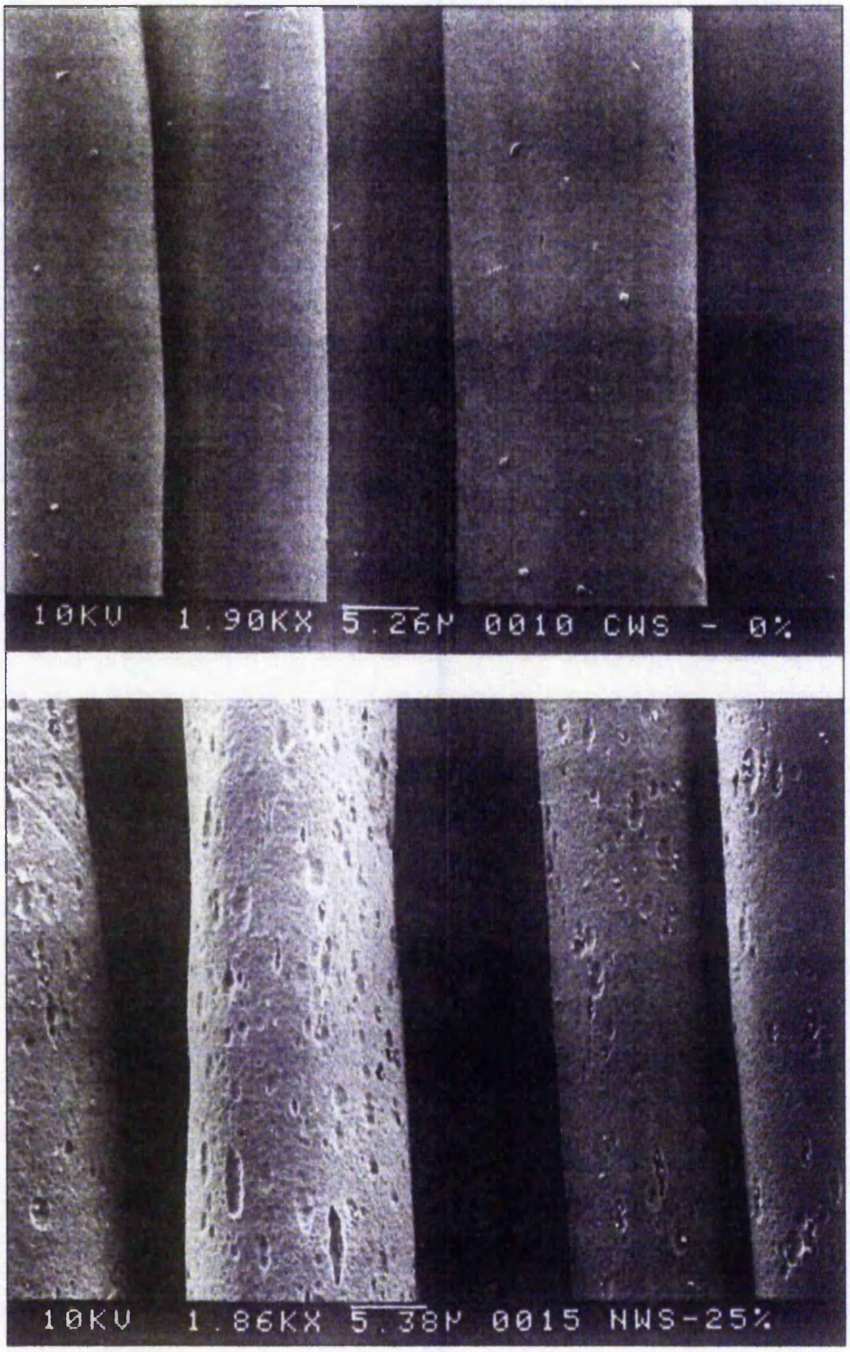
APPENDICES

Appendix 1 - Example of Treated and Un-treated fibres



Top: untreated

Bottom: after treatment with 10% acqueous NaOH at 60°C

Weight loss = 25 %

Source: [32]

Appendix 2 - Fast Properties

RS	Relaxation Shrinkage	%
HE	Hygral Expansion	%
F	Formability	mm^2
E	Extension	%
B	Bending Rigidity	μN.m
G	Shear Rigidity	N/m
T	Thickness	mm
ST	Surface Thickness	mm
STR	Released Surface Thickness	mm
W	Weight	g/m^2

Appendix 3 - Fabric Details

Notation	% WR	Story	Warp Type	Endage	Weft Type	Picks	Twist
G0	0	Geisha	50 den 36 fil flat	15,000	75 den 72 fil nonionic	108	v. low
G5	5						
G10	10						
G15	15						
P0	0	Portia	50 den 36 fil flat	15,000	70.2 den 36 fil nonionic	110	none
P7	7						
P10	10						
P12	12						
P15	15						
J0	0	Juno	50 den 36 fil flat	15,000	75 den 36 fil nonionic	107	mid
J10	10						
J17	17						
V0	0	Venus	50 den 36 fil flat	13,000	75 den 36 fil cationic	109	high
V9	9						
E0	0	Electra	50 den 36 fil flat	13,000	75 den 72 fil nonionic	109	low/ mid
E5	5						
E14	14						

Appendix 4 - Manufacturing Data Sheet

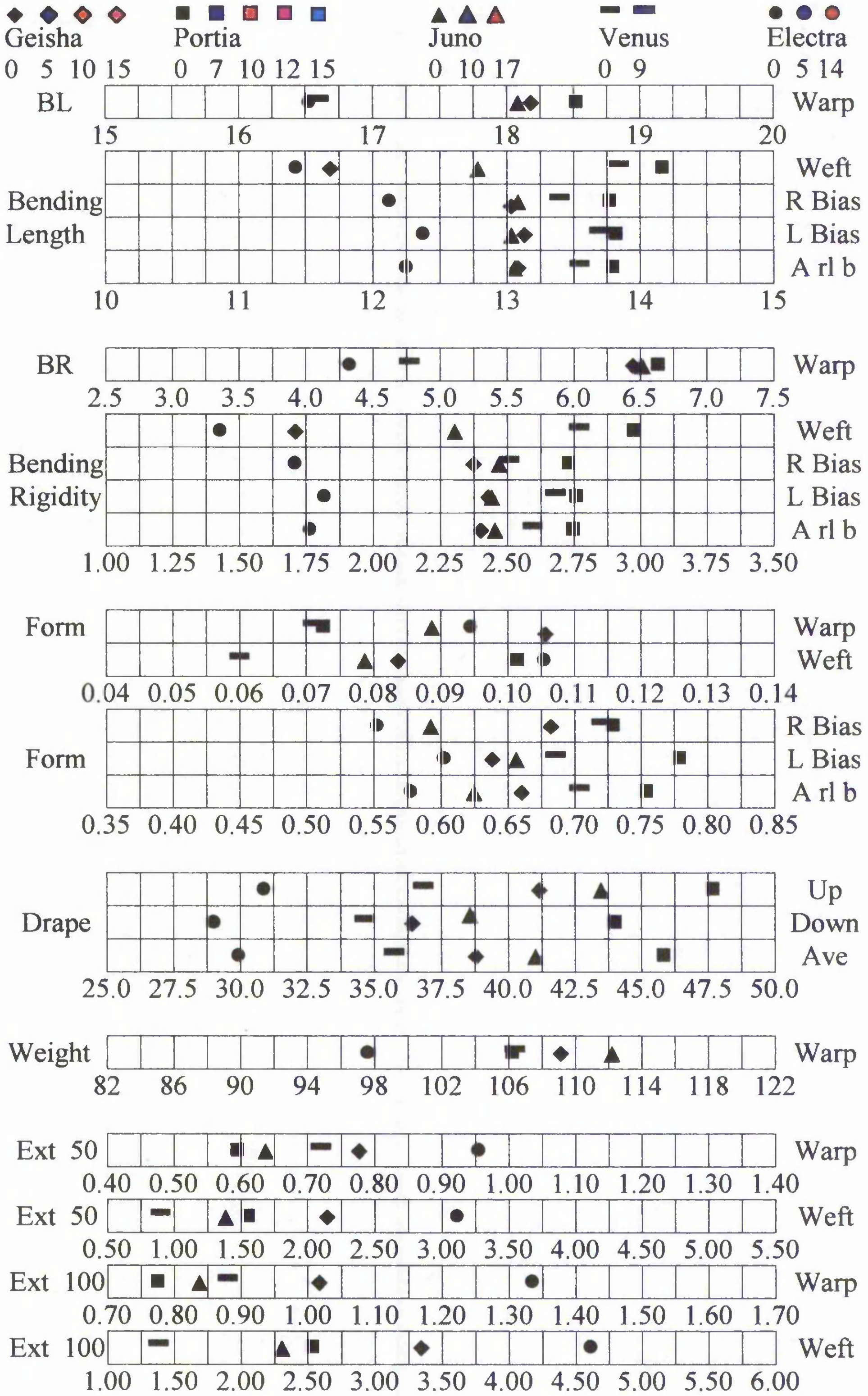
Fabric:
Date :
Time:

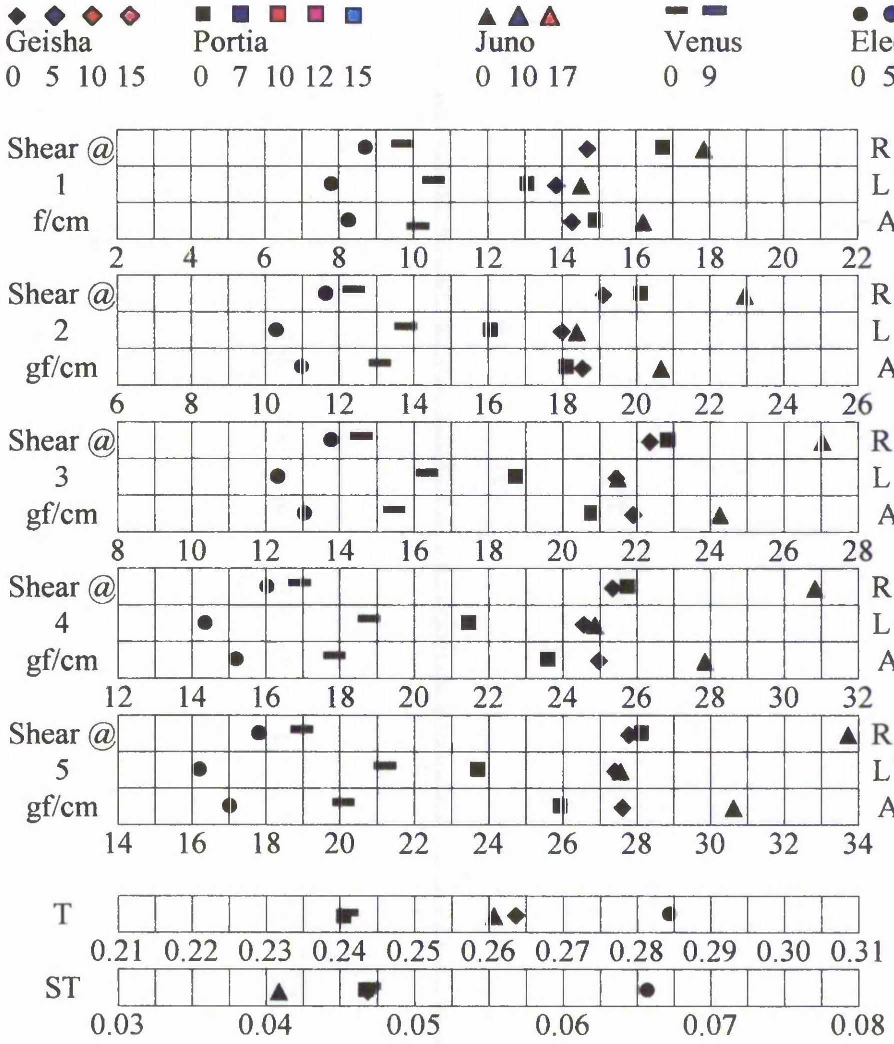
No.	Operation	Difficult → Normal → Easy				
		1	2	3	4	5
1	Lock stitch darts – front					
2	Overlock & join shoulders					
3	Overlock edge centre back seam					
4	Lock stitch join centre back (leave 13 cm at top for neck opening)					
5	Lock stitch neck binding inserting loop					
6	Lock stitch neck opening					
7	Overlock insert sleeve into armhole					
8	Overlock & join side seams					
9	Overlock edge sleeve hems & dress hem					
10	Lock stitch sleeve hems & dress hem					
11	Attach button					
12	Overall opinion of fabric					

Appendix 5 - Fabric Data Sheet

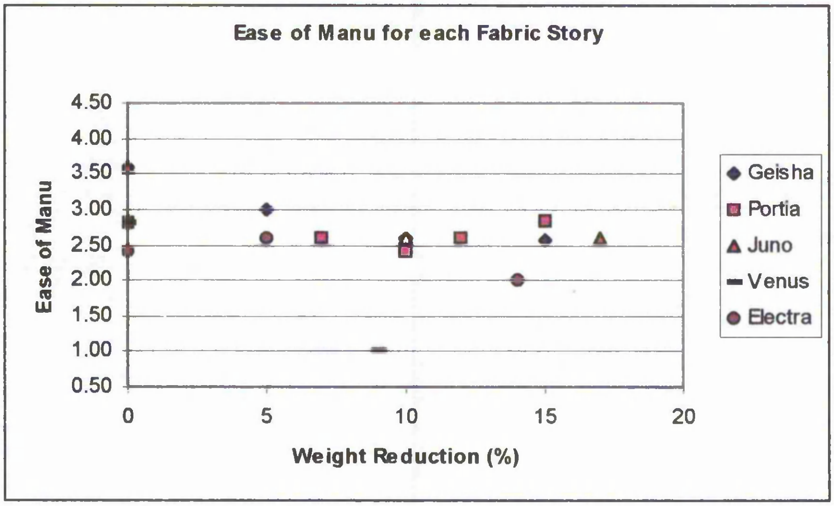
Fabric:							
Bending				Extension			
C 1*	average of 5			E1 1#	average of 5	E1 3#	Average of 5
C 1*	average of 5			E1 2#	average of 5	E1 4#	Average of 5
C 3#	average of 5						
C 4#	average of 5			E2 1#	average of 5	E2 3#	Average of 5
				E2 2#	average of 5	E2 4#	Average of 5
B 1*	weight x $C1^3$ x 9.81 x 10^{-6}						
B 2*	weight x $C2^3$ x 9.81 x 10^{-6}			E3 1#	average of 5	E3 3#	Average of 5
B 3#	weight x $C3^3$ x 9.81 x 10^{-6}			E3 2#	average of 5	E3 4#	Average of 5
B 4#	weight x $C4^3$ x 9.81 x 10^{-6}						
				E4 1#	average of 5	E4 3#	Average of 5
Formability				E4 2#	average of 5	E4 4#	Average of 5
F 1*	((E20-E5)*B)/14.7						
F 2*	((E20-E5)*B)/14.7			**E5 1***	average of 5	**E5 3***	Average of 5
F 3#	((E20-E5)*B)/14.7			**E5 2***	average of 5	**E5 4***	Average of 5
F 4#	((E20-E5)*B)/14.7						
				E10 1#	average of 5	E10 3#	Average of 5
Shear				E10 3#	average of 5	E10 4#	Average of 5
G 1#	24.5/E1 3	24.5/E1 4					
G 2#	49.1/E2 3	49.1/E2 4		**E20 1***	average of 5	E15 3#	Average of 5
G 3#	73.6/E3 3	73.6/E3 4		**E20 2***	average of 5	E15 4#	Average of 5
G 4#	98.1/E4 3	98.1/E4 4					
G 5*	122.6/E5 3	122.6/E5 4		E30 1#	average of 5	E20 3#	Average of 5
				E30 2#	average of 5	E20 4#	Average of 5
Drape							
DC FU#	cut out / original %			E40 1 #	average of 5	E25 3#	Average of 5
DC FD#	cut out / original %			E40 2#	average of 5	E25 4#	Average of 5
Nodes FU#	average of 6						
Nodes FD#	average of 6			E50 1#	average of 5	*E30 3#*	Average of 5
				E50 2#	average of 5	*E30 4#*	Average of 5
Weight*	average of 5						
				E60 1#	average of 5	E35 3#	Average of 5
Thickness				E60 2#	average of 5	E35 4#	Average of 5
T 2*	average of 5						
T 100*	average of 5			E70 1#	average of 5	*E40 3#*	Average of 5
ST*	T2-T100			E70 2#	average of 5	*E40 4#*	Average of 5
				E80 1#	average of 5	E45 3#	Average of 5
In all cases: **1 = Warp** ↑ **2 = Weft** → **3 = 45 degrees** ↗ **4 = 135 degrees** ↖ **Normal FAST = *** **Modified FAST = #**				E80 2#	average of 5	E45 4#	Average of 5
				E90 1#	average of 5	E50 3#	Average of 5
				E90 2#	average of 5	E50 4#	Average of 5
				E100 1*	average of 5		
				E100 2*	average of 5		

Appendix 6 – Base Fabric Results Chart

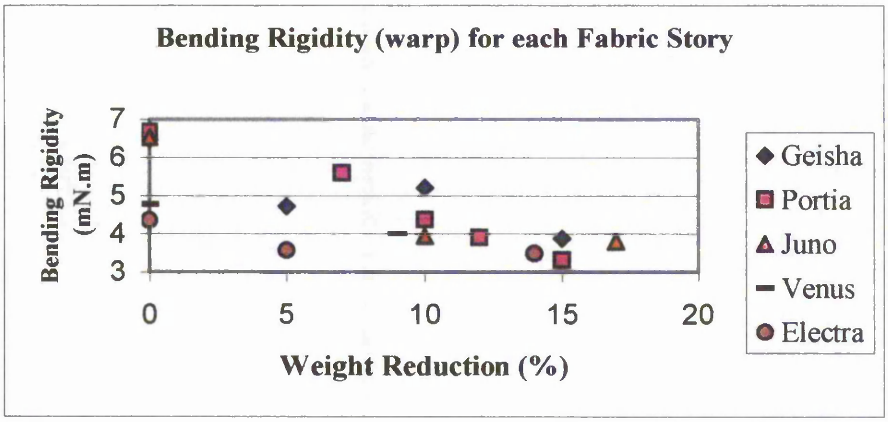


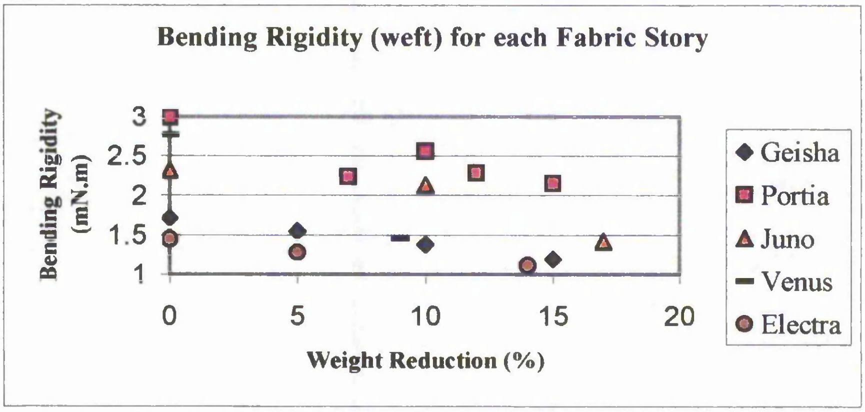


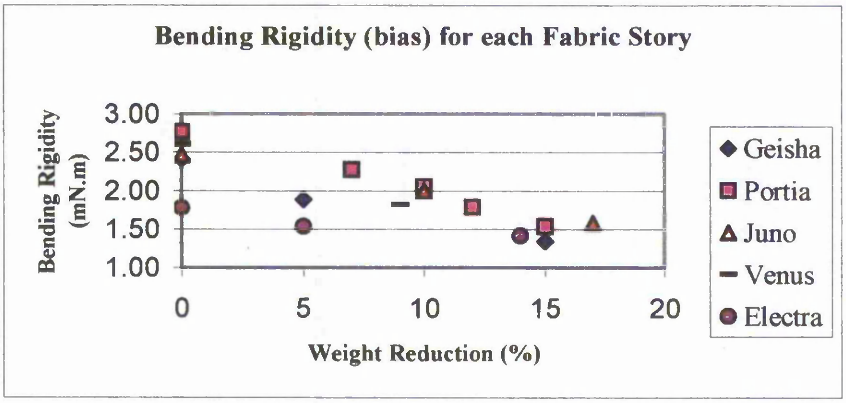
Appendix 7 – Effect of Weight Reduction on Manufacturing Grade



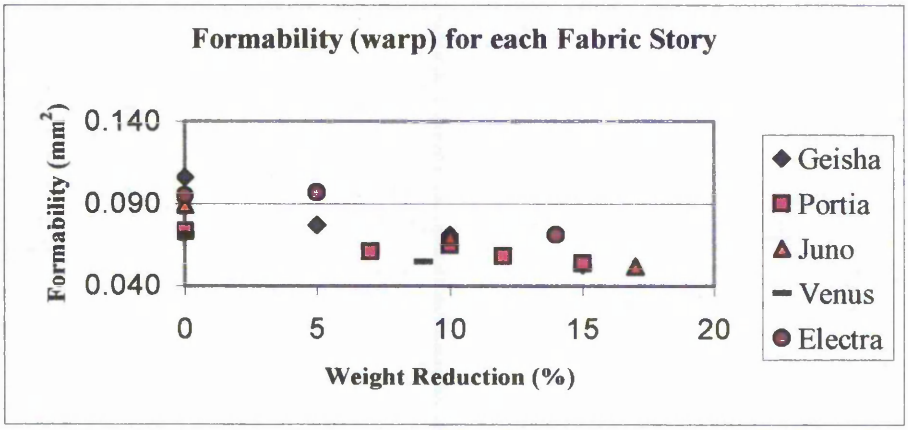
Appendix 8 – Bending Rigidity Results

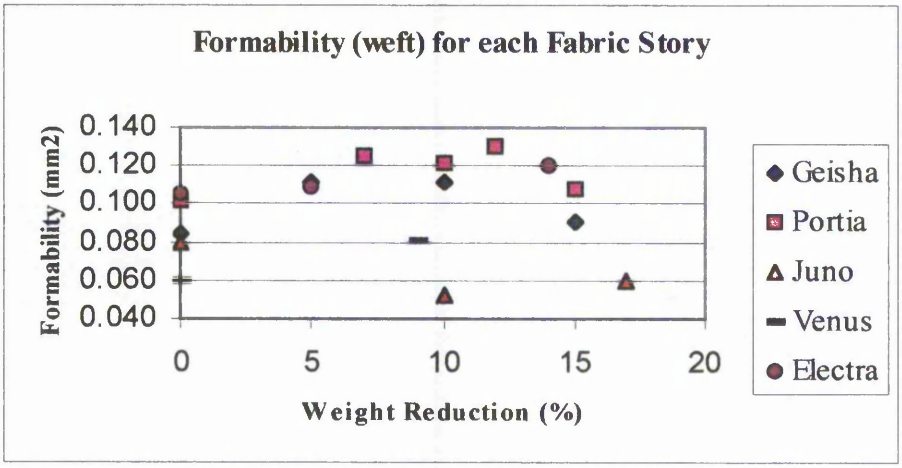


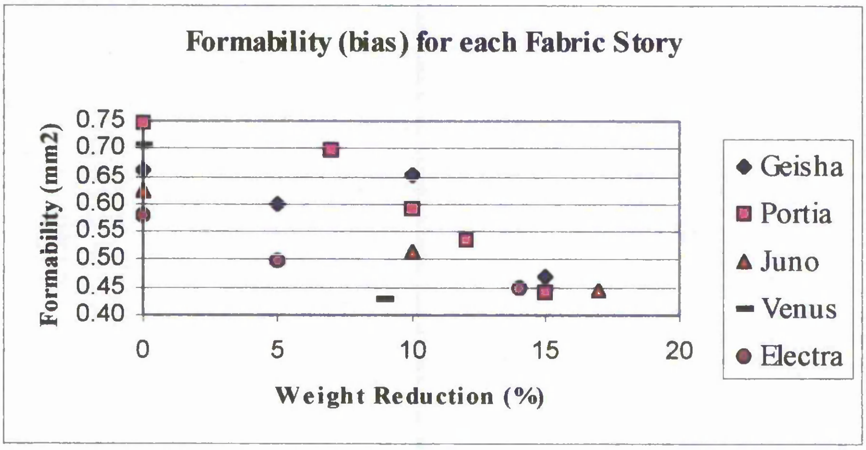




Appendix 9 – Formability Results







Appendix 10 – Results for Shear Rigidity