SIMULTANEOUS POLYMER PROCESSING

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ABSTRACT.

A review of recent literature and current knowledge on the implementation of Concurrent Engineering (CE) philosophy within the plastics industry has been presented.

Concurrent Engineering covers many aspects of design and manufacture, and its successful implementation depends to a great extent on an individual manager's ability to identify the necessary tools to satisfy the company's particular needs.

The research has focused on the widely used extrusion moulding process, where manufacturers deal with demands for high levels of quality, short production lead times and small lot delivery schedules.

A range of software packages are currently available all of which contribute to the creation of a Concurrent Engineering environment, and a selection of these has been analysed by the author. The packages currently available are mainly stand-alone packages, used in isolation, whose outcomes are not being interrelated. A study of current Electronic Data Exchange Systems has revealed that some software packages could be effectively linked and incorporated into a broader manufacturing system offering more integral solutions to meet customers demands.

In order to generate an integrated System for the design and manufacture of extruder components which would contribute to the implementation of a CE environment within the extruder components plastics industry, an integration of selected software packages to optimise the Design and Manufacture of Plasticating Screw Extruders was carried out, as a basis to the feasibility of Computer Aided Systems integration.

CHAPTER 1

INTRODUCTION

1. INTRODUCTION.

There is a huge demand for plastics world-wide, not only for materials currently available, but also newly developed materials offering enhanced characteristics and improved processing.

Plastics are establishing themselves into new markets for a number of reasons. The principal one is their substitution for "traditional" materials, such as paper, iron and clay, as a result of straightforward commercial considerations: plastics often meet the specifications required for a given application more cheaply than other materials [1-4].

The reasons for the continued substitution of "traditional" materials in existing markets are two-fold. The first is that plastics are relatively new materials, and they have taken time to penetrate long established markets. In this sense, the markets for plastics have yet to reach full maturity. The second reason is that technological developments in plastics processing have allowed the development of new grades of polymers which can be used for applications which were not previously appropriate for plastics.

Automobile and aircraft manufacturing are examples of major industries where substitution of materials is an important ongoing activity and similar trends are also evident in many consumer-product related areas. For example, plastics are becoming common place in sporting goods, and new Engineering polymers are being introduced into many everyday household products, such as vacuum cleaners, kettles and toasters, owing to its desirable properties, such as corrosion resistance, wear resistance and electrical insulation.

Plastics processing has thrived because plastic is a new material and is being developed for applications where traditional materials can be replaced. Also plastic has been the preferential material used in many new products because its technical qualities have allowed the creation of new markets, whilst allowing those mature markets to continue to grow.

This market growth, however, brings to the plastics industry intense competition. New customer's requirements for improved quality assurance and shorter product development lead times is pushing many companies forward in the relentless search for new ways to develop and manufacture their products, and Concurrent Engineering (CE) philosophy is spearheading the approach to face these new challenges.

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from concept through disposal, including quality, cost, schedule, and user requirements [5].

The aims and objectives of this research are to examine current practices in the plastics processing industry and to consider methods of improving quality, productivity, and above all, the cost effectiveness of the industry. The implementation of Concurrent Engineering philosophy is investigated for its viability in helping companies to achieve improvements. Although Concurrent Engineering philosophy can be applied to all areas of the plastics industry, this research concentrates in particular on applying the principles to the extrusion moulding process. Although injection moulding is more common, extrusion was chosen because, whilst there are fewer machines used for extrusion than for injection moulding, in tonnage terms, the throughput of polymer by the process is actually greater than injection moulding. Not only is the process widely used to make finished products, it is also used for such intermediate operations as preparation of plastic sheets for vacuum forming.

The aim of this research was to explore the best approach to implementing CE Philosophy in extrusion moulding companies. The proposed task list can be summarized as follows:

1.- Review of polymer processing methods and analysis of key points to satisfy the new market requirements.

2.- Study of CE philosophy and its implementation requirements.

3.- Study of the available tools to support the philosophy.

4.- Report and Conclusions.

This thesis constitutes the final report. Chapter 1 is an introduction to Simultaneous Polymer Processing. Chapter 2 is an overview of the current situation in the plastics industry and gives an analysis of how it has evolved in recent years. Chapter 3 is an introduction towards CE philosophy. Chapter 4 describes plastics design processes in general, identifying problems and possible solutions under a CE environment. Chapter 5 examines the available Computer Aided Systems to support the implementation of CE philosophy in an extrusion moulding process and in Chapter 6 an Integrated System for the Design and Manufacture of Extruder Components is described. Finally, Chapter 7 gives the conclusions drawn from this work. Information related to the work, but not directly affecting the outcome of the research, is included in the appendices.

CHAPTER 2

BACKGROUND TO THE RESEARCH

2. BACKGROUND TO THE RESEARCH

2.1. PLASTICS PROCESSING REVIEW

Plastics, and polymers in general, may be converted into products in a wide variety of ways. Within the plastics industry today the most common processes are:

- Extrusion.
- Blow moulding.
- Injection Moulding
- Calendering.
- Thermoforming (Vacuum/Pressure forming).

The three major processing methods are injection moulding, extrusion, and blow moulding, accounting for the processing of 78% (by weight) of all plastics. Approximately 32% goes through injection moulding machines, 36% through extrusion moulding machines, and 10% through blow moulding machines.

Polymers usually are obtained in the form of granules, powder, pellets, or liquids. Processing mostly involves their physical change, though in some cases chemical reactions occur (thermosets). A variety of processes are used. One group consists of the extrusion processes (pipe, sheet, profiles, etc.). A second group takes extrusion and in certain cases injection moulding through an additional processing stage (blow moulding, blown film, etc.) A third group consists of injection and compression moulding (different shapes and sizes), and a fourth group includes various other processes such as Calendering, Thermoforming, and Rotational moulding.

The common features of these groups are:

1. mixing, melting and plasticizing,
2. melt transporting and shaping,

3. drawing and blowing,
4. and finishing.

Mixing, melting and plasticizing produce a plasticized melt, usually made in a screw (extruder or injection). Melt transporting and shaping involve applying pressure to the hot melt in order to move it through a die or into a mould. The drawing and blowing technique stretches the melt to product orientation of the different shapes (blow moulding, forming, etc.). The final feature of processing, finishing, is the usual solidification of the melt.

Many product designs are inherently limited by the economics of the process that must be used to make them. For example, thermosets cannot be blow moulded, and to date they have limited extrusion possibilities. Many hollow parts, particularly very large ones, may be produced more economically by rotational processing than by blow moulding. The need for a low quantity of parts may eliminate certain moulding processes and indicate the use of casting or others. The extrusion process has fewer problems with thermoplastics than does injection moulding but has greater problems in dimensional control and shape.

So plastics component designers should have a deep understanding of different processing and materials properties to optimise designs and subsequently manufacture.

A comprehensive description of the processes mentioned is given in Appendix I, and the most commonly used polymers are described in Appendix II.

2.2. SUBSTITUTION OF MATERIALS BY PLASTICS.

In general, plastics have found an important place in today's manufacturing industries and their use is increasing still further, particularly in industries such as automotive, packaging and construction. For example, the use of plastics and rubber in the building industry has significantly reduced product cost over their metal equivalents. In addition, their thermal and mechanical properties are exploited to advantage in such applications as sound and thermal insulation and anti-vibration mounts [6].

A survey carried-out for PERA [7] shows how plastic and composite materials have replaced metals in particular situations; and also indicates the potential for further applications of plastics and composite materials.

The survey was carried-out for 85 components converted from metal to plastic and covered the eight main engineering industries: general mechanical engineering, transport, domestic hardware, pipe fitting and accessories, electrical equipment, agricultural equipment, packaging, building and construction, and marine and offshore industries.

During this research, the major factors which influenced the changeover from metal to plastics were identified as:

- low weight
- corrosion resistance
- reduced cost
- wear resistance
- electrical insulation.

One of the major constraints in the use of plastics has been their limited performance at high temperature, but with the development of new materials this is progressively being overcome.

However, in some cases, where initially the utilisation of plastics seemed advisable, subsequent studies have shown their unfeasibility. An example of this is car body replacement [8].

Legislative pressure to reduce fuel consumption, and greater consumer expectation in higher performance cars, has led manufacturers to consider making body panels from aluminium or plastics. Both have the potential to produce individual vehicles which are lighter, and can offer other benefits such as fewer parts to assemble.

Plastics offer potential weight savings and high corrosion resistance. They also possess high shape flexibility and good dent and stone chipping resistance which makes them attractive for certain vulnerable parts, such as bumpers.

However, the investment in new manufacturing equipment and environmental issues represents a significant disincentive to manufacturers converting to the use of plastics, especially if considerable cost has already been sunk into stamping and pressing equipment.

While plastics undoubtedly offer benefits to car manufacturers, their higher production costs must also be taken into account. For example, new handling and post stamping treatment facilities would have to be developed. In addition, advanced transfer presses sometimes incorporate magnetic handling facilities which cannot be used with plastics.

Another advantage of steel is that it is also easier to separate from the waste stream through the use of magnets, while the recycling of plastic body parts cannot occur until the parts are dismantled and each alloy or resin is identified and separated.

Although disassembly is a relatively new area, it has generated a lot of interest among manufacturers, governments and consumers. Disassembly is the process of systematic removal of desirable constituent parts from an assembly while ensuring that there is no impairment of the parts due to the process. Although there are economic and environmental reasons to support disassembly, there are technical and operational problems that are necessary to overcome beforehand [9].

2.3. PLASTICS INDUSTRY OVERVIEW

2.3.1. Plastics Utilisation.

2.3.1.1. The situation World-Wide

World production of plastics is projected to expand just under 4% per year to 138 million metric tons by the end of the century (Table 2.1.). This growth forecast is based on the improving prospects in markets such as motor vehicle industries and consumer products, as the economy strengthens. Demand for thermosets is forecast to increase as demand for construction supplies grows, for example, insulation, building boards, laminates, etc. [10].

South America (excluding Mexico) is predicted to enjoy the biggest growth in plastics production based upon an improved political and economic environment. The collective region of Africa and the Middle East has also increased their production levels at an above-average pace, but aggregate volumes are much smaller and the region as a whole significantly lags the rest of the world in terms of per capita consumption. The best prospects are expected for the Asia/Oceania region, based upon expanded production capacity. The combined output of North America, Western Europe and Asia/Oceania accounted for nearly 90% of world production in 1994.

	1985	1994	2000	Average annual change 1994-2000 (%)
World plastics Production	**71,032**	**109,505**	**137,990**	**3.9**
North America	**22,198**	**37,315**	**46,860**	**3.9**
Latin America	**2075**	**3830**	**5650**	**6.7**
Western Europe	**24,021**	**31,065**	**36,820**	**2.9**
Eastern Europe	**6644**	**6575**	**7620**	**2.5**
Africa/Middle East	**855**	**2100**	**2840**	**5.2**
Asia/Oceania	**15,239**	**28,620**	**38,200**	**4.9**

TABLE 2.1. World plastics production (1000 metric tons). **Source**:The Freedonia Group.

As shown in Table 2.1. the plastics industry is already an important economic sector all over the world and it is expected to increase further in importance.

The term "plastics" covers a heterogeneous group of materials with a variety of characteristics and properties. This includes hundreds of different grades of material, produced by the inclusion of various resins, additives and fillers. However, overwhelming majority of plastics sales comes from the commonly known *Commodity Thermoplastics*; Polyethylene, Polypropylene, Polystyrene, PVC and bottle-grade PET (Figure 2.1.). They are so called because they behave in a similar fashion to primary commodities. They are low priced, high volume, relatively homogeneous goods which react almost spontaneously to changes in the supply-demand balance. A comprehensive description about the most commonly used polymers is given in Appendix II.

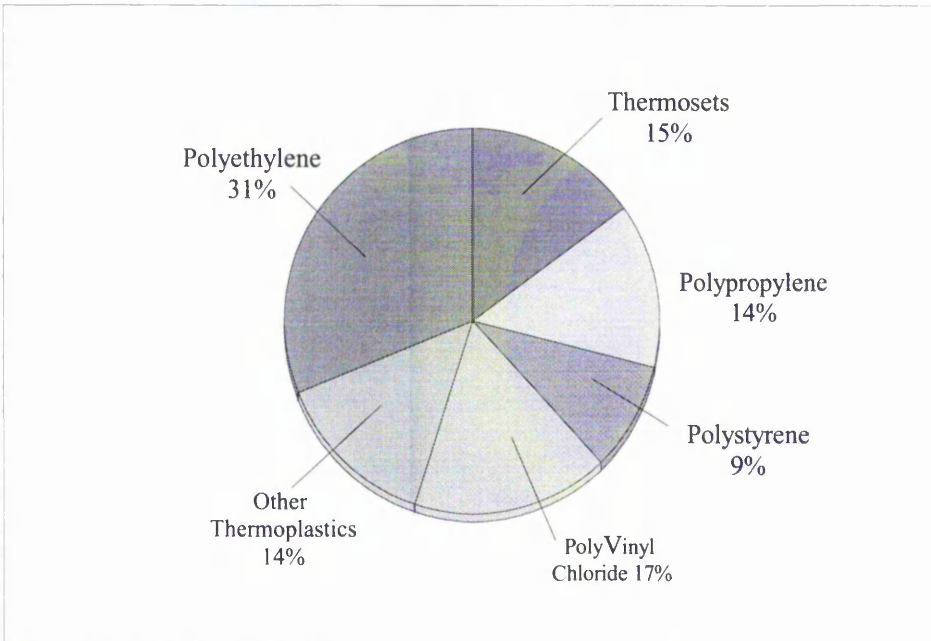

Figure 2.1. World plastics production, 1994. (110 million metric tons).
Source: The Freedonia Group.

2.3.1.2. The situation in Europe

In 1994, Europe accounted for 37 million tonnes or one third of the plastics production of about 110 million tonnes. In second place is the United States with 31%, followed by Japan with 12%. Within Europe, Germany with about 10% of the world-wide production is by far the largest individual producer, followed by Italy, Great Britain and Spain (Figure 2.2.) [11].

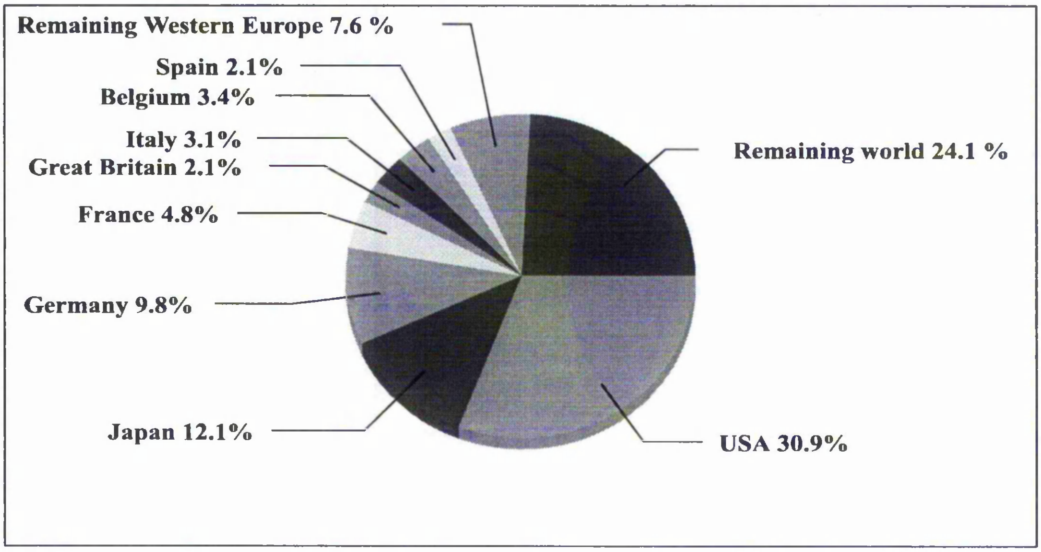

Figure 2.2. World-wide plastics production by the country of Production (1994). **Source:** UKE.

According to statistics published by the Association of Plastics Manufacturers in Europe (APME), packaging comprises the single largest market for plastic, followed by building and construction products [12]. Plastics used in electronic devices, motor vehicles and agriculture, each represent substantially smaller markets, although important nonetheless. Other markets include furniture, toys and leisure products, house wares and medical (Figure 2.3.).

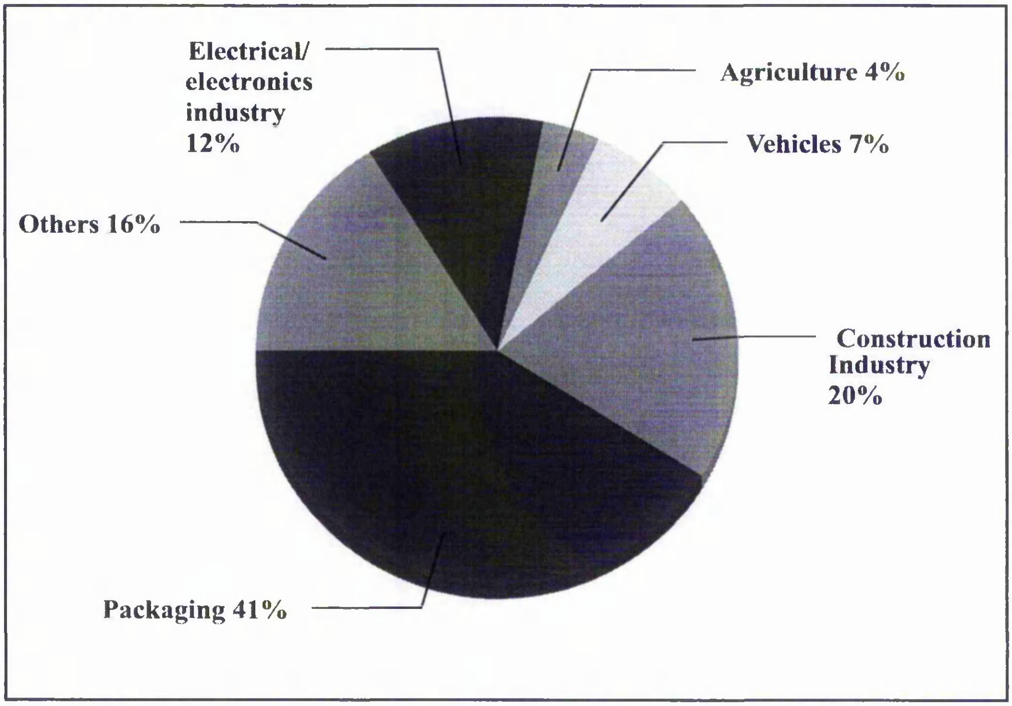

Figure 2.3. Plastics Consumption in Western Europe by the area of application (1993). **Source:** APME.

2.3.2. THE CURRENT STATE OF THE PLASTICS INDUSTRY

2.3.2.1. Packaging industry.

The function of packaging manufacturers is to meet demand and to offer improved designs and types of pack. Making the pack visually attractive for sale is an important function, but one which tends to be dismissed by environmental purists [13].

In 1994, Europe plastics constituted 32% of the packaging market, with more than 40% of global plastics consumption, and it is expected that demand will increase in both flexible (such as plastics sheet) and rigid packaging (such as bottles) [14].

Environmental groups have seized on packaging as being to some extent an unnecessary luxury, a source of litter, a pollutant in landfill and in general a waste of natural resources. They have consequently pressed governments to encourage or even enforce legislation to determine minimum use of packaging and the recycling of used packs.

In June 1994, the British Secretary of State for the Environment exhorted the industry to be the driving force for the recovery of waste and he set targets for the proportion of waste to be recovered. In response to the challenge, the packaging industry set up a Producer Responsibility Group which has now submitted a reasoned plan, called "Real value from packaging waste" [15].

The concept of recycling is obviously attractive and it is being heavily promoted and governments are paying heed, but the scientific and economic aspects of the recycling process are complicated and also it has been estimated that the annual cost of recycling could be more than 20 times that of an efficient country-wide incineration system [16].

More importantly, there is the question of what is actually being saved or wasted in energy terms. The conversion energy that is actually saved in the successful recycling of plastic, metals and glass is the energy required to bring each to the stage where it can be put through melting and forming processes to make the final package. Against this saving must be offset the energy required to transport the contaminate waste, sort it into its different types and bring it to the form and level of purity required by the conversion process. The problem is to identify whether the latter energy can be smaller than the former

2.3.2.2. Automobile industry.

The claims for alternative automotive materials in respect of weight reduction, improved fuel efficiency, better performance and greater environmental friendliness have been much publicised, and in the light of these claims, car manufacturers have looked seriously into the selection of the optimum materials [17-18].

European car manufacturers and plastics producers are currently working actively together, and this co-operation will strengthen in the future in order to improve the recovery of plastics from cars. Plastics are playing a fundamental part in reducing the environmental impact of the modern automobile.

Mattews Austin [19] and Jan von den Otelaar [20], argue that the use of plastics represents the greatest opportunity to reduce the weight of material used in automobile production. Substitution of components like plastics bumpers, fuel tanks, engine covers and radiator grills gives a car significantly improved fuel efficiency throughout its life. Another advantage of the use of plastic is its simplification of some painting processes. This is due to flexibility of plastics in carrying the colour pigments in them.

Future of the Automotive Industry

As car manufacturers respond to higher environmental standards, tomorrow's cars will be lighter, handle better and offer improved acceleration, braking and cornering. They will be more fuel efficient and cause less pollution, so the car's lightness will be an important factor with respect to environmental impact, rating in importance with other factors such as: safety, cost, styling, technical feasibility and the car's life-cycle.

In the future, co-operation between the plastics industry and car makers will lead to increasingly 'recyclable-friendly' models because it is possible to recycle metal and glass economically, as long as the waste is segregated and delivered without extra charge [21]. However, the use of plastics represents another order of difficulty in that it is first necessary to identify and segregate a number of suitable materials and their specifications (colour etc.), and secondly the properties of plastics many change with reprocessing.

According to the European Automobile Manufacturers Association (ACEA), over 75% of the weight of each car is recycled with **almost all the metals and some plastics** being recovered. Patrick Peuch, director of the Technical and Environmental Centre at the association of Plastics Manufacturers in Europe, reports ever increasing use of polymers improves the energy efficiency in the conversion of products [22].

However, while plastics undoubtedly offer some substantial benefits to the car manufacturer, their higher production costs must also be taken into account, as must the efforts being made by steel manufacturers to halt the inroads by competitive materials into the market.

2.3.3. In depth study of a plastic processing company.

In order to discover the current situation of the plastics packaging situation in the UK a visit was arranged to visit one of these companies. The company chosen, who wish to remain anonymous, was selected because it is typical of a medium sized packaging company. The company manufactures mainly injection moulded plastic packaging for the food, brewery, personal toiletries and household chemical markets.

Products range from pudding basins, containers for herbs and spices, talc and shower and gel containers, to caps and closures for gravy granule containers, sauce caps, brewery product, shower gel closures and reusable plaster boxes.

Between 70-80% of their products are manufactured to customer specifications. The remainder, accounting for 20-30% of their business, are standard products, such as pots and enclosures, with very short lead-times. Some of these standard products were always kept in stock to satisfy immediate demands.

Designed to appeal to the consumer through its aesthetically pleasing shape, any standard pack provides considerable scope for customisation and product differentiation, yet is available with short lead times. For example, bottles can be pad printed on their front and rear faces in up to four colours, and are compatible with a wide selection of closures.

Customer specifications.

According to the customers product requirements can vary greatly. Sometimes the company designs and develops the new product working closely with their customer. Otherwise they receive the specifications and the design and development is carried out in collaboration with different consultants. Sometimes the customer may supply the mould, so the company works purely as a manufacturer.

Material specification is not normally defined by the customer, but frequently the product specification restricts the choice of material. A typical example is the case of certain pots which need to be printed, as printing requires the polymer to be pre-heated in order to promote adhesion to the base.

The department responsible for deciding the feasibility of the customer specification is the Technical Department. Their decision is based on the expertise of the people who work there.

In this particular company, many of the staff have been working there for over 30 years, and are widely experienced in their particular subjects.

Product Design Stage.

Once the feasibility of a project has been established the design process commences. In this company, design has gradually evolved since the nineteen seventies, when prototyping and testing were not employed.

After product feasibility, design and development stages have been completed, the product moves into production. A trial mould, or soft mould, which enables the customer to test production on their particular filling machines, and possibly place a trial product on the market, may first be used.

The company does not have in house simulation software packages to ensure correct filling of the mould to optimise cycle time, however sometimes analyses are done outside the company.

Although this company, with reference to design, seems to be still working in the seventies, they are slowly introducing new concepts such as Concurrent Engineering. Every week they have what they call "new product development meetings". In these meetings they discuss all the projects that are being developed. The people who take part in this meeting may vary from week to week, but in most cases, all disciplines of the company are fully represented. In these meetings, the current project situation is analysed and suggestions made about design, materials and production.

Quality Control

Until recently, quality was ensured only by visual inspection, which proved acceptable to them as their products had generally been quite simple. However, in the past few years they have been assessing the process capabilities comprehensively measuring dimensions and variability of products, and recording the information for future use with the possible introduction of Statistical Process Control.

With regards to training people, the company is investing substantially by committing themselves to constant training development. They believe through experience that skilled people are the driving force behind the company's success.

Conclusions

The overwhelming message that came from the visit was the antiquated way in which they operate and to date have made little effort to adopt any aspect of advanced manufacturing technology in any form. Nevertheless, it is a profitable company, and soon is going to acquire new injection moulding machines to satisfy the increasing product demand.

This company's interests are more orientated to the optimisation of a machine's performance, rather than increasing overall company efficiency. While all the machines are linked to a computer to detect possible problems in production, design and management in general, are in a primitive state.

There is no laid down procedure established for the development of new products, each product is developed individually according to customer requirements by a team of development staff. These have been working in the company for a long time and have become expert in their particular fields; and they firmly believe that it is not possible to transfer this knowledge to computer for general use.

Until recently, they have been producing plastic components, but increasingly more and more customers ask for more complex shapes, using a wider range of materials with shorter lead-times.

In the author's opinion, if this company wants to continue to maintain its profitability within an increasingly competitive market, the introduction of new technology is paramount. In particular, the design department should be fully upgraded with suitable Computer Aided Systems integrated to the production and quality departments, to allow fast track development of tooling and product. This will enable them to satisfy shorter lead times now demanded by customers, and also meet increased production demand when necessary.

The author also believes that solely in house design and development would be more cost effective than the use of independent consultant companies, as a high proportion of the overall cost of a product is associated with the design stage.

2.4. STATE OF THE ART OF DESIGN-MANUFACTURE TECHNOLOGY.

The objective of any manufacturing system, is to produce a part with specified dimensions and properties at the lowest cost. The production of plastics components is only possible if all the process capabilities are taken into consideration when designing the part, mould and die.

Because a particular design is eventually manufactured into a product, design and manufacturing must be intimately interrelated. Design and manufacture should never be viewed as separate disciplines or activities. Each component or sub-component of a product must be designed so that it not only meets design requirements and specifications, but also can be manufactured economically and with relative ease. This approach improves productivity and allows manufacturers to remain competitive [23-24].

This broad view is known as Simultaneous or Concurrent Engineering (CE). Although the size, product and strategy of companies varies considerably, to successfully implement CE a similar approach is often needed; namely an interdisciplinary team environment using the correct tools and methods effectively.

A number of technologies exist to support CE implementation: Computer Aided Design (CAD), Computer Aided Manufacture (CAM), rapid prototyping, simulation programs and other Computer Aided Engineering (CAE) techniques.

Computer Aided Design (CAD) can be defined as the use of computer systems to assist in the creation, modification, analysis or optimisation design. Although the word CAD could be used to classify many applications, the common perception of a CAD system is a computer work-station with a graphics display, capable of generating lines, arcs and models which are widely used in Engineering. Computer

Aided Manufacturing (CAM) can be defined as the use of computer systems in efficient running and maintenance of manufacturing process. CAM software comprises computer programming systems that are used to monitor operations, while the hardware includes numerical control of machine tools. Computer Aided Engineering (CAE) functions include automated manufacture, simulation, analysis, process design, tool design and automate testing. CAD and CAM contribute to the overall CAE environment.

A computer-integrated CE system is expected to facilitate higher productivity among workers, shorter design/manufacture lead time, improved product quality, and thus lower product costs. In the recent years, technologies are emerging with a huge impact on the development of Computer Aided Systems (CAD/CAM/CAE) bringing the concept of concurrent design and manufacturing closer to reality.

CE for development projects has only been initiated recently. However, the firms which have adopted such a process seem to build a competitive advantage as they are able to develop new products and the corresponding new production processes under particularly good conditions in terms of lead-time and cost.

Several articles have described how simultaneous development has been applied by different firms. The approach became popular in Japan, where it was first applied to two major industrial sectors, the car industry and consumer electronics. In these fields, Japanese companies developed in the 1980s a significant competitive edge by greatly reducing product development times. Clark, Fujimoto [25] describe in detail the case of the car industry. Other examples are discussed by Jelinek, Shoonhoven [26] and Teece [27].

In plastics engineering in particular, with its high degree of integration, any alteration may create considerable problems for the entire project. Any change after making the mould, for instance, gives rise to very high additional cost. The extra time that is needed endangers the milestone deadlines and, in some cases, the defined deadline for the beginning of series production.

Alteration times, which require considerable time and expense, are considerably shortened by using Computer Aided Systems continuously linked to the construction and design of the moulded parts, model and mould manufacture in a CE environment.

2.5. SUMMARY AND CONCLUSIONS.

Plastics have finally become established in today's manufacturing industry, and world-wide demand remains high for the foreseeable future.

Packaging and Automotive industries are two of the major sectors in which plastics components are used, comprising more than 50% of the total amount of plastics processed.

The analysis carried out during this research in these significant sectors within the plastics industry, highlight the fierce competitiveness that plastics companies are currently facing. The use of Computer Aided Systems within the plastics industry is scarce and, companies are unable to efficiently design products which satisfy new market requirements, but as market forces demand companies gain a competitive edge, they are being forced to introduce the new technology.

The design process of plastics components is, in principle no different from any other design process. It is essentially a process of understanding, adjustment, accommodation, and compromise. It is, however, particularly challenging in the field of plastics design because of the pronounced interconnections between form design, material selection, and manufacturing process selection.

Due to this, plastics component designers must simultaneously select the material and its processing method while they develop the geometry of the product during the design stage [28].

After the concept, form, material choice and manufacturing process have been discussed and decided upon, it is necessary to review the details of the design. Aspects such as tolerances, possible shrinkage and swelling areas should be considered to ensure compatibility of the product-design drawings with the practical possibilities of the manufacturing process.

For instance, one of the most important problems that designers must solve in designing extrusion components is to determine the cross-section of the die which will generate the required extrudate shape. The extrudate flow from the die can be quite complex. The velocity profile is not uniform within the die. Once past the die lip, the velocity field is reorganised and soon becomes uniform. This rearrangement of the velocity profile, together with stress relaxation, induces extrudate deformations. The extruded shape can differ radically from that of the die.

In the plastics industry one cannot fall back on semi-finished articles or standard components, it is therefore even more important than in other industry sectors to produce things right first time.

Product development is becoming more and more complicated and the development of a new environment to improve concurrency in the design process is needed. A philosophy, namely Concurrent Engineering, is described in the next Chapter of this thesis, which could help to break down the barriers between different departments improving concurrency during the design stage.

CHAPTER 3

CONCURRENT ENGINEERING

3. CONCURRENT ENGINEERING.

3.1. INTRODUCTION TO CONCURRENT ENGINEERING (CE)

Throughout the world for the past two decades, most companies have faced new challenges. Amongst these are ever more demanding customers, rapid technological change, environmental issues, competitive pressures on quality and cost. Furthermore, smaller markets require additional new product features. In order to face these new market demands, a change in the traditional design and manufacture process is required.

In the 1980s, smaller companies started to feel the influence of large multinational organisations on the markets, through increased product complexities and new developments in innovative technologies. This influenced their ability to develop and introduce new products to the market. This was especially true for the electronics industry, where continuous development meant that product life cycle were reduced significantly.

Since then, the time available for development projects has become increasingly shorter in almost all branches of industry. This is particularly noticeable in the computer industry, where the next wave of innovations becomes tangible every two years brought about by a considerable increase in available computing power or a drastic price reduction. Other industrial areas, including the majority of clients of the plastics supplier industry such as the automotive industry, have also shortened their development times forcing the plastics supplier industry to save time and cost by introducing more efficient methods in the design and manufacture of plastic components.

The need for improved quality assurance and shorter product development lead times is pushing many companies forward in the relentless search for new ways to develop and manufacture their products, and Concurrent Engineering philosophy was the approach often adopted. But what is concurrent engineering, and what are the advantages and disadvantages of this new way of working?

The concept of CE is not new. It has long been practised in part by manufacturers, but no one has paid much attention in applying it in a systematic way. However Japanese industry has practised CE, without using its name, for some time. This is clearly illustrated by the studies carried out by Hartley, Mortimer in 1991 in the automotive industry, comparing the time to market of Japanese and European manufacturers [29]. While Japanese companies can develop and introduce a new car to market in 43 months, the average for European companies is 63 months; the Europeans taking almost a third more time than their Japanese counterparts (Figure 3.1.). Obviously, in the current competitive marketplace this may result in a significant loss in market share

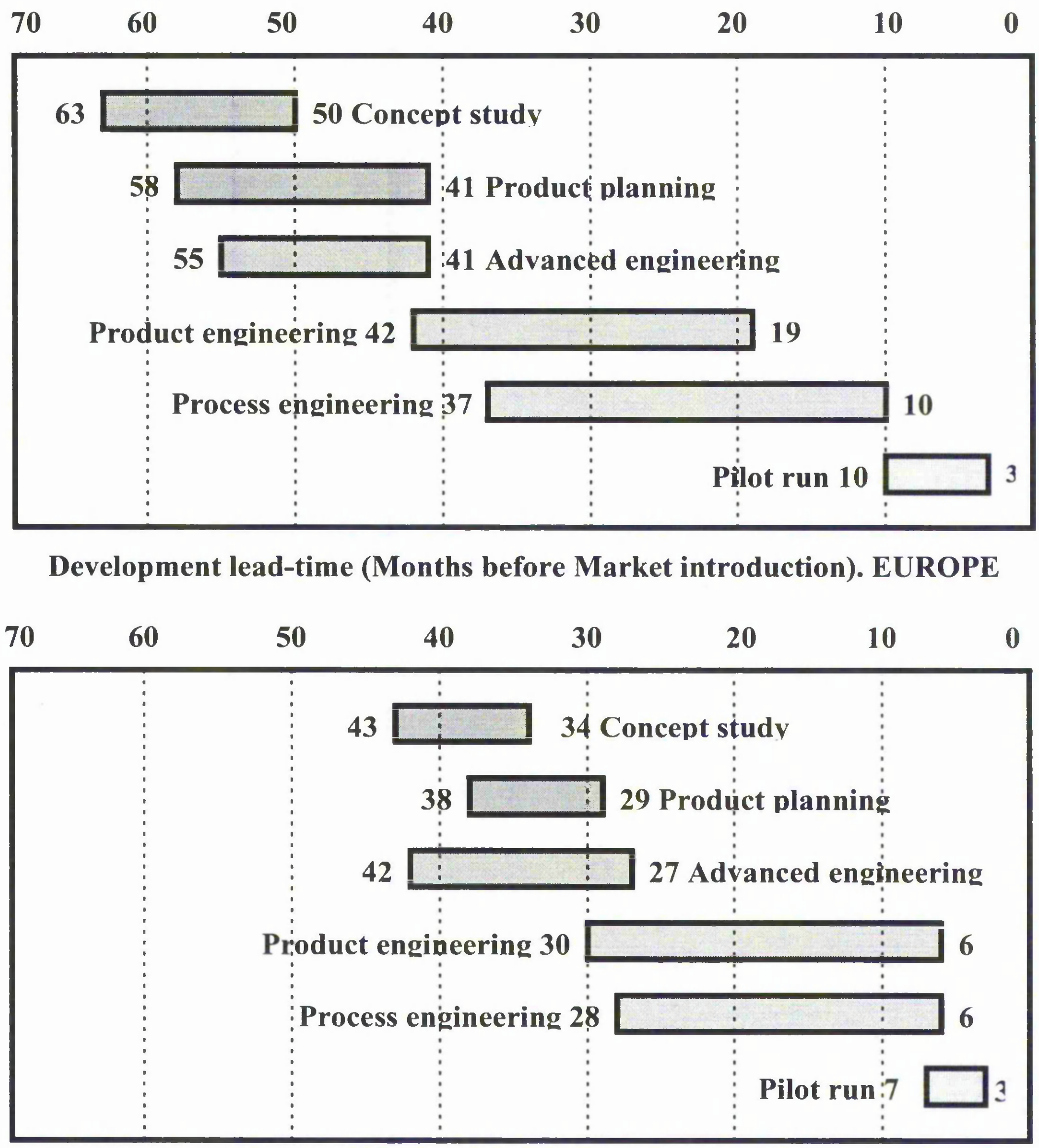

Figure 3.1. Comparison of European and Japanese development lead times for the automotive industry. Hartley, Mortimer (1991)

The following figure (Figure 3.2.) illustrated how a company can measure the impact of potential delays in bringing a product to market. Every market has a growth phase and a decline phase. The goal is to introduce a product as early as possible in the market growth phase. Because delaying a product's entry into a market, significant revenues can be lost for each month the product is late.

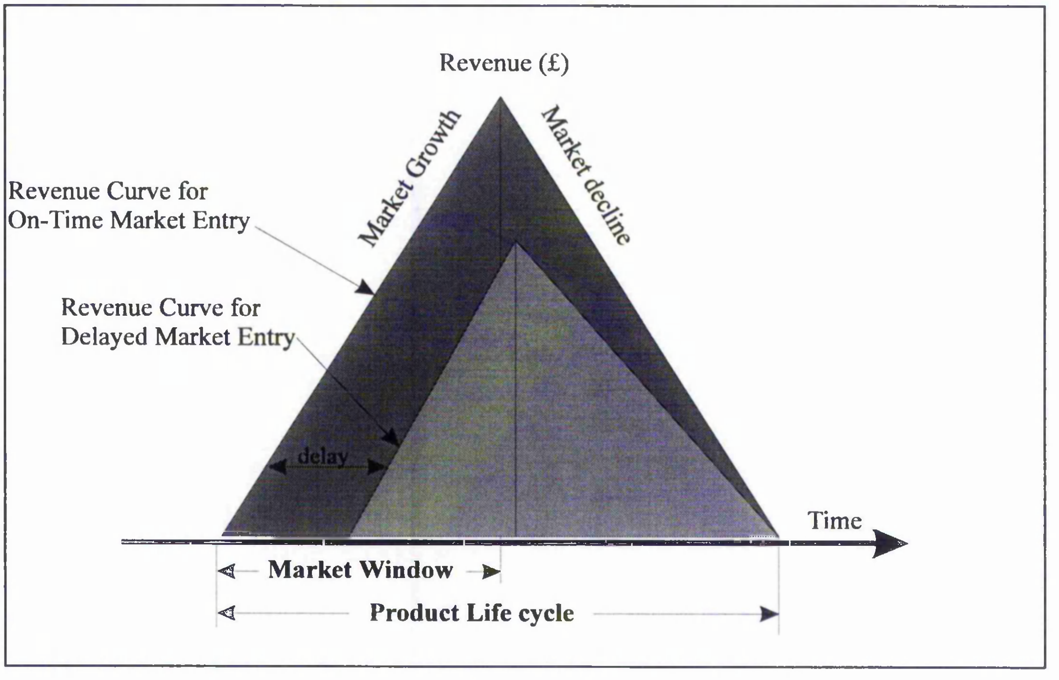

Figure 3.2. Revenue lost from delayed market entry. **Source:** Logic Automation

In summary, the world-wide competitive economy is forcing companies to utilise fully the best equipment and techniques available with efficient control of organisational structure to produce high quality, well-designed products at lower prices and in less time.

3.2. CONCURRENT ENGINEERING PHILOSOPHY.

First of all it is important to emphasise that Concurrent Engineering is a philosophy and not a technology, and in order to understand it fully, it is useful to describe the traditional introduction and product development practices which many manufacturing companies still employ.

Most of the time, the product development cycle begins with the realisation of a need based on market analysis and research and development (R&D) activities. Conventionally, a series of sequential steps is followed to design the product, identify the manufacturing processes, manufacture the parts, assemble the components if necessary, and ship the products to the marketplace. Product designers are mainly concerned about their product's performance and functionality and rarely take manufacturing's constraints into consideration. This traditional sequential path has not entailed a detailed dialogue between the design department and the rest of the company with most of the design output going straight to process planning (Figure 3.3).

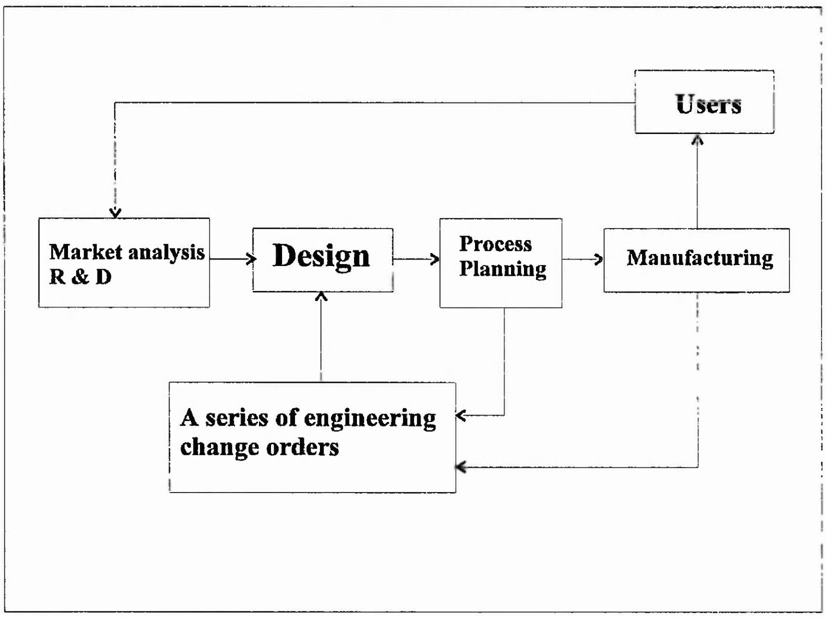

Figure 3.3. Sequential product development cycle.

However, as has been mentioned earlier, design decisions made early in the product development cycle can have a significant effect on the manufacturability, quality, product cost, product introduction time, and thus on the ultimate marketplace success of the product. More than 70% of the total cost is influenced by design [30] [31], 40% of all quality problems can be traced to poor design [32] and more than 70% of manufacturing productivity can be determined at the design stage [33]. Furthermore, according to Siegal the corrective cost of engineering changes increases logarithmically as the orders are placed later in the product's life cycle [34]. Therefore the product designer should include manufacturing considerations as early as possible along with customer requirements.

Although the data listed is open to debate, what must be accepted are the weaknesses that arise in a sequential engineering process, also called "over the wall engineering", such as insufficient product specifications or little attention to manufacturability issues of the product, generating quality problems, increasing costs and development times. Thus a change from the sequential engineering process to concurrency in the design stage is needed.

In **1982** the Defence Advanced Research Project Agency (DARPA), aware of long time development problems, started a study to look for a way to improve concurrency in the design process. In 1986, the Institute for Defence Analysis (IDA) Report R-338 coined the term "concurrent engineering" to explain the systematic method of product and process design, as well as other support processes and services [5]. The IDA report also gave a definition of CE as follows:

> ***"Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life***

cycle from concept through disposal, including quality, cost, schedule, and user requirements".

CE provides a systematic and integrated approach to the introduction and design of products, illustrated graphically in **Figure 3.4.** Functions such as design and engineering are integrated in terms of continuous and complete information exchanges.

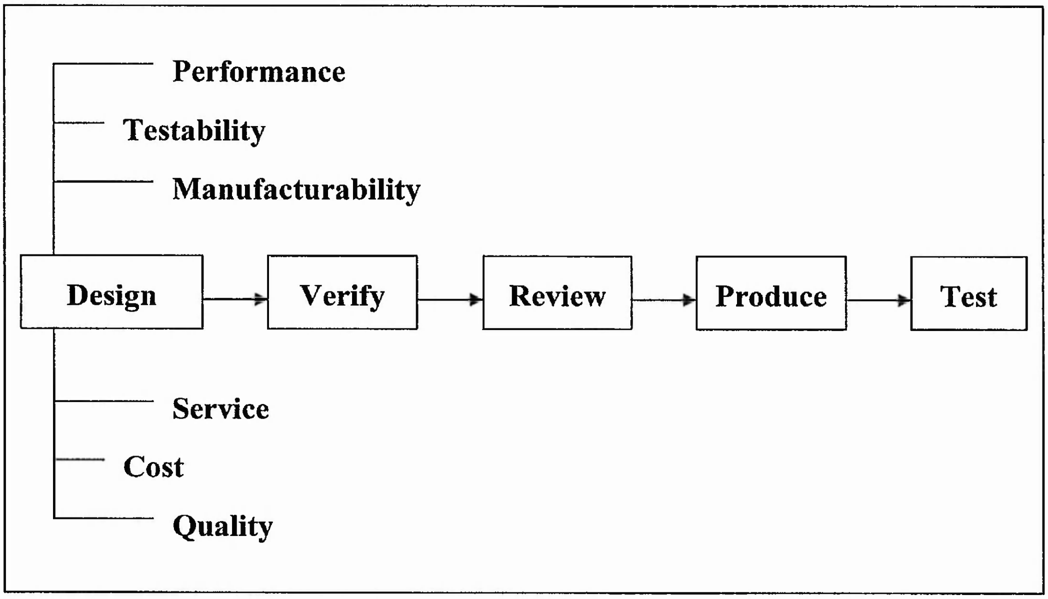

Figure 3.4. The concurrent engineering process

In general, the positive impacts of concurrent engineering are felt most in three important areas: shortening the development time, combined with financial saving, creating in-house development capacity and enhancing the quality level at a similar cost. However, to fully benefit from the concurrent engineering philosophy it maybe necessary to go through sometimes tedious implementation.

Those companies which have successfully implemented CE philosophy are the best proof of the effectiveness of concurrent engineering. According to the research study carried out by Anderson Consulting, a study of 18 auto component plants concluded that companies which were working in a CE environment were able to achieve outstanding levels of productivity and quality compared to those who were not [35]. Thus, for a company to achieve and maintain a competitive edge the case for transition to a concurrent engineering environment becomes paramount.

3.3. AN IDEAL CE ENVIRONMENT.

To find a company operating a balanced concurrent engineering environment is not that uncommon. However, it is more likely to be in a one person company where product development is fairly simple.

In this company that person is both the manager and product development team, therefore there is only one communication path for all information. Also, he alone is responsible for meeting customer requirements and keeping them in mind during the total product development process. In this ideal environment, this manager and team of one person has the same vocabulary, purpose, and priorities; the technology for a communication infrastructure may be an answering machine, a computer, and a few simple tools. The end products are likely to satisfy the customer requirements because only one person needs to understand these requirements and keep track of their implementation; and all development processes, from design to manufacturing to marketing, are in the hands and mind of a single individual and are almost simultaneously applied to all aspects of the product's development.

In the defined concurrent engineering environment, organisation and communication co-exist together and the requirements and product development process are perfectly integrated. However, this ideal concurrent engineering environment rarely exists beyond a single-employee company; larger companies having to continuously examine the concurrent engineering implementation situation, and adjust each aspect to bring it into balance with the others.

Before detailed examination of the concurrent engineering environment aspects, it is important to point out that *organisation and communication infrastructures* have a "philosophical aspect". Their creation is based on decisions, usually taken by management, concerning what constitutes an effective team, what the boundaries of authority and responsibility are, and the most effective means of communication.

These *infrastructures* reflect management's belief about what will work for a particular company producing a specific set of products of a certain complexity, while *requirements and product development* have a "methodical aspect". It is therefore necessary to follow specific procedures to capture and specify customer requirements and to integrate a product with development processes.

In the next few paragraphs a description of each of these dimensions will be given. Although "philosophical aspects" can be changed by only a few people, they are described to give a better understanding of the concurrent engineering environment.

3.4. IMPLEMENTING CONCURRENT ENGINEERING.

When a company decides to initiate the transition to a concurrent engineering environment for development of its products, it makes a commitment to harness and control the forces of change that keep sweeping through the product development environment: technology, tools, tasks, talent, and time [36].

The way to nurture and keep control of these forces is to create a dynamic environment whose foundation can be changed within the following interconnected dimensions:

- staff-management interaction,
- communication,
- customer requirements,
- the design process by which the product evolves, adapts, and continues to sell.

At this stage it is important to mention that there is nothing secret in the implementation of CE methodology. The dimensions, which in the author's opinion, are the most important for the correct implementation and maintenance of a CE environment are described in the following sections. Nevertheless, it is only a general description about the factors which influence the implementation of a successful CE philosophy.

3.4.1. Staff - Management interaction.

Managers play a key role in preparing the company for changes, including those involved in creating a concurrent engineering environment. Managers should create product development teams and then empower those teams with the authority and responsibility to make decisions. They should continually assess the professional and technical needs and provide the necessary training and education, tools and rewards.

To reach a successful CE environment every member of staff must understand their responsibilities and tasks. Every employee must feel, as an individual and team member, that they play a key role in increasing the productivity and effectiveness of the company. Then everyone can consciously and proudly take ownership of the product.

Both managers and teams must understand the role of the team in the concurrent engineering environment and the way it is supported by management from the outside and a group process from the inside.

3.4.2. Communication

In a CE environment, communication infrastructure is referred to any system, equipment, or software that facilitates the meaningful exchange of information relating to the product or process. CE often requires that one or more teams work and share information in an integrated product development environment; therefore, effective communication is critical to success. Databases that handle customer requirements, electronic mail systems, and other product data are examples of the technologies that must be in place to support the communication and collaboration necessary for product development.

It is the responsibility of management, who know the company's vision and understand the tool and technology requirements of their employees, to implement an efficient communication infrastructure and thereby ensure the continued success of the company.

3.4.3. Customer Requirements.

The interpretation of customer requirements includes all product attributes that impact customer satisfaction, including design requirements and all internal requirements. Adequately capturing and expressing the total set of these requirements is crucial to concurrent engineering, and one of the tools to do it is Quality Function Deployment (QFD), which will be described later.

The more the team can specify the design constraints on a product and its development, the fewer the problems later in the development process. These constraints can take the form of environment conditions, industry standards, limitations of the materials used in manufacturing, or aesthetic considerations. Knowing the constraints helps to keep the development teams focused and helps to guide and validate other design decisions.

In a concurrent engineering environment the product must be continually evaluated and validated, from the smallest component to the integrated product, and this is only possible by teamwork and making use of the available tools to facilitate communication.

3.4.4. The Design process.

The main objective of any development process is to design the product that satisfies customer expectations, but to determine a good design can often be difficult. Dr.

David G. Ullman of the Department of Mechanical Engineering at The Oregon State University has identified the five "shoulds" for a good design, that have been widely accepted [37]:

1. A good design should clearly represent the customer's needs and wants for the product.
2. A good design should be based on engineering requirements and targets.
3. A good design should follow a function model of the product.
4. A good design should incur a decreasing number of design changes throughout the design process.
5. A good design should use mature technology that is tried and tested.

CE approach would help to resolve the five "shoulds" of a good design through the implementation of team-work. The development team has a method for finding and producing a good design, and it is called "collaborating on knowledge". A good design comes from the total development process; how well the development team has a shared understanding of the problem to be solved.

3.5. SUPPORT FOR CE IMPLEMENTATION.

3.5.1. Formal techniques

A number of technologies exist to support concurrent engineering implementation: rapid prototyping, and other computer aided engineering techniques (CAD/CAM). There are also several methodologies that may be used to support concurrent engineering implementation and utilisation, for example, Quality Function Deployment (QFD), Taguchi methods, and Design for Manufacture and Assembly (DFMA).

QFD helps to "hear the voice of the customer" and is useful for brainstorming sessions with members of the design team to determine how best to deliver what the customer desires. Taguchi methods can help to determine how to make improvements in the existing processes to minimise the variability of the production, and thus maximise the quality of the product. DFMA techniques may bring great improvements in reducing costs and increasing the quality level during the design stage.

3.5.1.1. Design for Manufacture and Assembly (DFMA).

In the 1920s, Henry Ford introduced many features which gave the Model T Ford the competitive advantage [38]. He designed the product so that it was easy to drive, and easily repairable, by virtually anyone. He designed the parts of the product to be interchangeable and easy to attach to other parts. Within production, he implemented a system of the interchangeable worker, and designed the moveable production line. The combination of these sub designs led to the optimum design of mass production, for which he is well known. The main point here is that, in order to capture the competitive advantage, he designed for many different characteristics. Henry Ford designed for manufacture and assembly gaining competitiveness over other car manufacturers, applying indirectly what today is called Design For Manufacture and Assembly.

Analysis of a product for manufacture and assembly consists of two main stages:

1. Design for assembly (DFA) analysis, which is aimed at product structure simplifications, part count reduction and a detailed analysis for ease of assembly.
2. Design for Manufacture (DFM) analysis, which is aimed at process/material selection, and is based on realistic cost estimates and establishing the relationships between part features and manufacturing cost for a given process.

Frequently, it is when drawings are passed to the manufacturing and assembly engineers, when manufacturing and assembly problems are encountered, and when requests are made for design changes. Sometimes these design changes are large in number and result in considerable delays in the final product release. In addition, the later in the product design and development cycle the changes occur, the more expensive they become. Therefore, not only is it important to take manufacture and assembly into account during product design, but also these considerations must occur as early as possible in the design cycle.

This is illustrated qualitatively by the chart in Figure 3.4. where it is known that more time spent early in the design process is more than compensated for by savings in time when propotyping takes place. Thus, in addition to reducing product cost, the application of Design For Manufacturing and Assembly shortened the time to bring the product to market [39].

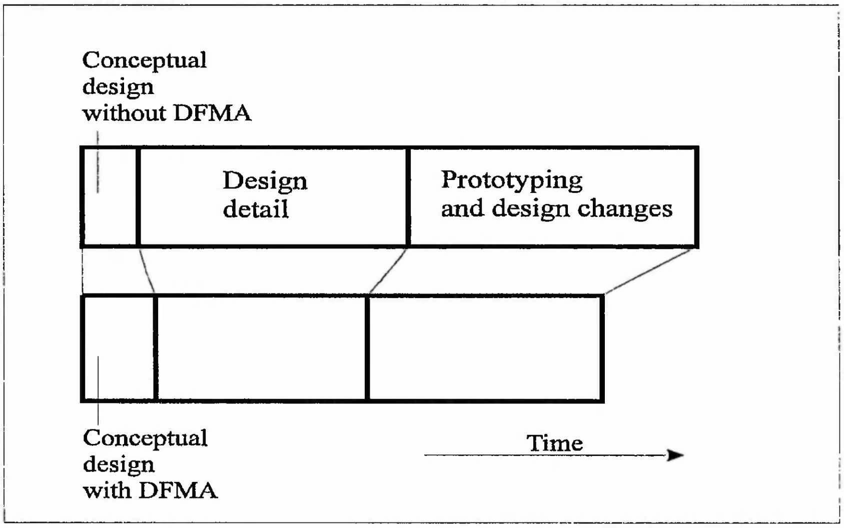

Figure 3.4. Showing shorter design to production times through the use of DFMA early in the design process.

In spite of all the successful stories, the major barrier to DFMA implementation continues to be human nature. People often resist new ideas and unfamiliar tools, or claim that they have always taken manufacturing into consideration during design. Designers are traditionally under great pressure to produce results as quickly as possible and often perceive DFMA as yet another time delay.

However, DFMA provides a systematic procedure for analysing a proposed design from the point of view of assembly and manufacture. It encourages dialogue between designer and the manufacturing engineer and any other individuals who play a part in determining final product costs during the early stages of design. This means that teamwork is encouraged and the benefits of concurrent engineering can be achieved.

3.5.1.2. Quality Function Deployment (QFD).

Quality Function Deployment (QFD) is a systematic approach which establishes customer requirements and accurately translates them into the appropriate technical design, manufacturing and production planning requirements. In order to achieve the highest level of customer satisfaction with the end product, it focuses on the key issues and provides a traceable path from the customer down to the most detailed processes, throughout each stage of the product development cycle.

The main tool used in quality function deployment (QFD) is the House of Quality. This is a matrix style chart that correlates the identified customer needs called "the whats" to the engineering specifications called "the hows." Ideally, in a concurrent engineering environment, the chart should be developed by a cross functional team made up of members from the core functions in product development. A comprehensive explanation of the implementation of QFD is given by Bosser [40], Cohen [41], Shillito [42], Yoji [43] and Zairi [44] among others.

Inappropriate application of QFD can generate considerable paperwork, sometimes with disappointing result [45],but correctly applied, it is a powerful technique which assists in ensuring that the product meets the requirements of the customer.

3.5.1.3. Taguchi methods.

Taguchi methods, also called robust design, are based on the design of experiments to provide near optimal quality characteristics for a specific objective. They are often demeaned by academia, but unfortunately, most of those who demean Taguchi methods have missed the whole point. Taguchi methods are not a statistical application of *design of experiments,* developed during the early part of the 20th century [46], but include the integration of statistical design of experiments into a powerful engineering process.

The goal of any experimentation in manufacturing is to devise ways of minimising the deviation of a quality characteristic from its target value. This can be done only by identifying those factors which impact the quality characteristic in question and by changing the appropriate factor levels so that the deviations are minimised and the quality characteristic is brought back on target. In other words, from a quality perspective, experimentation seeks to determine the best material, the best pressure, the best temperature, chemical formulation, cycle time, etc., which will operate together within a process to produce a desired quality characteristic, such as length and durability, taking cost into account.

A major part of what has become accepted as Taguchi's methodology is the use of his tabulated sets of *orthogonal arrays* as a tool to keep development and manufacturing cost low producing high-quality products. These are a representation of special experimental design of the *design of experiments,* but with fewer prototypes. Taguchi's orthogonal arrays fundamentally sacrifice information about interactions to reduce testing, but missing interactions can be identified and if necessary further trials run.

The true power of Taguchi methods comes from their simplicity of execution to improve their project and their processes. The objective is not just to optimise an arbitrary target function but to reduce the sensitivity of engineering design to uncontrollable factors.

Although a full explanation about Taguchi is not described here extensive literature is available that explains the methodology step by step [47-50].

3.5.2. Data exchange methods.

There is in some cases a misconception that an organisation can buy its way into concurrent engineering by purchasing the appropriate tools and software. While the hardware and software are necessary, their purchase will not ensure a successful CE implementation. The tendency to buy technology, without first understanding how it is to be utilised, can sap an organisation of its resources. Companies must be careful first to identify their specific needs before they make a purchase, because the technology that exists to support concurrent engineering is evolving rapidly.

Engineering design and support programs are useful in assisting in the design and manufacture of products. There are a wide variety of programs available of varying capabilities and complexities. They include systems such as computer-aided design and manufacturing (CAD/CAM), and others Computer-aided engineering systems. Computer-based support initiatives also include tools modelling and simulation production planning and costing tools which support CE implementation.

With the appropriate *shared Computer Aided tools*, CE will be easier to implement. One current method of ensuring that the information exchange is possible across the whole company, customers and suppliers, is to ensure that all systems purchased are compatible. However, this trend to tie companies to a single vendor can be very risky. Also it is highly unlikely that a single vendor could supply all the needed computer systems, so *electronic and product interchange standards* are needed for a fluent communication in and outside of the company.

This is an aspect that all too often is forgotten by software buyers, and software package vendors are more interested in showing their software capabilities than integration and compatibility issues. Besides, the requirements can greatly vary from one customer to another. One customer's desire could be to fully implement a Computer Aided System during the design and manufacturing stage, therefore requiring electronic and product interchange across while another customer could be looking for a Computer Aided System to improve a particular area of the design and manufacturing chain where the interchange of data is not required.

Although software developers are working towards providing more integral solutions to meet customers' demands, there is still much development work to be done. The current situation of product data exchange is described in the next few paragraphs.

Product data exchange.

Product Data Exchange has been defined as the method of expressing and exchange in a digital format all the design and manufacturing useful information about a given product. Product Data Exchange will enable those involved in a product's development (design, engineering analysis, manufacturing and support) to define access, and exchange all useful information via a computer. The deployment of this technology will mean shorter development times, higher quality products and lower costs. It will also introduce flexibility and responsiveness to the needs of customers, manufactures and their suppliers [51].

There are currently three main types of Product Data Exchange employed in an attempt to integrate CAD/CAM/CAE system. First is direct translation, where software is developed to translate one format into another, for example: Catia to Unigraphics. Although direct translation provides the most accurate exchanges, unique translators must be written for every two systems. Furthermore, if any vendor updates their software, new versions of the translator software must be written which is time consuming and expensive.

Next, it is the DXF format developed by Autodesk, which has been adapted by many PC CAD systems which allows native formats to be saved in DXF format, so that they may be read by any other system that can interpret this format. However, there are many compatibility problems with this format.

The third one is a formal standard format such as IGES, Initial Graphics Exchange Specification which offers most flexibility [52].

Initial Graphics Exchange Specification (IGES) is a mechanism for the digital exchange of data base information among computer aided systems. IGES information, including drawings, three-dimensional wireframe models, and surface models, is intended for human interpretation at the receiving site. The IGES format is designed to be independent of all CAD/CAM systems.

IGES is concerned with the data required to describe and communicate the essential engineering characteristics of physical objects such as manufactured products. Such products are described in terms of their physical shape, dimensions, and information which further describes or explains the product.

The benefit of this common format is that a user does not have to develop special translators for each software system used. The only requirement is to have a translator to and from the IGES format. These translators, called pre- and post-processors, are generally available from the IGES vendor.

To describe and communicate ***all the required data through the life cycle of a product*** a new solution has been proposed by the IGES Organisation. It is a universal standard that is a computer-interpretable neutral format that provides an unambiguous representation of product data throughout the life cycle (design, engineering, manufacture, production, support and disposal). This new approach has been called STEP, Standard for the Exchange of Product Model Data [53].

The overall objective of STEP is to provide a mechanism that is capable of describing product data throughout the life cycle of a product, independent of any particular system. The nature of this description makes it suitable not only for neutral file exchange, but also as a basis for implementing and sharing product data bases and archiving. The ultimate goal is an integrated product information database that is accessible and useful to all the resources necessary to support a product over its lifecycle.

In the long term STEP will be able to express all the information conveyed by IGES and much more. In the interim, however, there are many computer-aided-design (CAD), computer-aided manufacturing (CAM), computer-aided engineering (CAE) systems that use IGES.

STEP will enable all people contributing to the design, manufacturing, marketing, and supply of a product and its components to contribute, to access and to share its information. STEP's universal format means that corporate departments will no longer exist as "islands of automation", isolated and unconnected. STEP will facilitate the sharing of information throughout an organisation. Summing up, STEP technology will enable users to produce products faster, of better quality and at lower costs.

3.6. SUMMARY AND CONCLUSIONS

A review of the literature revealed that very little was written about "concurrent engineering" or "simultaneous engineering" before 1980, "concurrent engineering" being a recent concept in management and engineering which has rapidly grown in importance.

In some people's minds, concurrent engineering means gathering of designers, manufacturing engineers, marketing personnel, and the outside "X factor" people. Working with teams at the design stage is a laudable practice and should be adopted by every company. However, unless one can provide a basis for discussion founded in quantified cost data and systematic design evaluation, directions will often be dictated by the most dominant individual in the group, rather than being guided by knowledge. The introduction of the techniques described earlier: namely DFMA, QFD and Taguchi methods, as concurrent engineering tools can serve as a catalyst that provides dramatic increases in productivity and reduced new product development times.

Although the size, scope, product type and strategy of the companies vary, to successfully implement CE, a similar approach is needed operating via an interdisciplinary team environment and using the tools and methods effectively by altering them to meet their particular needs. They should share a common vision of focusing on the new product creation and development process and have clear management support for the team effort and its mandate.

The realisation of CE requires co-ordination and management of computer-based tools. It also requires creation of organisational structure for working in teams and project management, as well as evaluation and the use of appropriate new technologies.

Syan [54] and Hartley, Mortimer [29] share the same view of the future of CE (Figure 3.5.). According to them the future of CE involves a distributed database, with all the design tools on hand and experienced multi-disciplinary teams.

Concurrent engineering in the future will utilise tools which will enable team work to be performed in organisations where the various functional expertise is often geographically spread. To communicate effectively, these activities will need to be supported by fast and cheap networking systems, multi-media communications and integration, enabling the use of these tools in real time.

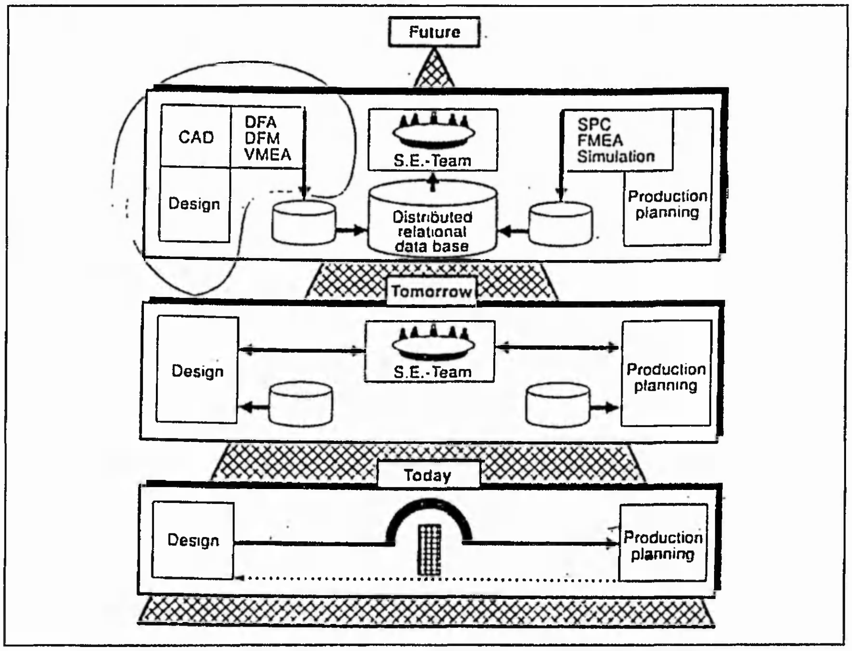

Figure 3.5. Concurrent Engineering future. Syan (1994) and Hartley, Mortimer (1990)

CHAPTER 4

DESIGNING PLASTIC COMPONENTS

4. DESIGNING PLASTIC COMPONENTS

4.1. DESIGN STAGE

The design of plastics products requires experience and is rarely successful in isolation. The plastics component design process is, in principle, no different from any other. It is essentially a process of understanding, adjustment, accommodation, and compromise. It is, however, particularly challenging in the field of plastics components design. This is because of the pronounced interconnections between form design, material selection, and manufacturing process selection. Each of these areas in itself is complex and is changing rapidly with time. To successfully assimilate all is a major challenge.

According to Brown [55], at least two, and often three, major participants should be involved in the successful design of a plastic product. These participants may be referred to by different titles, but often are known as the **product designer,** the plastics **manufacturing engineer,** and the **materials engineer**. The team these people constitutes is shown in Figure 4.1. Each member's task or function is detailed in the following sections.

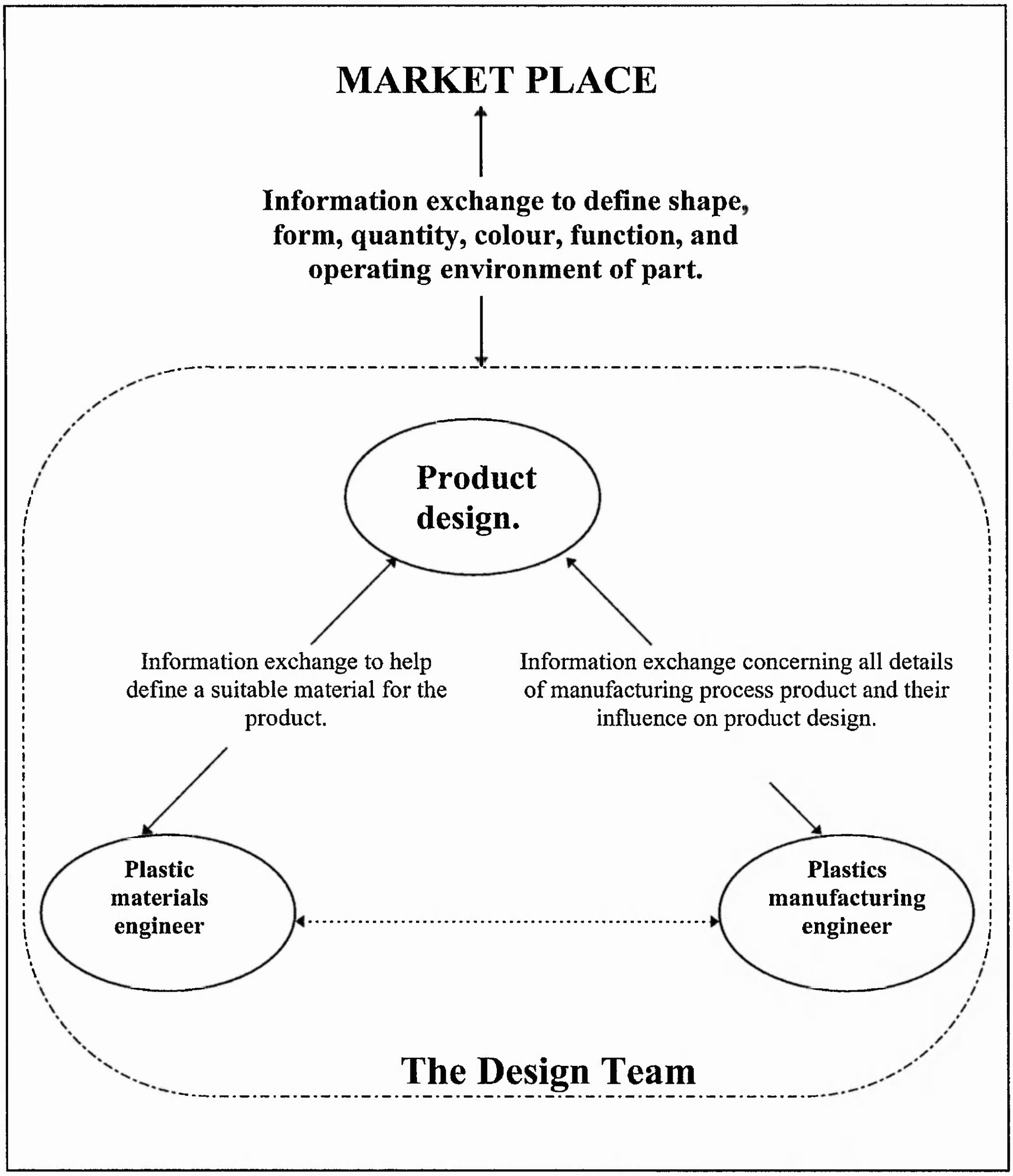

Figure 4.1. The product design team.

4.1.1. The design team members.

The **Product Designer is** responsible for all decisions affecting the design of the product. He or she will seek the advice of other specialists whose particular knowledge and skill can contribute to his/her understanding of the product design.

It is also the designer's responsibility to establish technical specifications for the product. In this regard, the designer considers not only the functional aspects such as, shape, and size of the product, but also Engineering aspects such as, the forces applied to the part, and the environmental temperature, chemicals, and radiation in which the product must function. It is the responsibility of the designer to prepare assembly and detailed drawings of the product according to the manufacturing process and to the personnel who will subsequently design the tools and manufacture the part.

The **Materials Engineer** is a specialist in plastic materials. He or she is usually performs a technical service function. It is his/her responsibility to be knowledgeable about all aspects of the materials to be used, including their service properties and their processing peculiarities.

The **Plastics Manufacturing Engineer** is a specialist in plastics manufacturing technology being capable of advising on both processing and tool making.

4.1.2. The design process.

In order for the expertise of the plastics engineer to be effectively used, the product designer must consult the plastics engineer at an early stage in the design process, and each must have empathy for the other's responsibility.

Having discussed and decided upon the concept, form, material choice, and manufacturing process, the plastics engineer should review the details of the design. Aspects such as tolerances, possible shrinkage areas, and hole location should be considered to ensure compatibility of the product-design drawings with the practical possibilities of the manufacturing process.

Once the product-design drawings are decided, the plastics engineer will usually be responsible for the design and construction of the mould or other manufacturing tooling required.

4.2. MATERIAL SELECTION

4.2.1. Computerising material selection

It is the responsibility of the design engineer, working in conjunction with materials specialists, to select materials to be used in converting the design into reality.

The material is selected according to its physical and mechanical properties. Geometry requirements and the choice of the process also impose constraints. From the physical and mechanical properties that mainly influence the choice of materials are some of the examples, stiffness, hardness, strength, erosion resistance, melting temperature, etc.

It is recognised that those who select materials should have a broad, basic understanding of the properties of material and their processing characteristics, and have ready access to multiple sources of data. One useful reference is the "Material Selector" issue of Materials Engineers. This magazine provides data about a number of engineering materials, as well as typical uses, process capability and the compatibility between material and process.

There are also several handbooks published by the various technical societies and trade associations. Engineering Materials Handbooks, published by ASM INTERNATIONAL, are comprehensive, exhaustive pre-reviewed handbooks of practical information of metals, adhesives, sealants, composites, plastics, ceramics and glasses, oriented specifically to engineers in user components. For example, Engineering Plastics covers plastics in detail [61].

It is obvious that applying computers to the polymer selection process as suggested by Farish, may dramatically increase accuracy and speed [62].

It should be noted that the available database systems are not merely catalogues of product data, stored in a computer readable form. They contain search routines that enable users to communicate their specific requirements with the system in order to precisely pinpoint the most appropriate grade of material and its suppliers details.

4.2.2. Materials selection software.

With the proliferation of new materials, and the increasing sophistication in materials applications, traditional data sources are rapidly becoming inadequate. According to Westbrook (1983), General Electric Materials Information Services, the computer offers inherent advantages difficult to match by the more conventional search systems. These include up to date comprehensive data, currency, speed, and accuracy. With a computer data base, breadth of coverage can be as wide as the corporate experts decide, and through Artificial Intelligence (AI), it is possible to encapsulate the available expertise and make it available for use by less experienced designers.

The Engineering Design Centre (EDC) at the University of Cambridge has tried to develop, validate and disseminate fundamental design methodologies for mechanical systems [63-64]. This includes:

- To create the theory and methods for a flexible design support environment;
- To provide an integrated computer system structure;
- To develop and test prototypes of an Integrated Design Framework and framework support modules.

With reference to Materials Selection, they have successfully introduced Computer Aided materials selection, creating the ***Cambridge Materials Selection.***

Cambridge Materials Selection is a software package based on charts and merit indices developed by Professor M.F. Ashby and his colleagues at the Engineering Department of Cambridge University. The software holds in a database all the relevant data of a representative range of materials. This covers metals, polymers, ceramics, composites and natural materials, displaying the various materials groupings as charts on the screen..

To select a material, the user performs a series of selection stages in which a pair of material properties of interest are specified.

The program presents graphs or charts with these properties as the axes. All materials contained in the database with applicable entries are plotted on each graph. The area of each graph which satisfies the selection criteria is specified by the user and the materials which lie in that area are considered to have passed the selection stage. Up to six independent selection stages can be performed.

One of the biggest advantages of this software package is the possibility to store a summary of a Computer Material Selection in a disk file. This summary file provides a high level interface which can be used by other programs to communicate the functional requirements of a component.

Cambridge Computer Materials Selector is particularly useful in the conceptual stage of design, when the designer **needs data for all materials** but with a low level of precision.

However, a number of class-specific databases are now being placed under the generic database, each containing a range of materials at a higher level of detail. Two of these general databases are 'PERITUS' by Matsel System LTD. and 'PLASCAMS' by RAPRA Technology [65].

PERITUS is described by the producers as a general material selection and data management system, and as such incorporates 13 modules. Selection of materials is performed within a particular module only and hence it is impossible to optimise between, for example, the options of metals, plastics and ceramics.

PLASCAMS, unlike PERITUS, contains only plastics, however it includes a more extensive range of plastics and has been found to be fast and reliable once basic familiarity is attained.

The selection procedures used in these databases are often referred to as expert system and, represent a tremendous advance over non-computerised materials databanks/books. On the other hand, they are also limited by many disadvantages such as the inability to contribute to the optimisation between design and material choice.

To exploit the full potential of computers in the area of materials selection, databases require artificial intelligence, to be able to apply reasoning in material selection. Such a system would store expert knowledge and select materials "intelligently", thereby forming Intelligent Knowledge Based Systems [66].

Such systems do not just store, sort and match material data, but they are capable of applying reasoning in materials selection. This is similar to what an experienced expert in the field does.

An example of this is **HyperQ/Plastics** which helps engineers in the selection of materials using both qualitative and quantitative selection methodologies [28].

When the designer decides the specific value of a required material property, (i.e. tensile strength or minimum operating temperature), the database can be sorted and ranked relative to these requirements. On the other hand when she/he does not have a quantitative value for a property but only suspects that this material must be “strong” or “tough” but not necessarily “smooth” or “rough” or when he or she only knows that certain properties are more important than others, there is a need for ranking procedure to sort potential candidate materials relative to the order of importance or their attributes to the designer. For instance, a plastic sledge designer may rank low friction as the most important characteristic of the design needs, strength and cost as relatively important, and stiffness as only minimally important. So, the database should be able to select polyethylene (a low friction, inexpensive, relatively strong but very flexible material) over nylon which is a more costly stiff counterpart.

To facilitate this sorting within the database, the process has been separated into two parts. First eliminate materials that do not meet the maximum/minimum property value cut-offs (quantitative pruning), and after the remaining materials are ranked by relative importance of all relevant property values (qualitative pruning). Incorporating suitable algorithms for both qualitative and quantitative pruning ensures the designer freedom in expressing product requirements.

4.3. PROCESS SELECTION.

For many advanced materials, including plastics, engineers must simultaneously select the material and its processing method during the design stage. In essence, the designer must resolve a number of major factors and the appropriate process simultaneously, because there is inter-dependence in the parameters production factor.

Materials selection is often deeply coupled with the selection of the processing techniques. Here, factors such as development time, production volume, shape complexity, wall thickness, and product size influence the decision.

The major factors that influence the process selection are classified in three categories [67-68]:

1.- **Material factors.**
Mechanical Properties
Physical properties

2.- **Geometry factors.**
Part shape
Part envelope size
Part weight
Tolerances and surface finish

3.- **Production factors.**
Time to market
Production quantity
Production rate

Material selection is not only affected by material factors, but also some geometry requirements such as minimum thickness and weight/size ratio. The choice of process will also impose certain constraints. There are also some inter-dependencies between the parameters in production factors. The production rate and volume depend on the product sales and the market life. The sales depend on cost, which in turn affects production volume.

Because of this it is necessary that the designer resolves material, geometry and production factors and selects the appropriate process simultaneously. Due to the high number of factors that influence the process selection it is necessary to devise a methodology which helps designers select a suitable manufacturing process.

In the past few years, the Department of Mechanical Engineering of The Ohio State University, has developed a system that uses the concept of **"Design Compatibility Analysis"** (DCA) to represent the suitability of a particular process with respect to a given part specifications.

Design Compatibility Analysis, developed by Ishii, Barkan [69-70], provides a general framework that can accommodate various simultaneous engineering issues. In DCA the focus is on the compatibility between the description of a proposed design and the design requirements. The requirements are not only functional but also relate to manufacturing methods and associated constraints, serviceability requirements, etc. DCA utilises a compatibility knowledge-base (CKB) which represents good and bad templates of design. Each piece of data in the CKB includes a measure of compatibility expressed with adjectives such as good and bad, or with a value between 0 -1. Given a partial or full description of the specifications and the proposed design, DCA checks to see if any of the compatibility data in the CKB match the current situation. From the set of matching compatibility data, DCA computes the measure of compatibility. Furthermore, DCA provides justifications for its evaluation and suggestions for improvement. Some obvious flaws may be automatically rectified, although the modification is usually left to the designer, because there may be more than one way to fix problem. Based on the rules in the compatibility knowledge base, Design Compatibility Analysis, the most compatible process for the given specifications is selected.

Different prototype systems, such as HyperQ/PP and DFPS programs, have been developed to implement the quoted methodology [28]. The difference between HperQ/PP and DFPS is that while HyperQ/PP only considers plastic selection, DFPS covers different production processes, not only focusing on plastics processing.

Another major research program is being carried out, in the Department of Industrial and Manufacturing Engineering of Rhode University, to get a systematic combined selection (process/materials) for component manufacture [71]. This method is being developed and implemented in a computer environment for use during the early stages of product design.

In this case the designer would first obtain a list of technically feasible materials and process combinations. The designer would then obtain an approximate estimate of manufacturing costs in order to rank the material/process combination, and hopefully to be able to make appropriate trade-offs as part of a CAD system.

4.4. DESIGNING INJECTION MOULDING COMPONENTS.

In designing the injection moulds and selecting equipment to be used for manufacture, the plastics engineer will attempt to balance processing cost relative to mould cost to achieve a minimum overall cost for the production. For example, the plastics manufacturing engineer will balance the investment in expensive, multicavity moulds which have to be run on large, against other alternatives, such as using smaller, cheaper moulds on smaller, slow-production machines. In the light of required production volumes and other considerations, the plastics manufacturing engineer will advise the product designer as to the type of mould or tool that should be built.

Once the product designer has identified the guidelines for making the mould, the plastics manufacturing engineer will finalise the detailed design of the mould. These guidelines cover areas such as surface finishes, location for parting lines and gate-area locations, all of which may be influenced by product application. In addition, the choice of plastic materials will affect many mould details such as runner, sprue, and gate sizes, the shrinkage factor to be used in sizing the dimensions of the mould so that product dimensions can be achieved and the necessary draft angles and tapers.

The benefits of CAE systems in injection moulding can be greatly enhanced by combining analyses that compliment each other, thereby promoting an important synergism in the technology [56].

Most plastic parts start at a concept stage. An engineering drawing of the part is prepared, preferably on a CAD station. The first CAE evaluation of the part should address whether the design and the intended material are adequate in terms of mechanical, aesthetic, or other criteria. Other CAE analysis should be attempted only after the design is finalised with regard to the basic mechanical requirements of the part.

There a number of tools that could be used and are described at the following sections.

4.4.1. CAE software tools moulding.

Mould filling analysis.

There are several types of commercially available CAE algorithms for injection moulding. The most popular software in terms of commercial offerings is mould filling analysis. This is understandable because of this phase of the process is the most technically complicated and difficult to predict.

The information obtained from a mould filling package depends on the type of analysis conducted and the input supplied. Two dimensional analysis does not require intensive computing power or many person-hours to set up. It does, however, depend on the expertise of the user in specifying the flow paths and is, therefore, best applied and interpreted by those familiar with polymer flow behaviour.

A second type of flow analysis involves a full three dimensional analysis of the mould cavity as well as the process parameters. The flow pattern in this case is determined from a solution of the three dimensional governing equations using a numerical method such as Finite Element Analysis. This type of analysis does not require specification of the flow paths and hence is more suitable for implementation by designers who may have less experience. However, removal of human expertise from the process and relying solely on the assumptions and rules of the program has certain disadvantages. Use of the program requires the user to be familiar with the limitations of the analysis and to exercise proper engineering judgement in creating the model and interpreting the results. The computation time and cost for a complete three dimensional solution can be prohibitive. Mathematically rigorous solutions of complex parts can consume hours or even days of computer time, and thousands of pounds in costs.

Solidification analysis.

Solidification analysis is an important facet of improved productivity in the injection moulding processes. Solidification time of the plastic is often the largest component of the moulding cycle time which is the primary barometer of productivity. Material selection, process parameters, part geometry, part quality and mould construction all contribute to this. Minimisation of cycle time was one of the early commercial CAE offerings and there are now a number of software packages available to achieve this.

Heat transfer analysis, as a component of mouldability analysis, leads to improved yield through better dimensional tolerances and appearance. Improper and unbalanced solidification is a principal cause of warpage and distortion of moulded plastics. CAE algorithms provide the capability to analyse the temperature gradients that develop within the part so as to minimise subsequent warpage on ejection.

Thermal analysis programs also consider the section thickness, the size and location of coolant channels, the heat transfer characteristics of the coolant flow, the mould material, as well as the process parameters.

4.4.2. Sequential use of CAE software packages.

Generally speaking, the most appropriate time to conduct mould filling analysis seems to be after the part has been optimised with regard to mechanical and thermal criteria.

Process parameters such as the melt temperature, mould temperature, and injection rate are most often altered when conducting flow analysis and the filling analysis provides the additional inputs needed to conduct in-depth economic analysis.

The general sequencing rule for applying CAE packages is to conduct analyses according to the order in which they impact downstream analysis and decisions. The wall thickness has a strong influence on thermal and flow behaviour as well as material costs; it should therefore be locked in at the first evaluation step. Solidification time and appearance are less sensitive to wall thickness and process conditions and are probably less critical with regard to part feasibility, than flow behaviour. Solidification analysis should therefore be conducted after the configuration of the part is set. Mould filling analysis is most likely to affect process conditions and gating, both of which have little effect on mechanical or thermal analysis results, so this should logically follow these evaluations. Economic evaluation is best conducted after all other analyses since it requires their information. It is unlikely to alter parameters arrived at from technical considerations unless the economic feasibility of the entire project is endangered.

C-Mold is a well known CAE software, developed in Cornell University, that follows a 3 layer philosophy to fully simulate the injection moulding process [57] (Figure 4.2.).

The first is used to design the part and the mould. Conceptual design of the part can consist of selecting material and mouldbase, generate a simplified model of part and mould and evaluate basic design parameters. C-view is used to model the part, include topology, runners and cooling system and prepare the finite element mesh for further calculations. Extensive interfacing can be incorporated, so users can import external geometry (IGES) or mesh from different sources.

The second layer focuses on improving productivity and operational consistency, using previously determined data. The task on hand at this level is to identify process feasibility, problem areas in general and the optimised utilisation of the machinery.

Integration of different numerical calculations, will lead to the determination of post-moulding part dimensions (layer 3). All important factors that determine part deformation during the filling/cooling of the plastic in the mould, are taken into consideration. The integration of both performs a simultaneous simulation of the total process from injection to ejection.

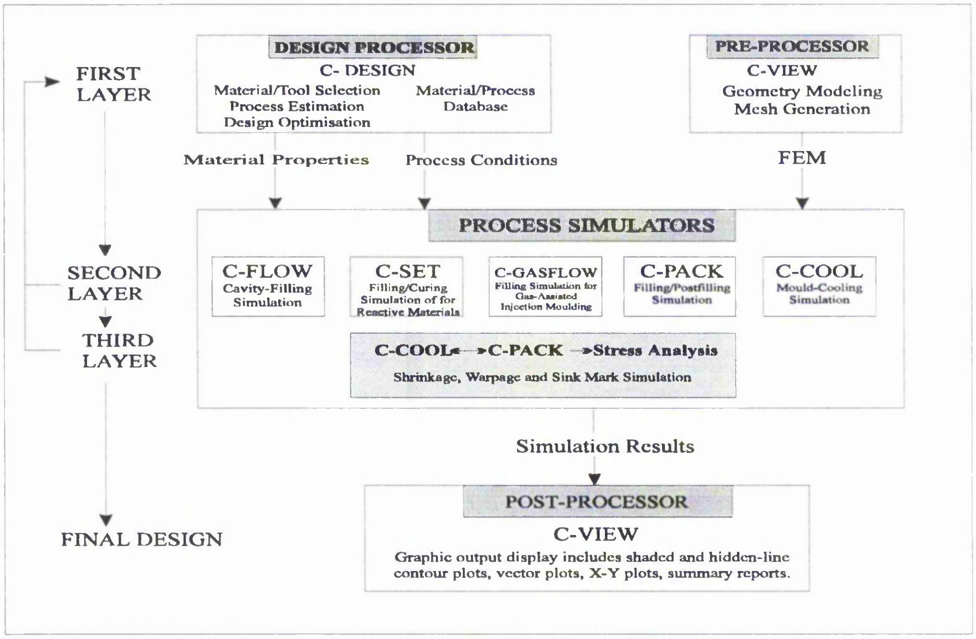

Figure 4.2. C-Mold. An integrated injection moulding process simulation

Another integrated CAE software package is known as Moldflow. "Moldflow" covers all injection moulding process aspects and gives an idea about what CAE Systems can offer in an injection moulding process simulation [58-59].

4.5. DESIGNING EXTRUSION MOULDING COMPONENTS.

The production of extrusion components, of profiles such as pipe, sheet and window frames is a very important commercial process. These profiles are being used in various industries such as the gas, water and telecommunication industries all over the world. It follows therefore that any slight improvement in the productivity of the process equates to major cost savings. The manufacturing process for a product such as pipe depends very much on a number of separate factors, among which are:

- materials selection
- the extruder design
- the screw design
- the die design

It is very important to consider the process as a whole, since all the above factors are intimately linked. The extruder, through the rotation of the screw must deliver melt of the right quality, at the correct temperature, to the die, which in turn must be designed to make allowance for any die swell that is likely to occur. The flow properties of the material are again crucial and will influence the design of screws and dies. The consequences of getting die and screw designs wrong could influence process performance.

4.5.1. Extrusion Die Design.

As has been explained in the introduction to plastics processing, extrusion is a process used to continuously form the molten plastic by pushing it through a die.

The molten plastic is forced through the shaped orifice of the die, and thus assumes an approximation of the final required profile section. As the material leaves the die it is hot, and must be cooled rapidly, to acquire the desired shape. Cooling fixtures are therefore used to achieve this. Cooling is normally achieved by cold-air blast, cold-water spray, or by submersion into cold water. When the plastic is cool enough to have significantly regained strength, it is carried along by a take-off mechanism, and cut-off to the desired length.

There is usually a significant difference in size and shape of the die orifice and the final dimensions of the profile section. This is due to the "drawing-down" or stretching, of the plastic immediately after leaving the die.

It is now possible to design an extrusion die using computers and to analyse the flow of polymer melt using the Finite Element Method (FEM). Such analysis also enables the die to be designed such that any stagnation zones, giving rise to recirculating flows, can be detected and eliminated. It can be used to calculate the velocity vectors throughout the die to ensure that melt is being delivered to the die exit at a uniform rate so as not to generate irregular die swell and thickness variations.

4.5.2. Screw Design.

A number or research groups have developed computer models for the flow of polymer through a single screw extruder. Some of these concentrated on the conveyance of solid material in the feed section and some on the pumping of melt. Some have concentrated solely on the melting of the polymer during its passage along the screw. Most of the models are based on the analysis first described by McKelvey [60]. The melting models are based on a similar analysis; basically they solve the three conservation equations; the conservation of mass, momentum and energy and a constitute equation for the rheology of the material. They enable the calculation of the amount of solid converted to melt due to the conduction of heat through the barrel from external heaters and by heat generated by internal friction within the polymer melt once it has formed.

A number of software packages are also available commercially, with which it is possible to predict the behaviour of polymer melts during their passage through the extruder. Input data to the software includes accurate information about the thermal properties of the material and especially full and accurate rheological data, without which the predictions are of little value.

4.6. SUMMARY AND CONCLUSIONS

The design of plastic components is a complex process where designers must consider material properties and manufacturing processes during the design stage.

Those who select materials should have a broad, basic understanding about properties of different materials and their processing characteristics, and have ready access to multiple sources of data.

During the design stage, the designer must simultaneously select the material and its processing method, and the use of Computerised Material and Process selection makes the job easier. A number of material and process selection software packages have been studied and described in this chapter, but the implementation of any of them within any company will be determined by a company's needs.

The use of Computer Aided Systems would be beneficial during the design stage in reducing development times, and during the manufacturing stage in reducing quality problems, and a study of the availability of plastic processing simulation programs has been carried out.

There are a several types of Computer Aided Engineering Systems commercially available that simulate part of the injection moulding process. The most commonly used are Mould Filling and Solidification Analysis, although software suppliers, such as Moldflow and C-Mold, cover all areas of injection moulding process simulation.

Within extrusion moulding processing, factors such as materials selection, and extruder, screw and die design are intimately related. However, although a number of software packages do exist in order to assist designers in each of the processes, a complete integrated system to simulate all aspects of the extrusion process does not exist. Several of these software packages are analysed in the next Chapter.

CHAPTER 5

UTILISATION OF CAE SYSTEMS IN EXTRUSION MOULDING.

5. UTILISATION OF CAE SYSTEMS IN EXTRUSION MOULDING.

5.1. INTRODUCTION.

The use of Computer Aided Systems in the design and manufacturing of plastics components will almost certainly bring advantages, the most notable being reduced development times and a decrease in manufacturing errors. In some cases, the appropriate use of these "new" techniques may mean the difference between a company's survival and liquidation in today's competitive market place. The basic requirements for the integration of Computer Aided Systems into the plastics engineering process chain, from design to production, are shown in Figure 5.1.

In this chapter the integration of Computer Aided Systems for design and manufacturing of extrusion components is studied. The quality and output rate of manufacture of any extruded component depends very much on a number of different factors, such as: processing material properties, the screw, barrel and die geometry, and the operating conditions (barrel temperature and screw speed).

The author has carried out an investigation into some of the available software packages to support the designer during die and screw design. The analysis of these software packages has not concentrated on the availability of mathematical models, but on the possibilities that each software package offers through its implementation within a broader design and manufacturing system.

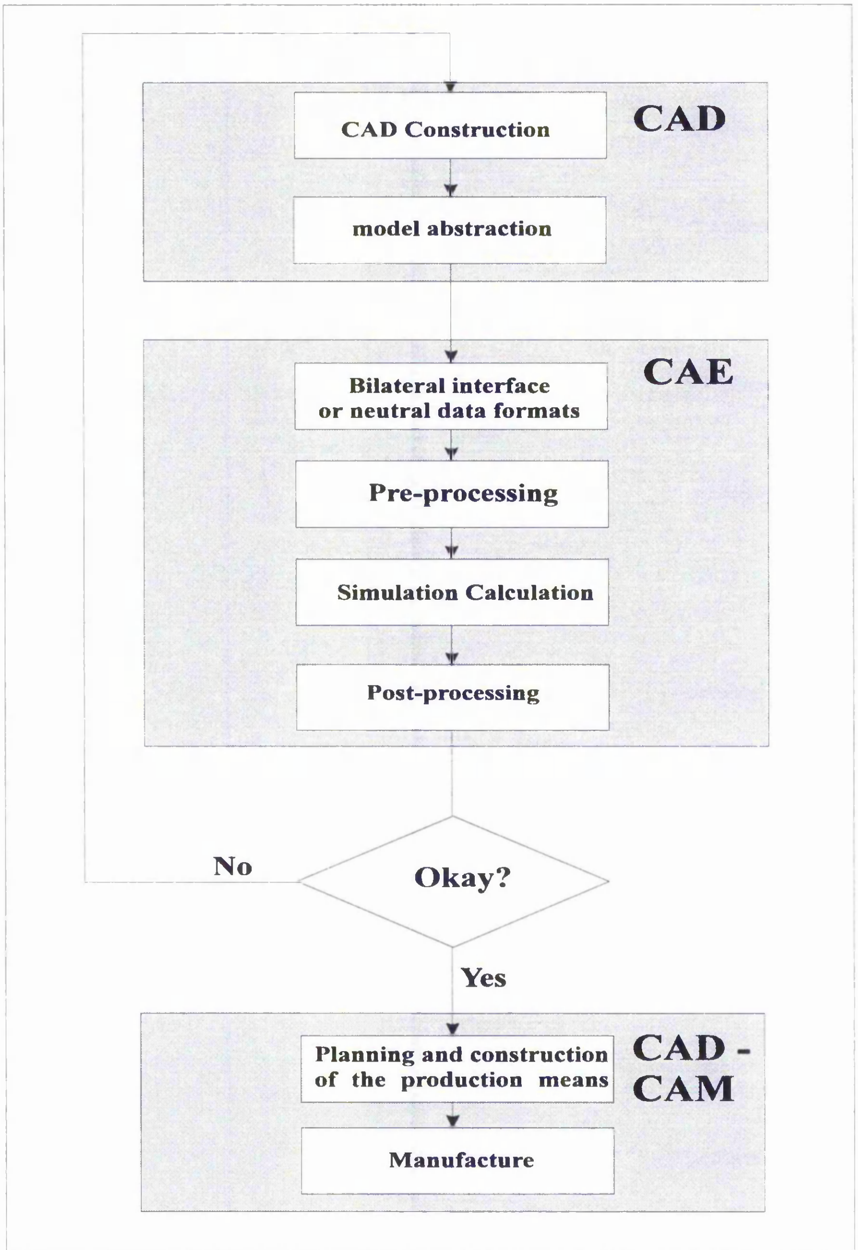

Figure 5.1. Requirements for the integration of Computer Aided systems for the plastics engineering chain from design to manufacture

5.2. EXTRUSION DIE DESIGN.

The objective of an extrusion die is to distribute the polymer melt in the flow channel, such that the material exits from the die with a uniform velocity, ensuring a good quality finished product. The actual distribution of polymer melt is mainly determined by the flow properties of the polymer, the flow channel geometry, the flow rate through the die, and the temperature field in the die.

A correctly designed extrusion die is of critical importance to ensure the manufacture of high-quality products. This calls for the introduction of advanced technology into the die design and manufacture process for reducing costs and the design cycle time. An integrated application of the computer techniques of CAD/CAM and finite element analysis in assisting the plastics extrusion die process for profile dies is likely to be an effective means of gaining a competitive edge in the market place through the assurance of product quality (Figure 5.2.).

The design of the die is one of the major factors in determining the quality and price of the final product. It is necessary to provide the designer with an easily accessible and comprehensive database of relevant knowledge of the factors which may influence the polymer flow. Numerous design handbooks and papers are available for reference containing design rules and the empirical data required [12, 72-73].

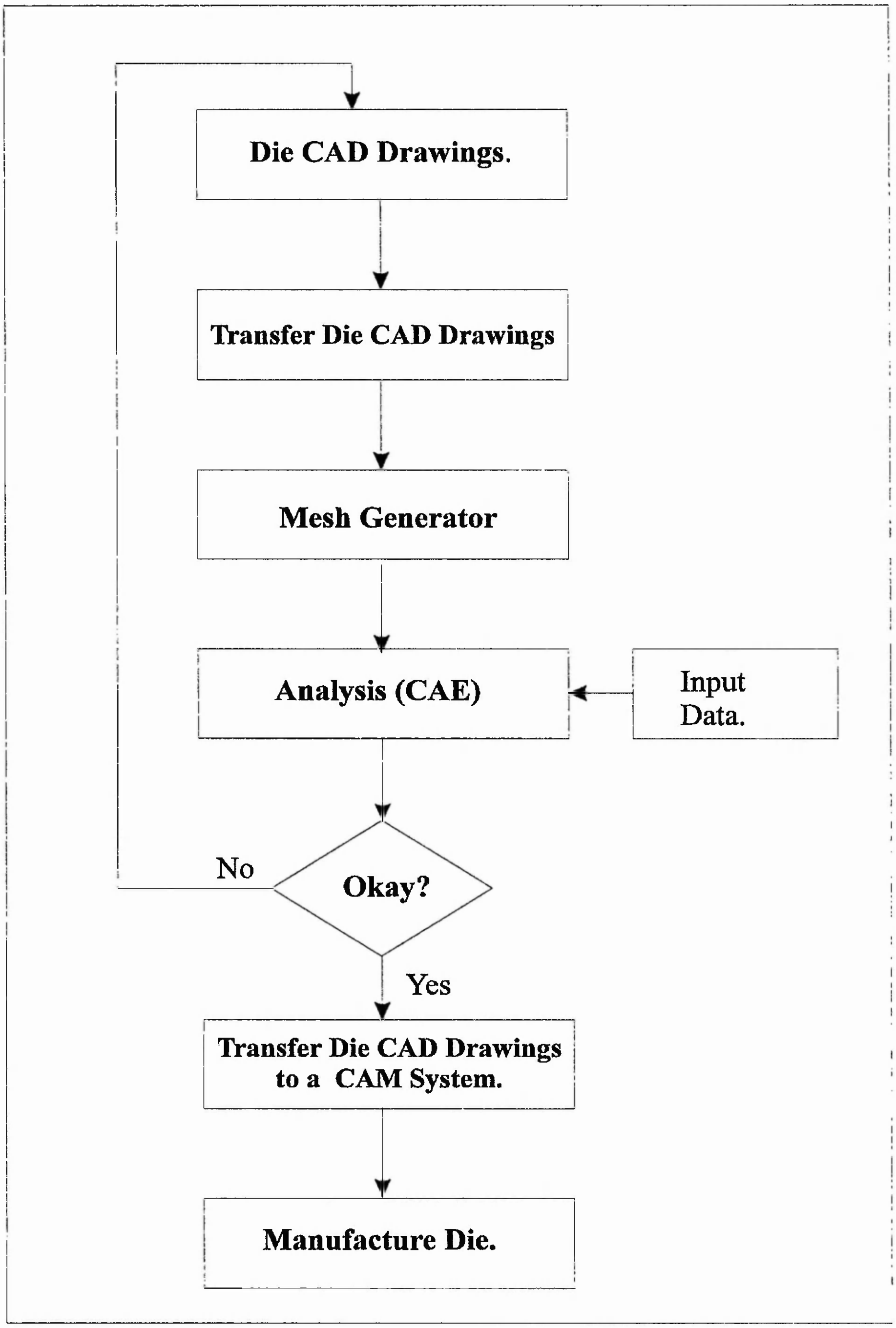

Figure 5.2. Die design and manufacture process.

However owing to the huge quantity of diverse information and factors to be considered, this may become a rather "hit and miss affair" governed by the individual subjectivity of the designer's experience.

A major consideration that die designers must face is the complexity of the extrudate flow from the die during extrusion. The velocity profile is not uniform within the die, with steep velocity gradients near the wall. Once past the die lip, the velocity field is redistributed and soon becomes uniform. This rearrangement of the velocity profile, together with stress relaxation, induces extrudate deformations, and the extruded shape can differ quite radically from that of the die. Consequently one of the most important problems is to determine the cross-section of the die which will generate the required extrudate shape. This can be obtained through flow analysis using the Finite Element Analysis Method.

Finite Element Analysis (FEA.)

The Finite Element Analysis method was first developed to compute the stresses and strains in complex structures. This mathematical technique is now used to solve a great variety of two and three dimensional engineering problems such as determination of displacement, stresses, forces, temperature distribution, fluid flow, pressure distribution and so forth.

Basically the method is based on the division of the problem's region or domain into a number of "finite elements" to form a mesh. This is the pre-processing phase. Finite Element Analysis packages normally provide a comprehensive library of elements from which users can make selections. In the solution phase, the contribution of each element to the problem's solution is evaluated. Finally, in the post-processing phase, the results are presented on the display as contours of displacement, stress, voltage, temperature or pressure and graphs to analyse variables. They may also be output to a pen plotter. The procedure for carrying out an analysis will depend on the package and the subject of analysis.

Appropriate definitions of system geometry, boundary conditions, material properties and system environment are required to simulate real systems. In describing the system geometry it is necessary to accurately define a mesh of suitable refinement. During the course of this study, some of the most widely used FEA software packages used for die design were assessed and a brief description of each is presented in the following sections.

5.2.1. FIDAP

FIDAP is a general purpose finite element program for simulating a wide variety of fluid flows and the effects of heat transfer within the fluid. Supplied by Fluid Dynamics International Inc, Evanston, Illinois, USA, its simulation embraces subsonic compressible or incompressible viscous flows. The flow may be turbulent or laminar. FIDAP provides viscosity models for Non-Newtonian fluids as well as Newtonian fluids.

Required data.

For the simplest analysis, an incompressible, two-dimensional, steady-state laminar problem, the basic set of required data is:

- a diagram of the flow domain, including dimensions,
- boundary conditions,
- initial conditions,
- fluid properties.

To this data is added:

1. For geometry and meshing.
    - locating points necessary to describe the geometry
    - deciding on a meshing strategy.

2. For program control.
    - considering the equations to solve
    - deciding on a solution approach.

Simulation Control.

The particular set of equations FIDAP solves is determined by the characteristics of the flow being simulated and is set by the user. In order to specify these equations to FIDAP, the following information is required:

- Whether the geometry for modelling is two-dimensional flow, axially symmetric, cylindrical or three-dimensional.
- Whether the flow is compressible or incompressible.
- Whether the flow is steady state or transient.
- Whether the flow is laminar or turbulent.
- Whether the flow behaves as a Newtonian or non-Newtonian fluid.

Sometimes these questions are difficult to answer, however in order to specify the correct equations to be solved, it is most important to identify the correct flow phenomena to be simulated, which means that ideally the system should be operated by an experienced designer.

Working with FIDAP

If only FIDAP modules are being used to create the problem description, then all the information quoted in the required data section needs to be supplied. However, it is possible to generate a description of the finite element mesh and boundary conditions using another program. FIDAP accepts data in the format of PATRAN neutral file and I-DEAS universal files. FIDAP also accepts drawings from different CAD Systems using IGES.

Although FIDAP's solutions have proved its efficiency in many cases (Ref.), it does have its drawbacks, namely: lack of user friendliness and high hardware requirements (for FIDAP 7.6, the most recent version of the software package, 35 Megabytes of disk storage is required and also for its execution 32 megabytes of memory, although it is strongly recommended that 64 megabytes of memory are available). These are two important aspects because it may be the case that other software packages can satisfy the company's personal requirement at a greatly reduced cost.

5.2.2. DIECAL.

Diecal is a product of Rapra Technology Limited, Shawbury, UK. It is a program intended for modelling streamlined profile dies. The program calculates temperatures and pressures throughout the die, and forecasts dimensional changes as the profile passes through calibrators, water troughs and other downstream apparatus. One of its advantages is that it enables the user to simulate the flow of rubber or thermoplastics during extrusion on a stand alone *personal computer*.

Required data.

Diecal's Material Database contains information about thermal and rheological properties of the most common rubbers and thermoplastics, but it is possible to simulate other rubbers and thermoplastics after their thermal and rheological data has been entered separately.

A three-dimensional die geometry is also required. Its construction can be produced interactively on-screen (this involves describing the shape of the system by means of surfaces which are used to create the finite elements using an automatic mesh generator) or it can also be imported from CAD programs, such as AutoCad.

Finally, Process Operating Conditions such as material and die temperatures, volume flow rate and pressure limits need to be specified.

Working with Diecal

"Diecal" monitors the condition of the polymer as it flows through the die. Three-dimensional distributions of temperature, shear stress, shear rate and velocity are calculated, and displayed graphically.

By using Diecal, the designer can optimise the die design parameter, ensuring the die is balanced (i.e. uniform exit velocities). However, the possibilities of integrating this software package within a larger Computer Aided System are very limited. The Diecal software package will not accept meshes generated through other mesh generators, such as PATRAN, or I-DEAS, and the post-processing possibilities it offers are also very limited.

Diecal does have the advantage, however, of only requiring minimal hardware (Processor: 80286, 8 Mb RAM, 10 Mb program area and DOS 3.1 operating system), which, because of the low operating costs makes it extremely attractive as a support tool during the design stage.

5.2.3. POLYFLOW

POLYFLOW software package is distributed by Polyflow S.A., Louvain-la Neuve, Belgium. It can be used for modelling a wide variety of processes, including extrusion and coextrusion, for fluids such as polymers, oils, liquid food stuff and molten glass, amongst others.

With POLYFLOW the extrudate shape is assigned, and the software automatically calculates the die shape required to produced that extrudate shape. POLYFLOW also gives data such as velocity and pressure distribution in the fluid's core, temperature and residence times, particle paths and stresses. In addition, it is able to simulate extrudate swelling.

Comprehensive pre and post-processors provide the means to fully exploit Polyflow. The software package contains interfaces to other commercial mesh generators, such as PATRAN and I-DEAS, so meshes can be imported and used ensuring compatibility with other existing software packages. It also provides an interface with other CAD packages through its capability to import geometry information in the IGES format. After POLYFLOW has calculated the die shape needed to obtain the extrudate, this information can be generated in IGES format to feed CAD/CAM codes used for cutting dies. By combining these segments, the POLYFLOW package produces tremendous benefits in understanding and improving the industrial processes simulated.

5.3. EXTRUDER DESIGN.

The single-screw extruder is the single most important processing machine used in the polymer industry. However, the quality of the final product is very sensitive to screw design and operating conditions. The simulation of this process by means of mathematical models has been studied extensively. Nevertheless, despite the theoretical developments in these models and their complexity, prediction of the overall performance of the extruder and the optimal screw design, with respect to operating conditions, seems to have room for improvement [74].

The performance of an extruder is governed by its capacity to convey, melt and pump the polymeric material. The development of mathematical models for the simulation of single-screw plasticating extruders has been widely covered. Some have looked at the way solids are conveyed in the feed section of a simple three element screw [75-76], some have considered only the pumping of polymer in the metering section [77-78], whilst others have concentrated solely on the melting mechanism [79-82]. Despite these developments, the perfect model which in theory would help the practising engineer to design extruder screws does not seem to exist.

The screw extrusion process can be represented by three distinct regions, and a different, but interdependent, model is necessary for each region:

- solids conveying
- plasticating
- melt conveying.

The plasticating zone presents a particular difficulty owing to the co-existence of solid and molten states of the polymer. Extensive research has been directed towards this area. A fairly complete literature review of existing plasticating single-screw extrusion models is given by Amellal, et al [83].

A comprehensive model developed as a computer-aided design tool for conventional and barrier screws is described by Amellal, Lafleur [84], which can predict the pressure, temperature and solid bed profiles developed along the extruder.

<u>Optimising extrusion output through screw design</u>

The extrusion process is the result of the interaction of the screw and the die, so that the output of the extruder depends to a large extent on the screw. The maximum useful output rate obtainable from a single screw plasticating extruder of a given size is generally determined by extrudate quality requirements. These can be defined on the basis of its external appearance, dimensional tolerance, and mechanical, chemical, and electrical properties, amongst other factors.

Thus to determine overall screw performance it is necessary to take into consideration the extrusion output, the cost of screw operation and the quality of the extruded polymer. If these variables are measurable quantities, the screw performance can then be assessed in accordingly [85].

Mathematical models of the extrusion process make possible the prediction of output quantities on the basis of input data. The extrusion input data embraces the following:

- data relating to the polymer being used, (primarily thermal and rheological properties)
- data relating to the extruder (geometry of the screw and barrel)
- screw rotational speed and temperature conditions

The predicted output quantities are mass flow rate of the polymer (extruder throughput), properties of the polymer leaving the die, power consumption, and pressure and temperature distribution of the polymer along the screw and die length. A software package based on this is called "Rex" (Figure 5.3.), developed to support designer in the design of the optimum screw and in the elimination of problems during the extrusion operation [86-87]. Equally a software package developed by Prentice and Wood (Melting) in the laboratories at Nottingham Trent University can optimise the output rate by changing the screw design for a specific material and operation conditions.

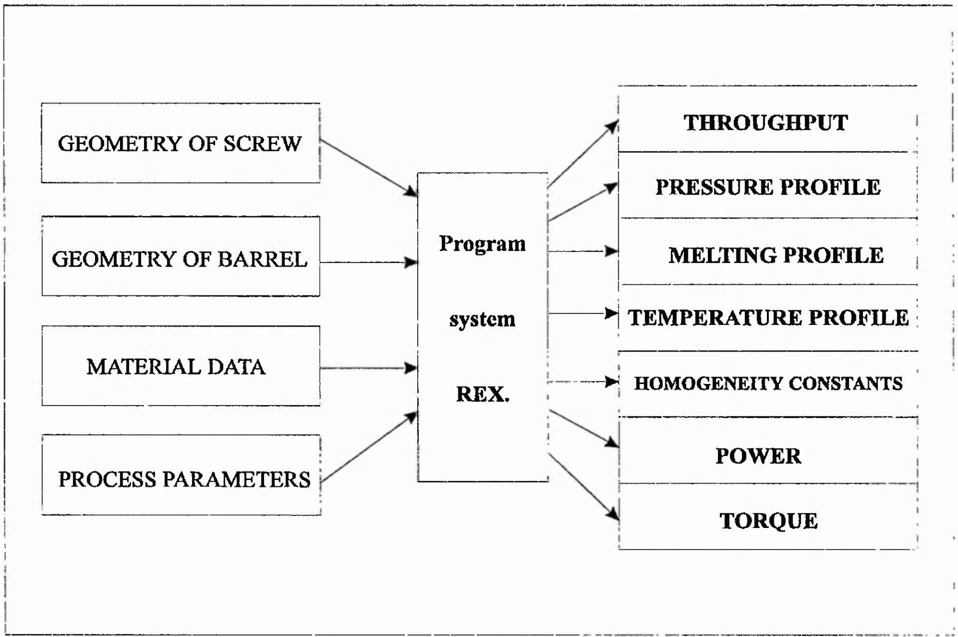

Figure 5.3. Overview of "Rex" System Components

Through the utilisation of any of the software packages mentioned, the screw design is optimised for a particular material and for operating conditions. This uniquely optimised screw is ideally suited to production of large quantities of a single product, i.e. gas pipe, oriented polypropylene (OPP) film or PVC window frames. However, the suitability of these software packages can then be called into question, as it remains to be answered whether it is more cost effective to have one versatile screw design able to handle a range of materials, or an optimal screw design dedicated to each material that the processor uses. Unfortunately, more research needs to be done to achieve such a universally optimised design of screw.

5.4. DISCUSSION ABOUT FINITE ELEMENT METHOD.

Using any of the Finite Element Analysis software packages described above, the designer can predict the correct die shape before any metal is cut, resulting in reduced cost, lead times and increased competitiveness. This is achieved by reducing product estimation/development lead times, overcoming dependence on "trial and error" design methods, saving cost on materials, and improving finished product quality.

The purpose of any finite-element analysis software package is to re-create the behaviour of an engineering system through the creation of an accurate mathematical model. To achieve this, it is necessary to predetermine the objectives of any analysis, to establish the level of detail required to be included in the model. Also, the kind of elements to be used, and how dense the elements need to be. In general, an attempt is made to balance computational expense (CPU time, etc.) against accuracy of results. The decisions made at this stage will determine the ultimate success or failure of the analysis.

A major objective of computer aided processing is that using the computer as a laboratory, the designer understands, improves, creates and tests processes in which flows play a dominant role. The designer can experiment with a wide variety of parameters to optimise design and obtain a quality product without wasting material,

But, which one is the ideal finite element analysis package that helps the designer during the die design process? There is no unique answer to this question. However, the following aspects should be considered when trying to determine the suitability of an FEA package for a particular task.

1.- The ability of a package's integration into a broader manufacturing system. For example, the ability of the software package to transfer the simulation to a different model through IGES.

2.- The complexity of the models that the software package offers.

3.- The quality of the model's mesh generator.

4.- The output graphics that the system can offer.

5.- Hardware and software requirements.

6.- Ease of use.

CHAPTER 6

A STEP FORWARD TOWARDS THE INTEGRATION OF DESIGN AND MANUFACTURE OF EXTRUDER COMPONENTS.

6. A STEP FORWARD TOWARDS THE INTEGRATION OF DESIGN AND MANUFACTURE OF EXTRUDER COMPONENTS.

6.1. SELECTION OF SOFTWARE PACKAGES.

Throughout the course of this thesis the author has shown how the implementation of the Concurrent Engineering philosophy will improve the performance of Extrusion Plastics Processing companies by reducing development times and increasing productivity. As the implementation of Concurrent Engineering Philosophy demands the utilisation of interrelated Computer Aided Systems, an exhaustive review of the different Software Packages currently available in the market was carried out. The study has concentrated on the possibilities that each software package offers for integration with other packages in order to facilitate the implementation of Concurrent Engineering philosophy. The available Electronic Data Interchange methods have also been analysed, and at this stage of the research the objective was to create a basis for an Integrated System for the Design and Manufacture of extruder components.

The most important element of a plasticating extruder is the screw, since it is this component that determines the overall MELTING performance of the process. It is therefore of the utmost importance that the design of the screw is such that a melt of the highest possible quality is produced at the highest rate. Design and Manufacture are intimately related, so the idea of creating an Integrated Computer System for the Design and Manufacture of Plasticating Extruder Screws seemed the ideal place to start in this integration process. For this purpose two software packages currently available in the Polymer Engineering Centre of the Nottingham Trent University were used:

- a Screw Design Optimisation Software package
- and a Computer Aided Manufacture System to Generate the G-Codes to manufacture the designed screw through the use of Numerical Control Machines.

Numerical Control (NC) is a means of operating machine tools by a series of coded instructions, based on alphanumeric characters and called G-codes. These G-codes are stored in programs that can be input automatically to the machine to facilitate the manufacture of components.

At the beginning of the software package selection stage, Finite Element Analysis was considered. However, the use of general purpose Finite Element Analysis systems that deal with fluid flow was finally found to be inappropriate when simulating the MELTING process. This is because there are currently no general purpose packages in the market that can accurately model Non-Newtonian Fluid Flow. The alternative was therefore to use one of the specialist packages for simulating the MELTING process such as the MELTING program, based on Fenner's model [88] and currently available in the Nottingham Trent University.

In order to design the manufacture module, the existence of a tailored software package; namely STEP3 developed by Fassihi [89], to generate the necessary G-codes from the screw geometry and parameters made its choice more suitable than any other general purpose Computer Aided Manufacturing System currently available in the market.

Production with NC machine tools is extremely flexible. To change from one component to another is a simple change of part program either by introducing it manually, changing a floppy disk or calling another program on-line form a host computer. As a result, one single product, such as an optimise extruder screw manufacture, can be produced very economically.

In the next paragraphs, Extruder Design and Manufacture modules are going to be analysed independently at a lower level.

6.2. PLASTICATING EXTRUDER SCREW DESIGN MODULE

Any optimisation procedure starts with the definition of resources and requirements. Resources in this frame-work are the description of the available extruder equipment. This would automatically impose some restrictions which are usually screw length and diameter. A further variable in the equation is the polymer material which needs to be processed. In addition, another set of variables is also imposed due to the type and capabilities of the machine and the production output requirements; e.g. thermal range of heater bands or the revolution rates (RPM) that provide a certain output rate. Hence, the optimisation procedure requires three sets of inputs:

- Initial Extruder Geometry Data
- Machine Operating Conditions
- Polymer Properties Data

The parameters in the first two categories are fairly straightforward and well known to its operators. The information mentioned in the latter case can be provided by obtaining the results of the actual physical test on the material and analysing them or, in cases where the material is well established, the materials data might be found in some data handbooks.

The MELTING Program generates screw geometry and recommendations about the operating conditions for the optimum overall MELTING performance. Screw geometrical data should then be passed on to the drawing module to identify the screw material and generate detailed drawings, ready to be passed on to the manufacturing module. The Screw Design Module is illustrated in figure 6.1.

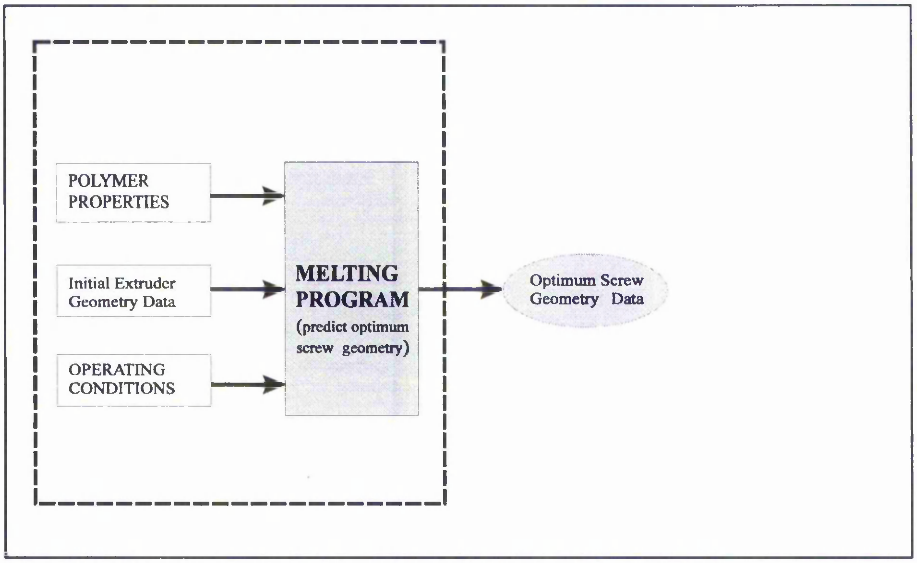

Figure 6.1. Screw Design Module's Operational Diagram

6.3. PLASTICATING EXTRUDER SCREW MANUFACTURE MODULE

The manufacture module deals with the generation of the G-codes to be introduced into a Numerical Control Machine in order to manufacture the screw. As has been mentioned before, for this purpose a tailored Computer Aided Manufacturing System developed by Fassihi (STEP3 program) was used[89]. The required set of input can be summarised in two stages:

- Screw Geometry Data
- and Screw Material Properties.

Screw Material Properties are well known, steel being the main material used and its properties are easily found in handbooks or databases. On the other hand, "Screw Geometry Data" may be related to the Optimum Screw Geometry Data obtained through running the MELTING Program. The output of this program generates a file with the required G-codes. This file can be electronically transferred to any Control Numerical Machine to manufacture the screw. The Manufacture module is illustrated in figure 6.2

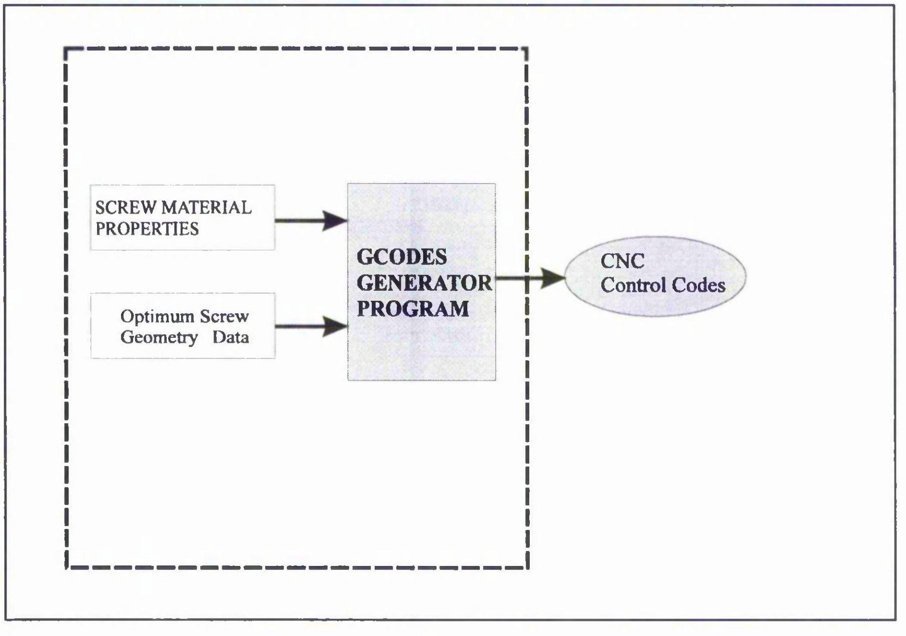

Figure 6.2. Screw Manufacture module's Operational Diagram

6.4. INTEGRATION OF SCREW DESIGN AND MANUFACTURE MODULES.

6.4.1. Definition of the Propose Integrated System

The author's analysis of the described modules shows interrelations between them, although until now they have been considered independently. The integration of both modules would be a step forward in a full integration of Computer Aided Systems to be used during the Design and Manufacture of plasticating screw designs. The proposed Integrated Design and Manufacture module system is as follows (Figure 6.3.)

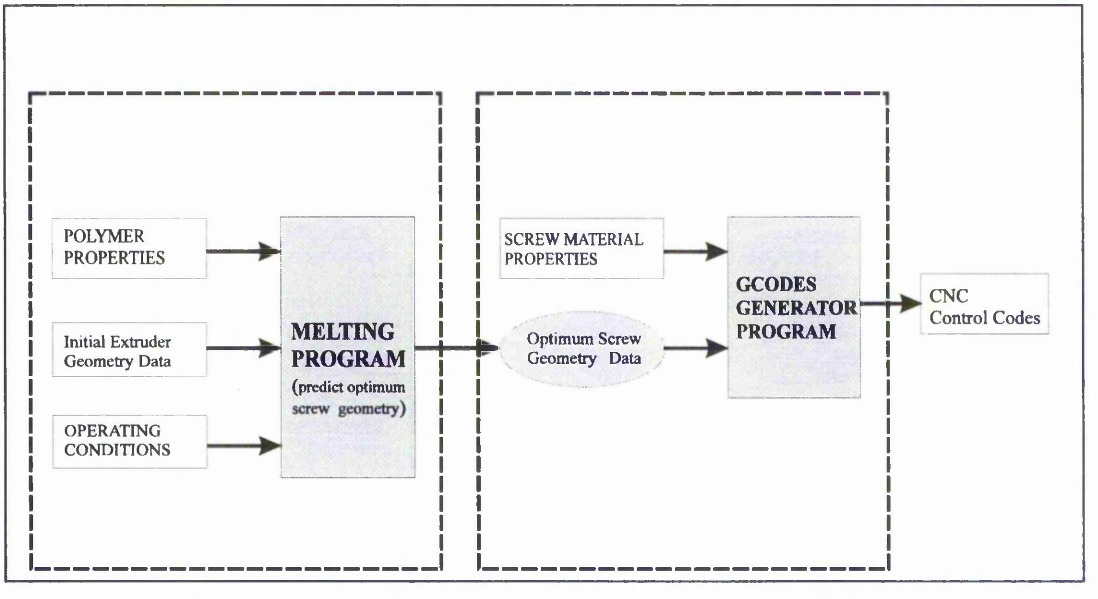

Figure 6.3. Proposed Integrated System for the Design and Manufacture of Plasticating Extruder Screws.

Table 6.1. shows the data which is necessary to be transferred from the Design Module to the Manufacture module. The left side of the table shows the screw geometry data required for the MELTING Program to optimise the design of a particular extruder screw, while the right hand side of the table identifies data used in the G-codes Program as well as in the MELTING program. The necessary remaining data in order to run G_Codes Generator Program will be introduced through the key board by the user.

Extruder Geometry Data existing on "MELTING Program".	**Extruder Geometry Data Required for "STEP3 Program".**
1. DESCRIPTION ....filename	
2. INTERNAL BARREL DIAMETER	INTERNAL BARREL DIAMETER
3. LENGTH OF FEED ZONE	LENGTH OF FEED ZONE
4. LENGTH OF COMPRESSION ZONE	LENGTH OF COMPRESSION ZONE
5. LENGTH OF METERING ZONE	LENGTH OF METERING ZONE
6. DEPTH OF FEED ZONE	ROOT (FEED) DIAMETER = INTERNAL BARREL DIAMETER - 2 * (DEPTH OF FEED ZONE)
7. DEPTH OF METERING ZONE	DEPTH OF METERING ZONE
8. RADIAL FLIGHT CLEARANCE	
9. SCREW FLIGHT WIDTH	SCREW FLIGHT WIDTH
10. SCREW PITCH	SCREW PITCH
11. NUMBER OF STARTS	
12. NUMBER OF BARREL HEATER ZONES	
13. BARREL HEATER ZONES	

Table 6.1. Screw Extruder Geometry Data.

6.4.2. Changing the MELTING Program

The MELTING Program basically runs as follows: a set of extruder geometry data, material properties and operation conditions are introduced, the program simulates the MELTING process and the output rate, potential consumption and the existence of any solid at the end of the extruder is shown on the computer screen. At this stage the engineer responsible for simulation evaluates the results and decides whether to continue simulating different situations by changing the screw geometry or operating conditions, or to finish the simulation.

It may be the case that changing screw geometry data to carry out another simulation results in the screw geometry data not being saved. To avoid this a change has been carried out in the MELTING program following the next statement: "If the remaining solid at the end of the screw is less than 0.05%", then screw geometry data required by G-codes is transferred to a file (with the same name as the one used in the MELTING program and with the extension ".DNC") that will be read by the G-codes program (Appendix III). The non-existence of remaining solid at the end of the screw doesn't mean the optimisation of the screw design, but it ensures the quality of the plastic output.

ALGORITHM FOR THE CHANGE OF PEPE2.FOR (The program which contains all the equations to simulate the polymer flow process).

IF the remaining solid at the end of the screw is less than 0.05% **THEN**

1. Initialise Filename.DNC to 0
2. Calculate root (feed) diameter and screw pitch
3. Transfer the screw geometry data required by G-codes Generator Program (STEP3) and known to Filename.DNC.

END IF

Note that if the MELTING program is run more than once and it is successful (Remaining solid at the end of the screw less than 0.05%) new screw geometry data will over-write the data saved to Filename.DNC, keeping only the last version.

The modifications carried out in the MELTING Program have been possible because it was possible to access the source software, in addition to using the FORTRAN PowerStation Compiler.

6.4.3. Building Software Bridges

After the Screw Optimisation program was changed and the geometry data required to run the Manufacture module was saved to a file (with the same filename and extension ".DNC"), it was necessary to generate a flexible menu to introduce the remaining data and transfer it to the G-codes Generator Program (STEP3), in order to generated the G-codes.

The data required by the G-codes Generator Program (STEP3) can be divided into three two main groups.

1. **General Information to identify extruder data**, where it is included :

- Date
- Job Number. The "job number" introduced in this section will be used to generate a file "Job_Number. GCD" where the G-Codes are going to be stored. Note that if the job-number is not modified, the G-codes Generator Program (STEP3) will over-write the file losing all the data stored last time.
- Customer Name
- Material Name
- Special Instructions

2. **Whirling details** which included all the necessary data to generate the G-codes for a particular extruder geometry. This includes:

- Extruder Screw Geometry
- Bar Material Properties
- Manufacturing Characteristics.

As access to the G-codes Generator source program was denied, any change in the execution of this program was equally denied. Due to this, in an attempt to demonstrate the feasibility of integrating different software packages and successfully run them, it was found necessary to develop a new module to link them. The concept of "software bridges" was developed, whereby data is transferred to this file and was read by the G-codes Generator Program (STEP3) (Figures 6.4 and 6.5). As shown in Figure 6.4, the generated menu allows the transfer of data from the optimisation program and introduces the remaining required data from the keyboard. Figure 6.5 shows how the "software bridge" links the two Design and Manufacture modules.

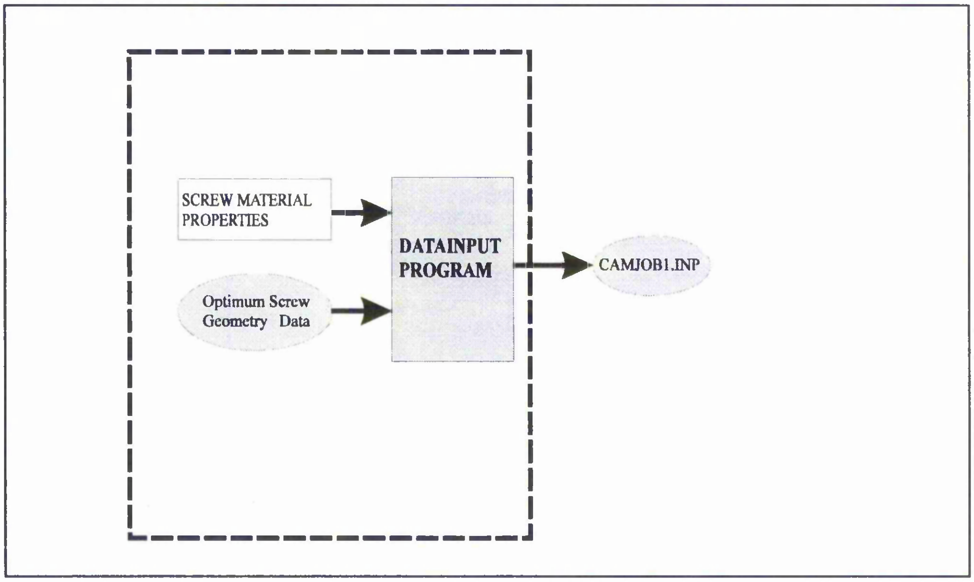

Figure 6.4. Software Bridge between Design and Manufacture Modules.

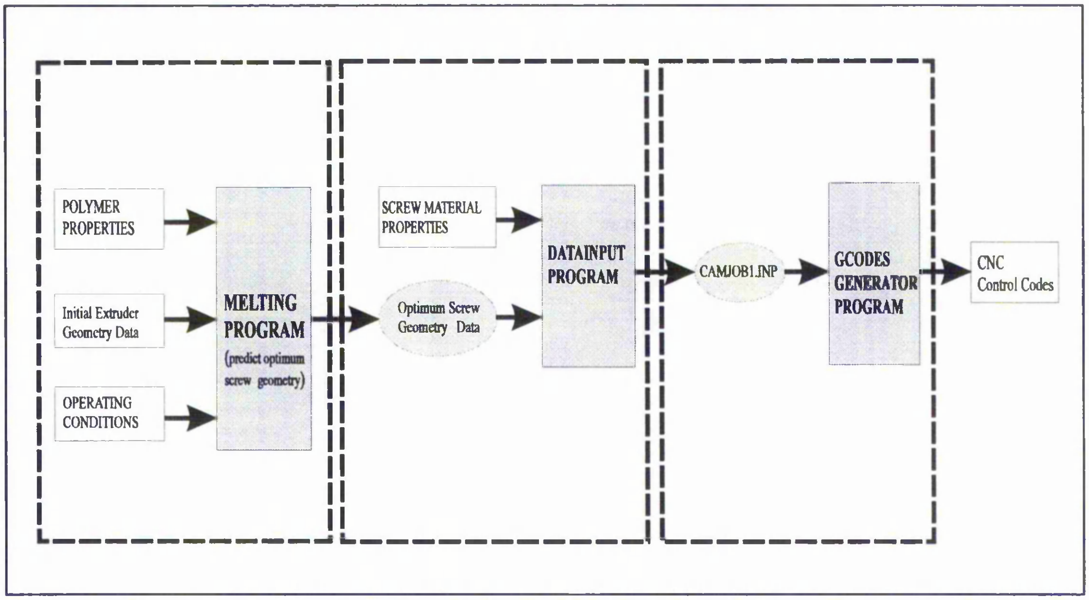

Figure 6.5. Newly proposed Integrated System for the Design and Manufacture or Plasticating Extruder Screws.

"*Datainp*" program has been generated to allow the user to introduce all the data to run the G-codes Generator Program (STEP3). It was written in FORTRAN and compiled using FORTRAN PowerStation (Appendix IV). The algorithms are shown below.

DATAINP Program First Algorithm.

1. Show on screw **Introductory Menu.**
2. **Read (DataTransfer)**

   IF DataTransfer = YES) **THEN**

   -Read (Filename)

   -Open (Filename. DNC)

   -Read (Filename-data)

   ELSE

   - Initialise Data to 0

3. SHOW **MAIN MENU ON SCREEN**
4. **READ (Answer)**

   While (Answer No Equal to 88) **AND** (Answer No Equal to 99) **DO**

   -**IF** Answer = 1 **THEN**

   Go to General Information Menu.

   -**IF** Answer = 2 **THEN**

   Go to Whirling Details Menu

   Read (Answer)

   End WHILE.

   IF Answer = 88 **THEN**

   EXIT

   IF Answer = 99 **THEN**

   SAVE and EXIT

DATAINP Program Second Algorithm.

General Information Menu.

1. Show General Information Menu + Known data
2. Read (Answer)

    WHILE Answer No Equal to 99 **DO**

        Change data

    END WHILE

3. Go to Main Menu

Whirling Details Menu

1. Show Whirling Details Menu + Known data
2. Read (Answer)

    WHILE answer No Equal to 99 **DO**

        Change data

    END WHILE

3. Go to Main Menu

Save and Exit

1. Open (Filename.DNC)
2. COPY (Data to Filename.DNC)
3. OPEN (Camjob0.INP)
4. COPY (Data to Camjob0.INP). The data is copied in a format that G-CODES Generator program can read.

DATAINP Program Third Algorithm.

Change Data.

1. Situate the cursor on the selected screen position.
2. Type the data
3. Press Return
4. Situate the cursor on the top of the screen ready to read the next answer.

After all the data has been introduced there are two options:

1. Copy the data to a file, on the format that can be read for the program, then generate the G-codes, and run it.
2. Alternatively, exit from the program. As all the data has already been stored in a file with the filename and extension ".DNC", it can be used in the future to generate the G-codes at a later date.

It should be noted that in order to generate an integrated system for the design and manufacture of a plasticating extruder screw, it was necessary to generate batch files which are shown in Appendix V.

6.4. SUMMARY AND CONCLUSIONS.

This chapter summarised the procedure followed to create a basis for an Integrated System for the Design and Manufacture of extruder components. The successful integration of The MELTING Program and G-codes Generator Program (STEP3) showed the feasibility of Computer Aided Systems integration.

The integration required the generation of a new program in order to introduce the data and save it in a format that the G-codes Generator Program could read. The program namely *Inputdat*, was written in FORTRAN Programming Language and Compiled using FORTRAN PowerStation.

Both integrated programs are written in FORTRAN. FORTRAN (**FOR**MULA **TRANS**LATOR) language is widely used for programs which solve numerical differential or integral equations.

In order to generate the *Datainp* Program, different program languages were considered, such as C++, COBOL or Pascal. As the MELTING Program was written in FORTRAN, a Compiler for FORTRAN was absolutely necessary, so in an attempt to optimise the available resources the same compiler was used to write *Datainp* Program.

The Design and Manufacture of the Extruder Screws Module runs under an MS-DOS environment. Although *Datainp* can be independently run under Windows or MS-DOS, the remaining programs were developed for running under an MS-DOS environment, imposing constraints on the integrated system.

With the generation of the integrated system typing errors are avoided because the data is transferred directly from The MELTING Program. This also avoided manually inputting data, therefore gaining speed and reliability.

CHAPTER 7

DISCUSSION AND FURTHER WORK

7. DISCUSSION AND FURTHER WORK.

7.1. DISCUSSION

Plastics are firmly establishing themselves into the new markets provided by materials substitution. They are increasingly being chosen to replace traditional materials such as metals and alloys because of their preferred physical characteristics, ease of processing and consequent cost advantage over their counterparts. This is demonstrated by the turnover within the plastics processing industry: in the UK plastics utilisation has increased by 40% over the past six years. Until recently, plastics companies have enjoyed increased market share relatively easily and have therefore not been forced into developing the high levels of efficiency and competitiveness adopted by other industrial sectors.

However, the intense competition prevalent in other sectors has finally caught up with the plastics processing industry and companies are now having to re-examine their business strategies and identify areas where they can improve their production efficiency solely to survive in this new competitive environment.

Companies now have to face new pressures such as demands from customers in terms of development capabilities, quality assurance and project management, low cost imports, and new environment legislation. Current levels of plastics recycling in the UK are very low, and with new environmental legislation which establishes a minimum requirement for the amount of plastics to be recovered, the development of a new infrastructure for the collection, sorting, washing and recycling of plastics materials is needed.

Competition is forcing companies to fully optimise the use of equipment and techniques available with efficient control of organisational structure to produce high quality, well-designed products at lower prices and in less time. They are also being forced to recognise and adopt the new technologies emerging from research establishments, both in the private and public sectors.

In a recent survey, carried out by the Polymer Engineering Centre of the Nottingham Trent University, it was found that most Small Medium Enterprises in the industry have no in-house polymer engineering expertise, and production operators have little knowledge about polymer processing. Companies were often found to be operating inefficient processes, possibly using a more expensive material than necessary, over specifying, or processing in an efficient manner. Following a process audit, it was found in virtually all instances that a materials reduction of 5-10% in polymer consumption could be achieved.

Design decisions made early in the product development cycle have a significant effect on the manufacturability, quality, product cost, product introduction time, and thus on the ultimate marketplace success of the product. Ideally, concurrency in the design stage is needed whereby the system is examined as a whole and all elements are considered simultaneously. This involves selecting the correct material for the desired application, and after selecting the most suitable manufacturing process, arriving at the optimum screw and die design to make a product most efficiently.

The complexity in integrating design and manufacturing processes has lead to the introduction of Computer Aided Systems during the design stage. On first consideration, the use of Computer Aided Systems seemed advisable, providing improved engineering productivity, higher design quality, shorter lead times and fewer manufacturing errors. However, experience has shown that prudent selectivity must be made by management in deciding on a system, specifically tailoring the individual requirements of their company with respect to the software and hardware available.

The research found that of particular importance to the most efficient operation of many CAE systems, was a requirement for a regularly updated computerised database; one which contains relevant and accurate information about the materials and the operating conditions of the process to be simulated. The rheology data of the material was identified as being of fundamental importance for the polymer flow analysis. Selection of materials should be based on a broad, basic understanding of the nature and properties of materials and their processing characteristics. Easy access to multiple sources of data through computerised material selection is also desirable.

All the software packages considered for die-design were CAE systems using the Finite Element Method to simulate the flow of polymer. This is because polymers behave as Non-Newtonian fluids, so a numerical technique which can accommodate this must be used to model systems from discrete elements.

The author's comprehensive survey has revealed a wide diversity of Computer Aided Engineering Software packages. At first many appear to offer similar features to the designer but may fall short in many important respects, such as the ability to communicate electronically with other computer systems. Thus their integration into a software package offering the designer a complete solution was found not to be plausible, so their ability to integrate effectively should be an important factor that would influence software package choice.

The communication problems to transfer Computer Aided Design (CAD) drawings to other Computer Aided Systems have been almost solved through the utilisation of Initial Standard Exchange Specifications (IGES), as already described in Chapter 3. Within many remaining Computer Aided Systems the data transfer problems have not been fully solved to date. However, STEP is emerging as a promising new solution in this area, although it is still in the development stage. STEP's developers goal is to create an integrated product information database that is accessible to all computer systems necessary to support a product over its lifecycle, ultimately removing all communications barriers between software packages.

In the long term, the feasibility of communication between Computer Aided Systems through STEP seems very hopeful. However, the current working situation requires immediate solutions, thus companies and software development groups are currently trying to integrate different software packages using other resources.

Within this research, the integration of the Design and Manufacture modules of Plasticating Screws required the creation of a program (Datainp.FOR) in order to allow data transfer to take place, because it was not possible to access the G-codes generator source program.

With the development of Datainp.FOR Program, which allowed the transfer of data from one program to the other, a sequential process for the design and manufacture of Plasticating screw extruders was established. This partial integration provided a basis for the complete integration of the design and manufacture of extruder components. However, to incorporate it fully into a CE Environment for the design and manufacture of extruder components still requires further development, described in the section on Further Work.

The advantages of integrating different software packages into a broader manufacturing system are widely acknowledge. Unfortunately, in many cases the task is a lot more difficult than initial considerations indicate. One of the main problems that any company who is willing to integrate different software packages has to face is the impossibility to modify standard source programs. In some cases, this problem can be solved through the creation of "Software Bridges", or data links, so data is read and copied to a file that can then be accessed by another software package. The concept of this methodology was conceived and successfully implemented during this research.

Another solution that is becoming very popular is through the use of Graphic User Interfaces, for example Windows, but it is a necessary prerequisite that all the software packages used must run under a Windows environment. The "multiwindows" approach is a typical example of how many of today's tools can use data directly from each other. Two or more tools may reside on the same computer at the same time and present their information in windows which allows the user to copy data from the window of one tool and paste it into the window of another tool. Although new software package developers are aware of data transfer problems, and in many cases are developing software packages to be used within the Windows environment, there are still a large number of software packages which run under other Operating Systems, such as MS-DOS.

Software suppliers will sometimes offer what is called a "Customised Service", whereby software suppliers will introduce specific data into the databases they supply which can be accessed during the running of the program, but this trend does not allow the creation of a broader manufacturing system. Therefore, a more global solution is required.

Although none of the mentioned solutions is absolute, the practical work carried out during the research showed that the integration of software packages could be feasible. Powerful Computer Aided Systems, until now used in isolation, could be integrate into modules, in order to integrate them and generate a broad design-manufacturing system. Using this system the job will be done without losing time, without making many false starts, and without repeating work that has been done before.

Computer Aided Systems may assist in the implementation of the Concurrent Engineering philosophy, nevertheless one of the biggest problems in implementing CE is people's resistance to change. The research has shown that Small and Medium Companies have little interest in implementing new philosophies, such as Concurrent Engineering. In general, they demonstrate an antiquated way of operating and little effort is being made to adopt any aspect of Advanced Manufacturing Technology in any form, mainly because they are too busy tackling daily problems.

It was also observed that companies are more orientated to optimising machine performance rather than increasing overall company efficiency.

This point of view should be challenged and the need to adopt new ways of designing and manufacturing their products is an important prerequisite to remain competitive in the market. Smaller companies need to improve their performance significantly, invest in new technologies and staff training, restructure their business and expand their operations to quickly meet the changing demands of their customers.

During the course of this research a study of CE philosophy has been carried out and the philosophical aspects considered, however the work has mainly concentrated on the necessary tools to implement CE in an extrusion moulding process company. Other aspects, such as the definition of interfunctional groups and responsibilities of each member, were considered to be beyond the scope of this research.

The current situation is that Computer Aided Systems are still not widely used within the industry. Part of the reason is that the systems are not cheap, and also require a reasonably high level of expertise to operate. Small companies, who may only be required to design one or two items a year may not consider the expense of renting the software package justifiable.

Although the integration of Computer Aided Design and simulation programs in the engineer's database brings definite benefits to the design of extrusion moulded components, it is only one of the tools available to implement the Concurrent Engineering Philosophy throughout the company, and further work is necessary to realise the full benefits of a wholly Concurrent Engineering environment.

7.2. FURTHER WORK.

The development of the Design and Manufacture of Plasticating Screw Extruders Module is already showing advantages over the utilisation of the software packages used independently. The advantages could be defined as user-friendlier and direct data transfer, but to fully appreciate the advantages of a complete Computer Aided System integration, the development of new Modules is required. Further Work would include the development of these Modules and their integration into a broad Manufacturing System.

The analysis of the Design and Manufacture of Extruder Components process identified the need for the development of the following modules:

- Design of Extruder Component Module
- Design and Manufacture of Extruder Screw Module
- Design and Manufacture of Die Module

During the Design of Extruder Components, it is necessary to take into account factors such as, Material Factors, Geometry Factors and Production factors. The proposed Design of Extruder Components Module would comprise a CAD system, a Material Database with Material Selection Support and a database with Production Requirements. Process selection software packages could be useful, but may not be absolutely necessary, because in many cases companies only have one process.

The Die Design and Manufacture Module would include a CAD System, a Computer Aided Engineering (CAE) Simulation Program and, a CAD/CAM system in order to manufacture the die.

The proposed methodology to develop the Modules is the same one that was followed during the generation of the Design and Manufacture of Extruder Screw

Module, which was successfully completed during this research: analysis of the process, selection of software and their link. After the Modules have been developed, it is proposed that they are integrated, generating a global Computer Aided System to be used during the Design and Manufacture of Extruder Components within a Concurrent Engineering Environment.

The production of an integrated, fully upgradeable computerised system to assist in the successful introduction of CE philosophy could bring untold rewards for its creators, and manufacturing industry as a whole.

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APPENDIX I

PLASTICS PROCESSING REVIEW

TABLE OF CONTENTS.

I. PROCESS REVIEW

Plastics, and polymers in general, may be converted into products in a wide variety of ways. Within the plastics industry today the most common processes are:

- Extrusion.
- Blow moulding.
- Injection Moulding
- Calendering.
- Thermoforming (Vacuum/Pressure forming).

The three major processing methods are injection moulding, extrusion, and blow moulding, accounting for the processing of 78% by weight of all plastics. Approximately 32% goes through injection moulding machines, 36% through extruders, and 10% blow moulding machines, extruder and injection moulding types.

Other processes exist but their usage is very limited and does not justify their detailed study.

I.I. EXTRUSION MOULDING.

Extrusion, in principle, is a process used to form a wide range of materials by forcing them through a die. It is a rotating screw which pushes the material forward and creates the necessary pressure to extrude it through the die, making a process into continuous operation. The screw and its shape are critical factors in determining the outcome of the extrusion process. The process may be applied to such diverse materials as pasta and metals, as well as to molten polymers.

While there are fewer machines used for extrusion than for injection moulding it is probably true that, in tonnage terms, more polymer is subjected to extrusion than injection moulding. Not only is the process widely used to make finished products, also used for such intermediate operations as preparation of plastic sheets for vacuum forming, mixing operations, and reworking of waste material.

I.I.I. Types of extruders.

The extrusion process is used in many different ways in polymer processing; single screw extrusion, double screw extrusion and even multiple screw extrusion, although it is very rare to find extruders with more than two screws in parallel in the plastics industry.

Single screw extruders.

Most extrusion machines use in the plastics industry have a single screw extruder, its function being to receive granules, plasticize them to the correct consistency and pump the materials into the die for shaping. In its most simple form the machine, shown in Figure 1.1., consists of the following elements:

- A feed hopper into which the polymer pellets are placed.
- The barrel which contains the screw and is equipped, on its exterior, with elements for heating and sometimes cooling.
- The screw which plasticates the pellets and conveys them.

It is usual to consider the barrel in three zones each of which has a specific role. These are:

1. **The feed zone**. It accepts granules from the hopper, pumps them up the barrel and commences heating.

2. **The compression zone**. As the granules melt, the plastic mass fuses together trapping some air, and possibly gaseous degradation products. It is essential to force such gases out of the melt before it reaches the die. This is achieved by compressing the melt in the compression zone.

3. **The metering zone.** The function of melt zone is to ensure that the material is in the correct molten state for feeding to the die.

Other components within a plasitcs extruder are:

- A motor and gear reduction unit to turn the screw.
- The die, which determines the shape of the extrudate.
- Instrumentation and control devices to indicate and control different operational variables such as temperature, pressure, screw speed, etc.

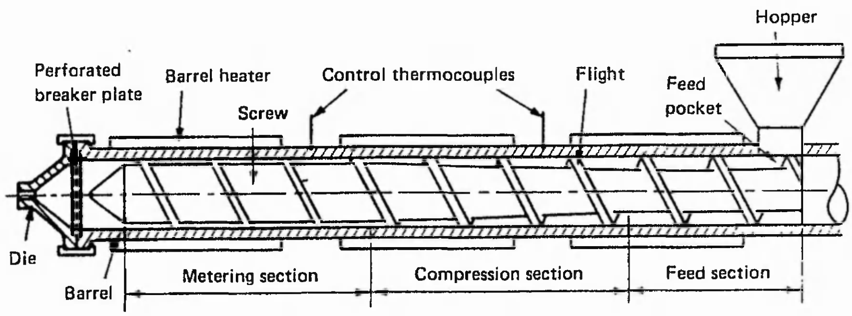

Figure 1.1. A typical plastics screw extruder.

Twin screw extruders.

The main difference in the method of operation between single and twin screw extruders is the way in which the material is conveyed within the machine; the single screw relies on friction between the material processed and the cylinder to move the material, whereas the configuration of two screws can produce positive displacement. This means that less work may need to be done (because of less frictional heat being generated) on the polymer and consequently degradation may be avoided.

Twin screw extruders find their main application in the extrusion of unplastised PVC, particularly large diameter piping produced from powder.

I.I.II. Finished Product Extrusion Processes.

Extrusion is a process used to produce **continuous shapes** of sheets, films . pipes, filament, tubes and a variety of profiles, some of them used like parisons in blow moulding. Extrusion is also used to cover metallic wires, cables, strips and roll-formed shapes with plastics.

Although all of these products are manufactured using an extrusion moulding machine, the outcome of the successive processes are different. The equipment used to produce them is called extrusion line.

Figure 1.2. is a simple sketch of an pipe extrusion process line. It starts with an extruder into which is poured solid plastic pellets. The extruder melts the plastic and pumps the melt (molten plastic) through a die hole of the desired shape. It then enters a sizing and cooling trough or rollers where the correct size and shape are developed. Next, the newly formed product enters a puller, which is often a pair of motor-driven, rubber-covered rolls. It is the puller which haul off the molten resin from the end of the die through the sizer. At the end of the line a cutter does the final handling of the product.

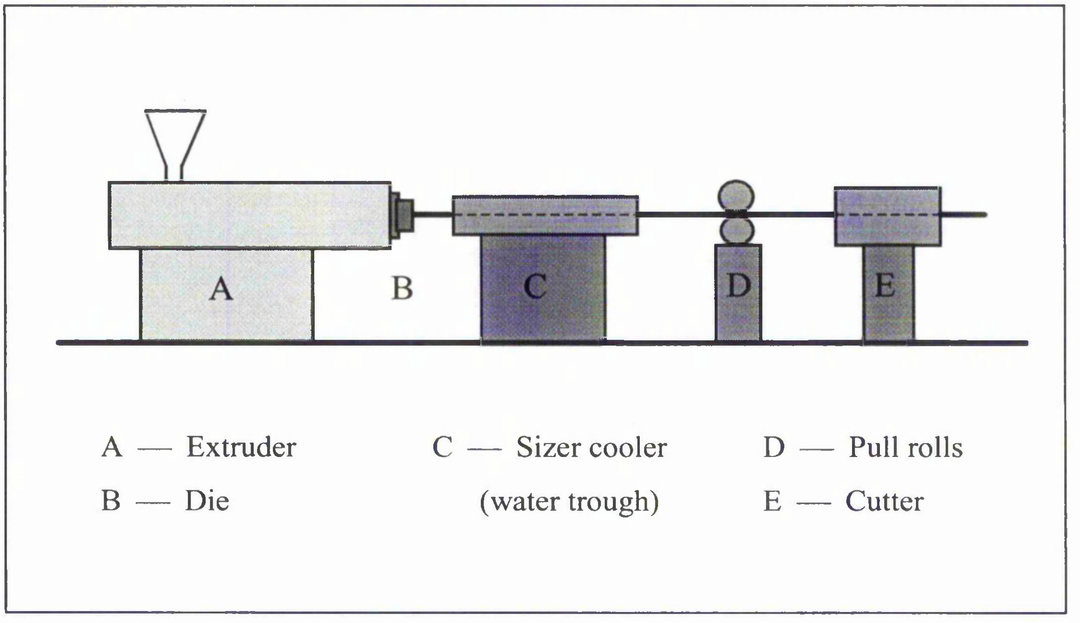

Figure 1.2. Pipe extrusion line.

I.II. BLOW MOULDING.

Blow moulding is used to describe processes used to produce hollow products by inflation of a tube or *parison*. The basic blow moulding process involves producing a plastic parison for extrusion blow moulding or preform for injection blow moulding; these are tube, pipe or test tube plastics shape. The parison or preform is placed into a closed two-plate mould where the cavity represents the outside shape of the part to be produced. Subsequent operations involve injection of air into the heated parison to blow it out against the mould cavity, cooling of the expanded parison, opening the mould, and removing the rigid blow-moulded part.

Blow moulding techniques can be divided into three major categories- namely:

- Extrusion blow moulding
- Injection blow moulding
- Stretch blow moulding

Extrusion blow moulding

In the first stage of this process a tube is extruded, usually downwards, between both halves of an open mould. The mould is then closed around the parison which is then inflated by compressed air to the shape of the mould cavity. The formed shape is then allowed to cool until it is capable of being ejected from the mould and the cycle is repeated.

In extrusion blow moulding, the advantages include high rate of production, low tooling cost, blown handle ware and wide selection of machine manufacturers. Disadvantages are usually high scrap, recycling of scrap, and limited wall thickness control and material distribution.

Injection blow moulding.

In the injection blow moulding process (Figure 1.3.) a parison is injection moulded directly onto a blow stitch. The blow stitch is then transferred, with the molten parison, to the blowing cavity. The parison is blown to the shape of the cavity by compressed air which is passed through the blowing stick.

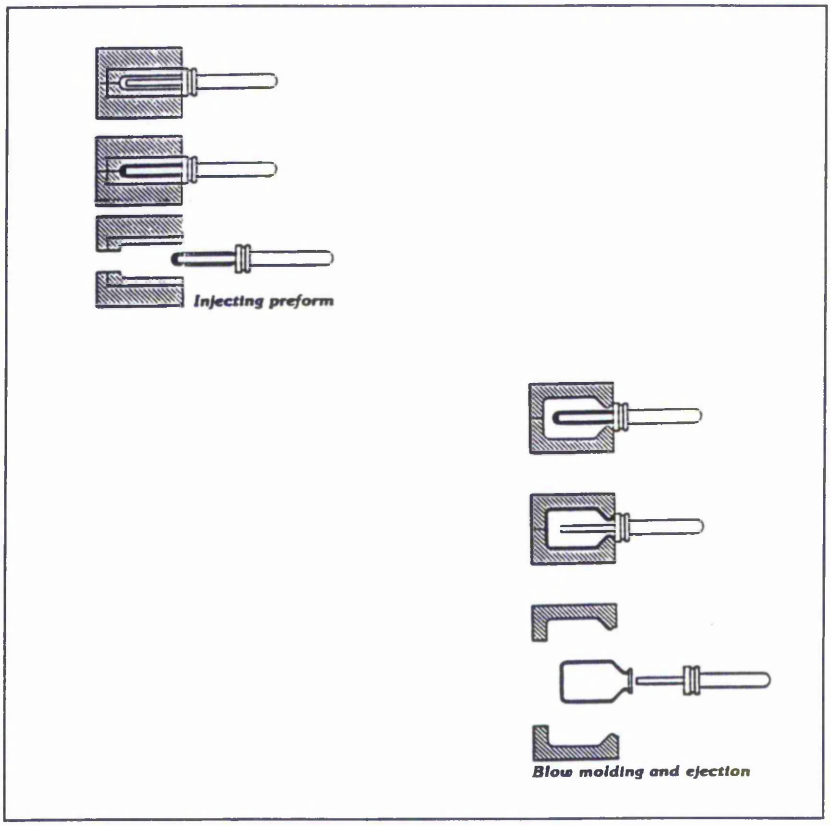

Figure 1.3. Injection blow moulding.

The weight of the parison may be accurately controlled, while the end of the parison may be properly formed rather than produced by squashing an extruded parison when the mould closes.

The major advantages include the fact that no scrap or flash is moulded, best surface finish of parts is obtained and low-volume production quantities are possible that are economically feasible.

Stretch blow moulding.

Stretch blow moulding can start with either the extrusion or injection blow moulding process. The preform is preheated until the proper orientation blow temperature is reached. The preformed shape is then transferred to the final blowing station in which, as in the previous process, longitudinal stretching is effected by means of a telescopic mandrel with simultaneous blowing to the shape of the cavity

The stretch blow process can give many resins improved physical and barrier properties. In biaxial orientation, bottles are stretched lengthwise by an external gripper or an internal stretch rod and then stretched radially by blown air to form the finished container against the mould walls. It is a process mainly uses in carbonated beverage bottle production.

The process aligns the molecules along two planes, providing additional strength and, even more important, better barrier properties than are possible without biaxial orientation. Other advantages include better clarity, increased impact strength or toughness, good neck finish and reduced creep.

I.III. INJECTION MOULDING.

Basically, the injection moulding process involves the **injection under pressure** of a predetermined quantity of heated and plasticised material into a relatively cold mould (Figure 1.4.). After the material solidifies it is allowed a further interval to cool before the mould is opened and the product removed. In most cases it is necessary to undertake post- processing operations to remove the sprue.

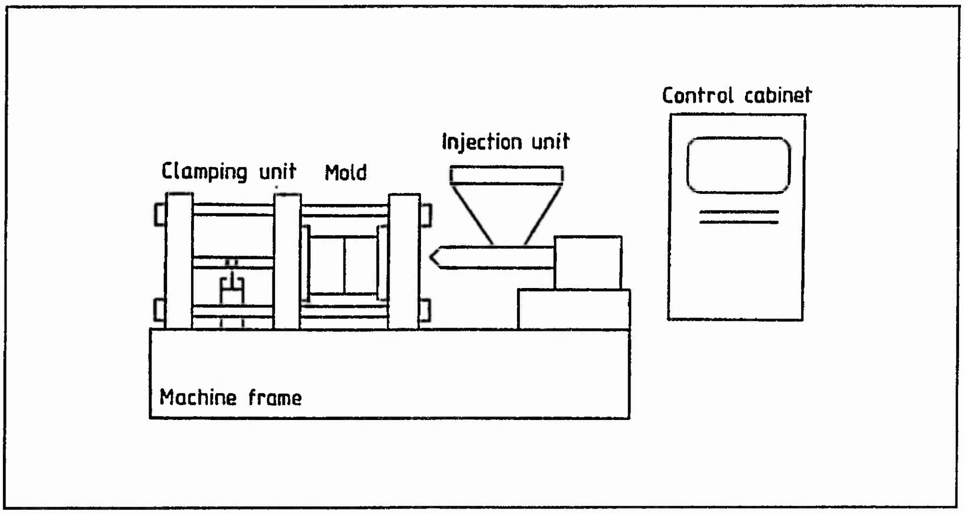

Figure 1.4. The basic injection moulding process.

I.III.I. Process development.

Early injection moulding machines suffered from the difficulty of reconciling the temperature and pressure control requirements necessary for good molding practice. Also there were another problems: materials in the centre of the cylinder will be some distance from the heaters and because of the plastics low thermal conductivity, a long time is required to heat the material in the core.

At an early stage in the development of injection moulding it became common practice to insert a solid cylinder of metal into the front of the injection cylinder (known as a *torpedo*). With such a system, shown in Figure 1.5., the distances that heat had to travel through the plastic material was very much reduced. Heating was much faster and temperature and product variability thus reduced.

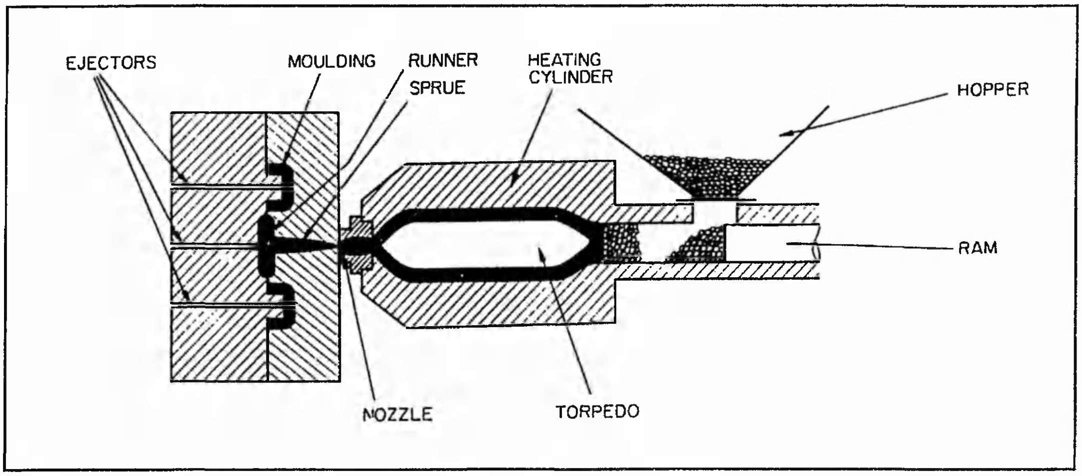

Figure 1.5. Injection moulding machine incorporating a torpedo inside the heating cylinder.

It is however much more difficult to push material through long narrow channels rather than short wide ones and considerable pressure losses were observed between the front of the injection ram and the distant corners of the mould cavity. This was both wasteful of energy and also reduced control over the process.

In the years following the Second World War many attempts were made to develop systems of cylinders and torpedoes which offered acceptable compromises between the temperature and pressure requirements. It became necessary to separate the plasticizing and the injection stages and pre-plasticizing machines were developed. Of the many types developed, the **in-line single screw injection moulding machine** has been so successful that it now dominates the market of injection moulding.

I.III.II. In-line single screw injection moulding machine.

The principle of an in-line single screw injection moulding machine, shown in Figure 1.6., is as follows:

- Granules of plastic are fed through a hopper to the cylinder and delivered up the cylinder by means of a rotating screw.

- During their movement up the barrel, the polymer is heated, both by conduction from external heaters and by internal frictional heating as it is pumped up by the screw. There is also some mixing and homogenisation of the melt caused by the rotation of the screw.

- The softened or "plasticized" material is collected at the front of the cylinder and to accommodate the accumulating molten mass arrangements are made for the screw to retract along its axis until there is the correct volume of melt at the head of the cylinder.

At this stage movement of the screw, both rotationally and axially, ceases. By this time the mould will have been closed and the nozzle of the injection unit will have come into contact with the mould.

- The screw is then activated to operate as a plunger, moving forward and pushing the melt into the mould cavity.

- The screw is held in the forward position under pressure until the material in the gate freezes, thus isolating the material in the mould cavity from the operations of the injection unit.

At this point the screw again commences to rotate, feeding more melt to the front of the cylinder. This material is held until the moulding has cooled and been ejected. Injection of the melt then takes place and the process is repeated.

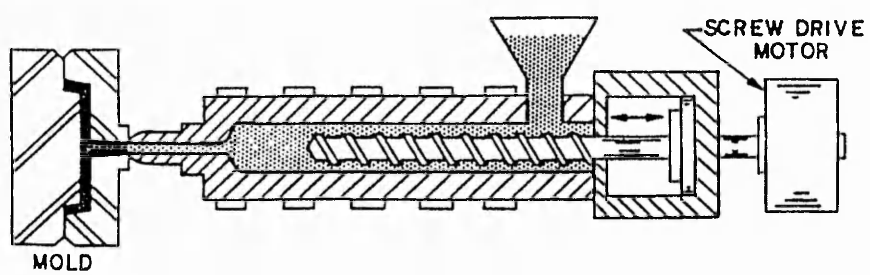

Figure 1.6. Single screw injection moulding machine

I.III.III. Injection moulding quality assurance.

Quality assurance is a complex task in injection moulding (Figure 1.7.). The objective of injection moulding, as with any other production method, is to produce a part with specified dimensions and properties at the lowest cost. This is possible with injection moulding only if all variables of the process are already taken into consideration when designing the part and mould, as well as when specifying the properties of the molded part. This does not refer to manufacturabiliy produced within a certain window. In this regard, the unavoidable fluctuations of process parameters, such as melt and mould temperature, injection and holding pressure, and injection time encountered, in practice should have only a little effect on the moulded part quality. Whenever this is the case, reliable, controlled production is the result. In fact, speed and pressure controls during moulding cycle and heating systems including temperature control methods are controls which are widely implemented in polymer injection moulding machines.

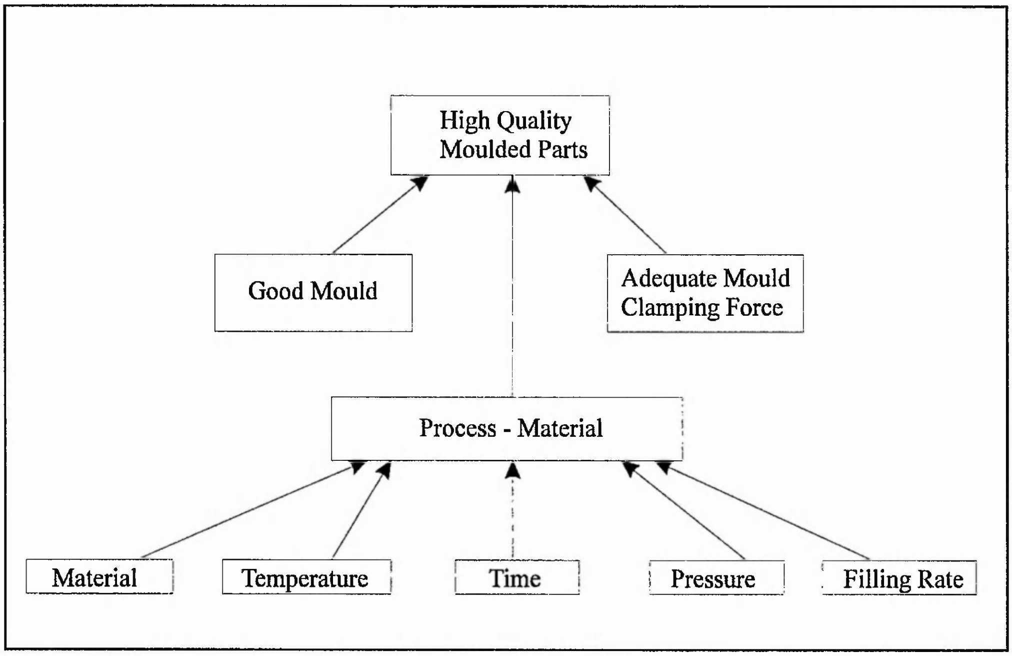

Figure 1.7. Quality assurance factors in the injection moulding process.

I.III.IV. Injection moulding limitations.

Injection moulding produces parts with a good finish on each side and allows production of a variety of cross sections and it remains as the most efficient method for high-volume production of small- to medium- size thermoplastic components.

The tooling cost (mould) is very high, so it is important to have long production runs to redeem the mould cost. The high costs of moulds is dictated by the fact that they have to withstand high pressures.

Injection moulding is a high-pressure process that is limited by the clamp force capability of the available equipment to a maximum projected area. The maximum practical thickness of the parts is limited to about 4 mm.; above this thickness, cooling time becomes excessive. The minimum normal thickness for injection moulding is about 1 mm.

I.IV. CALENDERING.

The Calendering process is a highly specialised one used for the manufacturing of plastic sheet and one which requires a high capital outlay. It is a rolling process combined with extrusion for coating webs such as plastics, fabrics, paper and other materials with a continuous plastics coating. It is essentially a continuous extrusion process which feeds into rollers which establish the thickness and surface characteristics of the applied coating (Figure 1.8.).

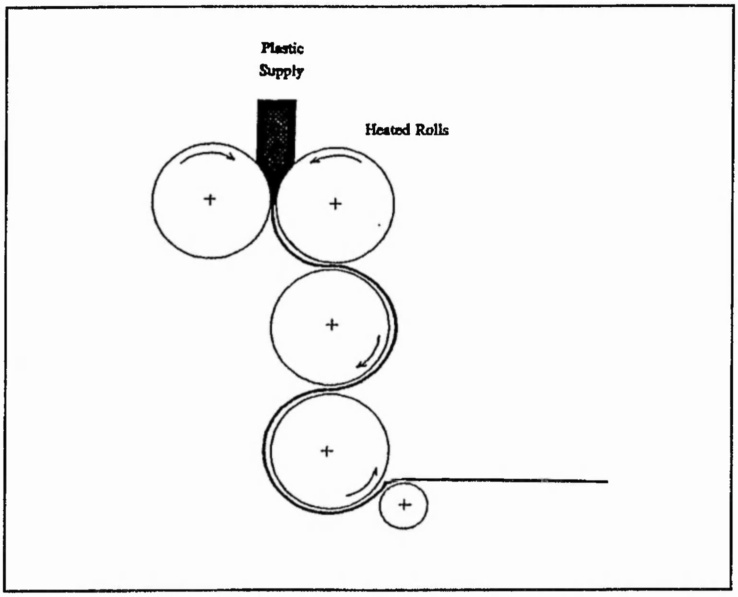

Figure 1.8. Typycal arrangement of calender rolls.

However the calender itself is only a small part of the overall Calendering process. The calender line commences with a mixing and prewarming stage, with material usually fed in strip form to the calender.

Originally it was developed for putting a sheen onto fabrics and paper, and for the manufacture of sheet rubber, but now it is used in the plastics industry for the manufacturing of PVC sheeting. With most other plastics materials extrusion processes are usually preferred because of the greater ease with which the latter are able to give products of high quality.

I.V. THERMOFORMING.

Thermoforming processes include many shaping processes which are applied to previously shaped plastics with the help of heat. In general, all thermoforming processes are used for thermoplastics which soften when heated and then harden when cooled.

This method was first introduced during the 1950s but its lack of accuracy and the crudity of the equipment was a major drawback to its large scale deployment. In recent years advances in technology in areas such as machine design, mould design and material design have contributed to its more frequent use. A wide range of products can now be identified that are made using this method. Amongst them are aircraft window reveals, refrigerator lines, car bumpers,...etc. Thermoforming could be subdivided into two sub-divisions of "Vacuum" and "Pressure" forming.

Vacuum Forming.

In the vacuum forming process a sheet of thermoplastic is shaped by the creation of a vacuum (pressure gap) between the mould and the sheet which is heated and softened. A simple type of such a machine known as "negative forming" is shown in Figure 1.9.

In this method a plastic plate is clamped on the mould and a heater panel is placed above the sheet. After a nominal time, which depends on the size and nature of the material, and having reached adequate softening, the heater is removed and the vacuum applied. This method is capable of producing parts with depths of 30% to 50% of the material width. In some instances this technique might not be able to produce a satisfactory result e.g. when dealing with thick materials or using moulds with tight corners. In these cases a slight variation of this method called "positive forming" is used. In this method after initially heating the material, a male (positive) mould is pushed into the material before the application of the vacuum. This results in a more uniform wall thickness and higher width to depth ratios.

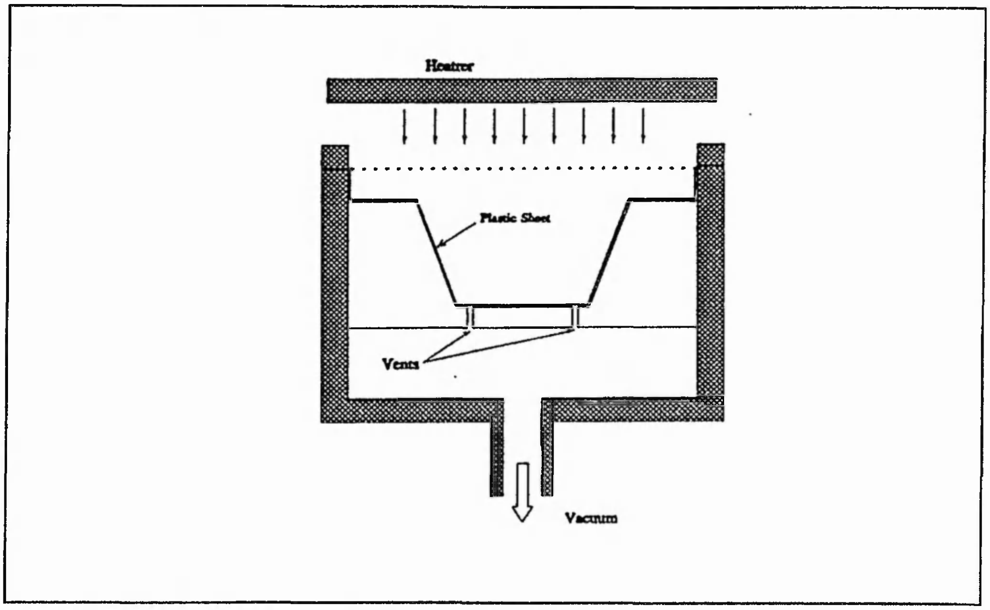

Figure 1.9 Basic Vacuum Forming Process.

Pressure Forming.

The Pressure Forming method (Figure 1.10.) is essentially the same as Vacuum forming with the difference that instead of creating a vacuum in the mould to achieve the pressure gap a positive pressure is produced outside the plastic material to force it into the mould. This technique has the advantage of being able to use higher pressure gaps between the outside of the material and the mould.

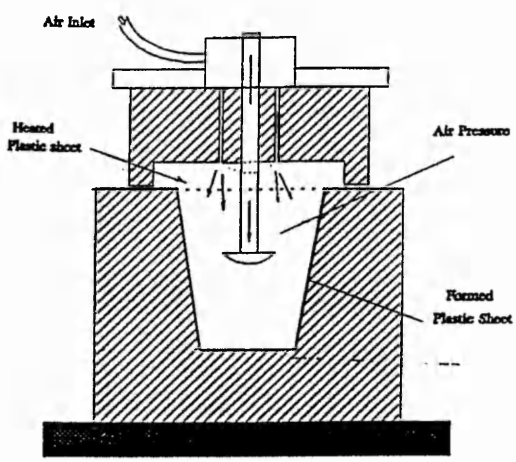

Figure 1.10. Basic Pressure Forming Process.

APPENDIX II

MAJOR PLASTICS REVIEW

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II. MAJOR PLASTICS MATERIALS.

II.I. SURVEY OF MAJOR PLASTICS MATERIALS.

There are currently in the market, several hundred types of plastics materials ranging from large tonnage materials such as polyethylene and PVC, to highly specialised materials. For each type of material there are many grades; in the case of the major tonnage materials there may be several hundred grades. It is, therefore, quite clearly impossible to cover all the grades of all the materials that are available.

It has therefore been necessary to be selective, and the materials covered in this section comprise the major tonnage materials (**Figure 2.1.**), known as commodity plastics (Polyethylene, Polypropylene, Polystyrene, Polyvinyl Chloride and Polyethylene Tereptthalate) and some engineering plastics such as ABS (Acrylonitrile-butadiene-styrene) and PEEK (Polyether Ether Ketone).

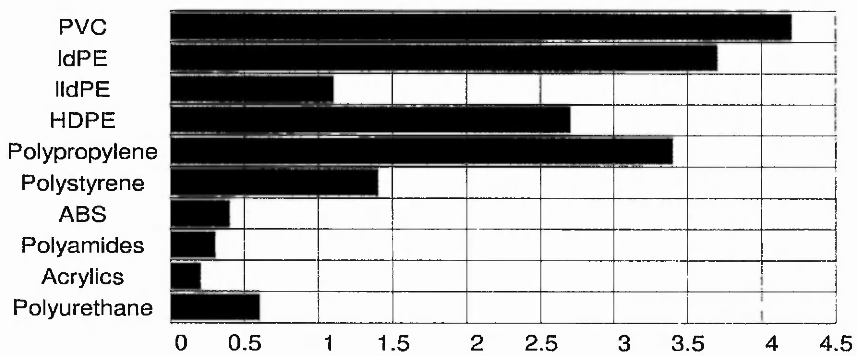


Figure 2.1. Western European Resin Comsuption 1994 (1000 metric tons). **Source:** MPI.

The "Commodity thermoplastics" are so called because they behave in a similar fashion to primary commodities. They are low priced, high volume, relatively homogeneous goods which react almost spontaneously to changes in the supply-demand balance.

II.II. POLYETHYLENE (PE).

Polymer structure.

$$\sim CH_2\text{-}CH_2\sim$$

Polyethylene's key application properties are low cost, easy of processing, excellent electrical insulation and chemical resistance, toughness and flexibility. Reasonable clarity of thin films (Linear Low Density Polyethylene and Low Density Polyethylene).

Its limitations include low softening point, susceptibility to environment stress cracking and oxidation, opacity in bulk, wax-like appearance, low hardness, rigidity and tensile strength.

Leading applications for PE (Polyethylene) include film, blow moulded bottles, and other packaging media.

Low Density Polyethylene (ldPE).

HDPE shares basic properties with linear polyethylene: high impact strength, toughness, chemical resistance and heat sealibity. In addition it benefits from higher clarity and greater flexibility and processing than linear polyethylene's.

The end user applications are dominated by extruded film products, including food packaging and non-food packaging. A small amount of ldPE is used in construction, in the form of foundation coverings, electrical wire and cable, pipe and conduit, and other extruded products. The remainder of production is shared by injection moulded products such as lids, toys, novelties and other housewares.

Linear low-density polyethylene (lldPE).

Processing of lldPE film is more difficult than ldPE and lldPE's greater degree of crystallisation results in a rougher surface and poorer clarity than LdPE.
lldPE applications mainly consist of film, with other end uses such as wire, cable, and pipe fittings each accounting for a much smaller share. Injection moulding of lids and rotomoulding of container, toys and other products, along with blow moulded products, account for most of the balance.

High Density Polyethylene (hpPE).

HDPE is an extremely versatile material which is used in all major plastics applications and which can be processed in a variety of ways. In comparison with other polyethylenes, HDPE is relatively stiff, has good stress crack resistance and a softening temperature of up to 135 C.

HDPE is primarily used to manufacture blow moulded containers and related products. These products represent the largest end use for HDPE, accounting for nearly one-half of the total demand. Included are bottles for household and automotive chemicals, milk and other food bottles, food containers, gasoline tanks, drug and cosmetic containers.

II.III. POLYPROPYLENE. (PP)

Polymer structure.

$$\sim CH_2\text{-}\underset{\displaystyle CH_3}{\underset{|}{CH}}\sim$$

Polypropylene is an extremely versatile product which offers a unique combination of heat and chemical resistance, tensile strength, optical gloss and clarity, low density, and excellent insulation and abrasion qualities. These characteristic make polypropylene suitable for a wide range of application in most industrial sectors.

As one of the lightest of the major plastics, polypropylene is one of the most popular plastics within the automotive industry where its lightness contributes to improved fuel efficiency. Polypropylene is widely used in automotive interior trim, in automotive battery casing, bumpers and other auto applications requiring flexibility and impact strength.

Polypropylene has a wide variety of applications in the packaging industry. Its high performance properties make it suitable for demanding uses such as food and medical packaging. Rigid and semirigid applications include large industrial shipping containers, which are will served by polypropylene's impact strength.

In the flexible packaging (film) area, it is used in cereal box lining, on bottle labels, and in wrapping for cigarettes, cheese and snack foods. These applications benefit from polypropylene's resistance to chemicals and water.

Fibres and filament markets, including cordage, webbing, upholstery (both in the home and in automobiles), clothing, disposable nappies and medical fabrics, are also important applications for polypropylene.

Good growth opportunities for PP exist within the packaging and fibers and filaments markets. Film, especially oriented grades, shows promise in snack food packaging and many other food and non-food applications. Opportunities are also favourable in containers, lids, and closures. Technological improvements in all grades of fibers and filaments are facilitating penetration into carpet, outerwear and swimwear markets.

II.IV. POLYVINYL CHLORIDE. (PVC)

Polymer structure.

$$\sim CH_2-\underset{\displaystyle Cl}{\underset{|}{CH}}\sim$$

There are two main PVC types: unplasticized PVC - a rigid material - and plasticized PVC - contains plasticizer. The main difference is that Plasticized PVC is flexible and that the plasticizer may reduce chemical resistance and flame retarder. Often PVC requires a variety of additives to achieve its various properties.

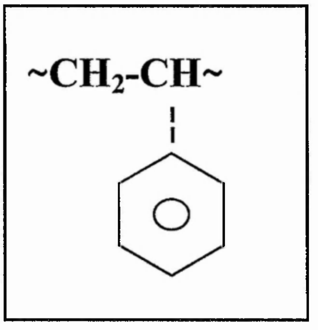
Applications for PVC are diverse, ranging from flexible sheet and pressure pipe to transparent bottles. The largest single market for PVC is the construction industry which accounts for over 60% of all PVC consumption. Its durability and high degree of water, chemical, weather and fungus resistance makes PVC suitable for pipes used in water supply, chemical processing, gas supply, drainage, and as conduits for electrical and telephone cables. PVC is also used extensively in house siding, panelling and window frames.

In addition to wire and cabling, PVC's properties also lend themselves to market opportunities in the electrical and electronics sector in plugs, connectors and business machines.

While PVC is used in a number of varied markets, construction applications comprise the largest end use. Recovery in the construction market is likely to fuel demand for the pipe and vinyl sidings. Controversy regarding PVC as a packing material has dogged the resin's growth over the years, and several European countries have restricted the use of PVC in these applications.

II.V. POLYSTYRENE.

Polymer structure.



Polystyrene resins are easy to process with excellent electrical properties, chemical resistance and transparency. They are available in crystal and impact grades and as expandable resins for foam moulding. Polystyrene's range of physical properties and processability has enabled it to replace more expensive engineering plastic, especially acrylonitrile butadiene styrene (ABS), in some applications.

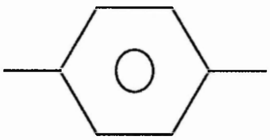
Polystyrene is used in the manufacture of a range of products such as furniture, houseware, cutlery, toys and recreational goods, small appliances, building insulation and housing for televisions and other electrical appliances.

Polystyrene for packaging purposes comes in solid and foam forms. Solid polystyrene packaging is used in dairy containers, and as housings for video and audio cassettes.

Foam polystyrene is used in meat trays, egg cartons, clamshell containers, cups, bowls and as packaging for electronical and fragile times.

II.VI. POLYETHYLENE TEREPHTHALATE. (PET)

Polymer structure.



COO.CH_2.CH_2.CH_2.OOC ~

Toughness, clarity, recyclability, lightness, shatter resistance, good barrier qualities and favourable economics have made PET one of the fastest growing resins in the recent years. Reinforced PET is also gaining ground as an engineering resin.

PET has made major inroads into packaging markets and has grabbed a large share of the carbonated soft drink bottle market in particular. In recent years, strongest PET growth has been in non-carbonated soft drinks, spirits and cosmetics and medical products which have made use of the development of green and amber grades.

Biaxially orientated PET film is used for X-ray and other photographic film, magnetic tape, electrical insulation, printing sheets and for processed meat and cheeses packaging.

II.VII. ACRYLONITRILE-BUTADIENE STYRENE. (ABS)

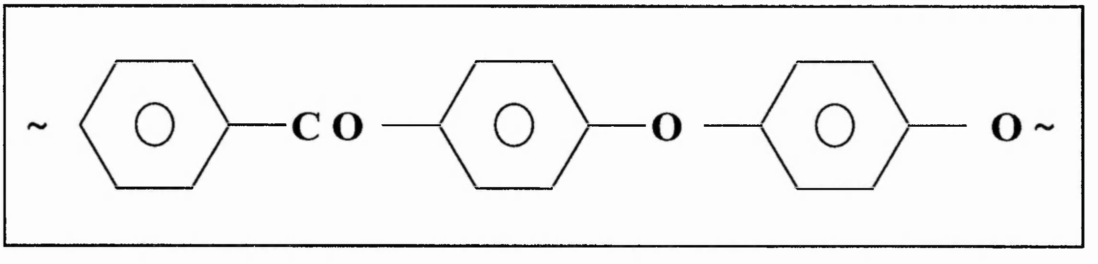
These materials are complex blends and there are many variations. In most types acrylonitrile and styrene are grafted onto a polybutadiene backbone.

Its key application properties are toughness, rigidity, and good surface appearance of well-moulded products. It has also generally better heat and chemical resistance than polystyrene.

These polymers are very widely used for "engineering applications" which do no have severe load bearing demands. It is particularly important for housings and in the automotive industry, where toughness, rigidity and good appearance are of importance.

II.VIII. POLYETHER ETHER KETONE. (PEEK)

Polymer structure.



Polyether Ether Ketone (PEEK) is a high cost speciality plastic. It is normally bring into consideration when other plastics do not meet specification.

It has a softening point, suitable for long term use above 200C. Low flammability and exceptionally low smoke emission. Excellent hydrolytic stability, very good stress cracking resistance and good radiation resistance.

It is normally used in critical and hostile environments. Of particular interest where heat resistance and hydrolytic stability important. Used for abrasion and chemically resistant linings, pump impellers and aircraft components.

APPENDIX III

MODIFICATION OF THE MELTING PROGRAM

```
C Part of the MELTING PROGRAM modified by S. Pagalday
C
.
.
.
C*****************************************************************
C      PROGRAMME HAS COMPLETED PROCESSING THE CURRENT SET
OF DATA.
C
9000  CONTINUE
      CLOSE(6)
C TRANSFER DATA TO THE FILE "filename".dnc to use in Gcodes program
      IF(EMSZP.LE.0.05) THEN
C Initialize to 0
      Date='        '
      Job=1
      Customer='        '
      Material='              '
      Special='              '
      rough=4
      Choice=1
      Hardn=0.0
      Chip=0.0
      Speed=0.0
      Bar=0.0
      First=0.0
      Overall=0.0
      Coating='Y'
      dia=d-2*hfeed
      pitch=3.141592654*(d-2*c)*dtan(thetar)

        open (5,file=filnam//'.dnc',status='UNKNOWN')
        write(5,6000)Date
        write(5,6050)Job
        write(5,6300)Customer
        write(5,6300)Material
        write(5,6150)Special
        write(5,4100)d*1000
        write(5,4100)Pitch*1000
        write(5,4100)dia*1000
        write(5,4050)Rough
        write(5,4050)Choice
        write(5,4100)Hardn
        write(5,4500)Chip
        write(5,4100)Speed
        write(5,4100)Lfeed*1000
```

```
      write(5,4100)Lcomp*1000
      write(5,4100)Lmet*1000
      write(5,4100)Bar
      write(5,4600)Hmet*1000
      write(5,4600)e*1000
      write(5,4600)First
      write(5,4600)Overall
      write(5,4200)Coating
     close(5)
    ENDIF
4050 FORMAT(I1)
4100 FORMAT(f6.1)
4200 FORMAT(A1)
4500 FORMAT(f4.2)
4600 FORMAT(f4.1)
6000 FORMAT(A8)
6050 FORMAT(I1)
6300 FORMAT(A15)
6150 FORMAT(A20)

C   data for plotting routine

        OPEN (9, FILE=filnam//'.dat', STATUS= 'unknown')
        REWIND (9)
.
.
.
```

APPENDIX IV

DATA-INPUT PROGRAM

```
C  MENU  To introduce the data to entittled the G-codes Generator Program run and
C generate the G-codes to manufacture plasticating extruder screws.

      INCLUDE 'FGRAPH.FI'
      INCLUDE 'FGRAPH.FD'

      INTEGER  dummy, var, pos, var2, i, j,
     +  sit, Job, Rough, Choice

      INTEGER*2 Answer2

      REAL*8 START,d, pitch, dia, lfeed, lcomp, lmet, hmet, e,
     +  Hardn, Chip, Speed, Bar, First, Overall

      CHARACTER*8 Date
      CHARACTER*20 Filenam, Customer, Material, Special, CRCT

      CHARACTER*1 Coating, Answer1

      RECORD /rccoord/    curpos

      CHARACTER* (51) text ( 29 ) /

     *  "  **General information**",
     *  "                    ",
     *  "1. DATE (DD MM YY).........................",
     *  "2. JOB NUMBER (MAXIMUM 5 DIGITS)............",
     *  "3. CUSTOMER NAME...........................",
     *  "4. MATERIAL NAME...........................",
     *  "5. SPECIAL INSTRUCTIONS....................",
     *  "                                        ",
     *  "    **Whirling details**                  ",
     *  " 10. INTERNAL(SCREW) BARREL DIAMETER (mm)..........",
     *  " 11. SCREW PITCH (mm).............................",
     *  " 12. ROOT (Feed) DIAMETER (mm)....................",
     *  " 13. No. OF ROUGHING TOOLS (4 or 6)................",
     *  " 14. CHOICE OF STEEL: 1, 2,3, 4, OR 5 (OTHER)......",
     *  " 15. STEEL HARDNESS (BRINELL).....................",
     *  " 16. CHIP THICKNESS...............................",
     *  " 17. MATERIAL CUTTING SPEED (m/min)................",
     *  " 18. LENGTH OF FEED (mm)..........................",
     *  " 19. LENGTH OF COMPRESSION ZONE (mm)...............",
     *  " 20. LENGTH METERING ZONE (mm)....................",
     *  " 21. DIAMETER OF THE BLANK BAR (mm)................",
     *  " 22. DEPTH OF METERING(mm)........................",
     *  " 23. FLIGHT WIDTH (mm)............................",
     *  " 24. WIDTH OF THE FIRST TOOL'S TIP (mm)...........",
     *  " 25. OVERALL WIDTH OF THE LAST TOOL (mm)...........",
     *  " 26. COATING ALLOWANCE (Y or N)...................",
     *  " ",
     *  " ",
     *  " 99. GO TO MAIN MENU"/
```

```
c INTRODUCTORY PAGE
   DUMMY= SETBKCOLOR(1)
   DUMMY= SETTEXTCOLOR(7)
   CALL intscreen
c  First Question
   CALL Firstquest
     Read(*,'(A1)')Answer1
   IF ((answer1.NE.'N').AND.(answer1.NE.'n')) THEN
c  Read current file name.
     OPEN(3,FILE='nam.txt',STATUS='OLD',ERR=99)
     READ(3,'(A)') filenam
     CLOSE(3)
     CALL Secondq(filenam)
     Read(*,420)Answer0
     IF ((Answer0.EQ.'C').OR.(Answer0.EQ.'c')) THEN
       CALL settextposition(20,20,curpos)
       DUMMY= SETTEXTCOLOR(11)
       CALL outtext('Write the new file name and Press Return: ')
       Read(*,'(A)')Filenam
     END IF
   DUMMY= SETTEXTCOLOR(7)
c Read existing data
     OPEN(1,FILE=Filenam//'.DNC', status='UNKNOWN')
     READ(1,600)date
     READ(1,606)job
     READ(1,610)customer
     READ(1,610)material
     READ(1,615)special
     READ(1,410)d
     READ(1,410)pitch
     READ(1,410)dia
     READ(1,605)rough
     READ(1,605)choice
     READ(1,410)hardn
     READ(1,450)chip
     READ(1,410)speed
     READ(1,410)lfeed
     READ(1,410)lcomp
     READ(1,410)lmet
     READ(1,410)bar
     READ(1,460)hmet
     READ(1,460)e
     READ(1,460)first
     READ(1,460)overall
     READ(1,420)coating
     CLOSE(1)
     CALL settextposition(20,20,curpos)
     CALL outtext('Press RETURN to go the main menu')

   ELSE
     Date='        '
     Job=1
     Customer='          '
     Material='              '
```

```
      Special='                '
      d=0.0
      pitch=0.0
      dia=0.0
      rough=4
      Choice=1
      Hardn=0.0
      Chip=0.00
      Speed=0.0
      Lfeed=0.0
      Lcomp=0.0
      Lmet=0.0
      Bar=0.0
      Hmet=0.0
      e=0.0
      First=0.0
      Overall=0.0
      Coating='Y'
    END IF
C Main menu
5       CALL Mainmenu
10      READ(*,105)Answer2

    SELECT CASE(Answer2)

    CASE(1)
    CALL clearscreen($GCLEARSCREEN)
    WRITE (*,500)
   *Text(1),
   *Text(2),
   *Text(3),date,
   *Text(4),job,
   *Text(5),Customer,
   *Text(6),Material,
   *Text(7),Special,
   *Text(8),
   *Text(28),
   *Text(29)
500  FORMAT(
   *13X,A46 /
   *13X,A46 /
   *13X,A46,A8/
   *13X,A46,I5 /
   *13X,A46,A15 /
   *13X,A46,A15 /
   *13X,A46,A20/
   *13x,A46 /
   *13X,A46 /
   *13X,A46 \\)
      CALL settextposition(1,7,curpos)
      CALL outtext
   *  ('Select option by entering the corresponding number.  ')
30      CALL settextposition(1,58,curpos)
      CALL OUTTEXT('       ')
      CALL settextposition(1,58,curpos)
```

```
      READ(*,220)VAR2

      IF (VAR2.LE.5) THEN

          DUMMY=SETTEXTCOLOR(14)
          POS=VAR2+2
          CALL settextposition(POS,58,curpos)
          CALL outtext('              ')
          CALL settextposition(POS,58,curpos)

      END IF

            SELECT CASE(VAR2)

              CASE(1)
              READ(*,200) Date
              GOTO 30

              CASE(2)
              READ (*,206)Job
              GOTO 30

              CASE(3)
              READ(*,210) Customer
              GOTO 30

              CASE(4)
              READ (*,210) Material
              GOTO 30

              CASE(5)
              READ (*,215) Special
              GOTO 30

              CASE (99)
              GOTO 5

              CASE DEFAULT
              GOTO 30

            END SELECT

C Whirling Menu
    CASE(2)
      CALL clearscreen($GCLEARSCREEN)
      j=3
        DO i=9,29
          CALL settextposition(1+j,5,curpos)
          CALL outtext(text(i))
          j=j+1
        END DO

      CALL settextposition(1,7,curpos)
      CALL outtext
     * ('Select option by entering the corresponding number.  ')
```

```
      CALL settextposition(1,60,curpos)


C Showing known data automatically
         CALL settextposition(5,59,curpos)
         Write (*,110) d
         CALL settextposition(6,58,curpos)
         Write (*,110) pitch
         CALL settextposition(7,58,curpos)
         Write(*,110) dia
         CALL settextposition(8,58,curpos)
         Write(*,205) rough
         CALL settextposition(9,58,curpos)
         WRITE(*,205) choice
         CALL settextposition(10,58,curpos)
         WRITE(*,110) Hardn
         CALL settextposition(11,58,curpos)
         WRITE(*,150) Chip
         CALL settextposition(12,58,curpos)
         WRITE(*,110) Speed
         CALL settextposition(13,58,curpos)
         WRITE(*,110) lfeed
         CALL settextposition(14,58,curpos)
         WRITE(*,110) lcomp
         CALL settextposition(15,58,curpos)
         WRITE(*,110) lmet
         CALL settextposition(16,58,curpos)
         WRITE(*,110) Bar
         CALL settextposition(17,58,curpos)
         WRITE(*,160) Hmet
         CALL settextposition(18,58,curpos)
         WRITE(*,160) e
         CALL settextposition(19,58,curpos)
         WRITE(*,160) first
         CALL settextposition(20,58,curpos)
         WRITE(*,160) overall
         CALL settextposition(21,58,curpos)
         WRITE(*,'(A1\\)') coating
         CALL settextposition(1,60,curpos)
C Changing data manually.
    READ(*,105)VAR
    DO WHILE (VAR.NE.99)
       IF ((VAR.GE.10).AND.(VAR.LE.26)) THEN
         SIT=VAR-5
       IF ((VAR.NE.26).AND.(VAR.NE.13).AND.(VAR.NE.14)) THEN
         dummy=settextcolor(14)
         CALL settextposition(SIT,5,curpos)
         CALL outtext(text(VAR))
         CALL settextposition(SIT,64,curpos)
         CALL Outtext('     ')
         IF (VAR.EQ.10) THEN
           READ(*,*) d
           START=d
         END IF
```

```
IF (VAR.EQ.11) THEN
   READ (*,*) pitch
   START=PITCH
END IF

IF (VAR.EQ.12) THEN
   READ(*,*) dia
   START=DIA
END IF

IF (VAR.EQ.15) THEN
   READ (*,*) Hardn
   START=HARDN
END IF

IF (VAR.EQ.16) THEN
   READ(*,*) Chip
   START=CHIP
END IF

IF (VAR.EQ.17) THEN
   READ (*,*) Speed
   START=SPEED
END IF

IF (VAR.EQ.18) THEN
   READ(*,*) lfeed
   START=LFEED
END IF

IF (VAR.EQ.19) THEN
   READ (*,*) lcomp
   START=LCOMP
END IF

IF (VAR.EQ.20) THEN
   READ(*,*) lmet
   START=LMET
END IF

IF (VAR.EQ.21) THEN
   READ (*,*) Bar
   START=BAR
END IF

IF (VAR.EQ.22) THEN
   READ(*,*) Hmet
   START=HMET
END IF

IF (VAR.EQ.23) THEN
   READ (*,*) e
   START=E
END IF
```

```
    IF (VAR.EQ.24) THEN
      READ(*,*) first
      START=FIRST
    END IF

    IF (VAR.EQ.25) THEN
      READ (*,*) overall
      START=OVERALL
    END IF
    CALL settextposition(SIT,58,curpos)
    CALL Outtext('                    ')
    CALL settextposition(SIT,58,curpos)
    CALL KAR (Start,Crct)
    CALL Outtext(Crct)
  END IF

    IF (VAR.EQ.13) THEN
      dummy=settextcolor(14)
      CALL settextposition(SIT,5,curpos)
      CALL outtext(text(VAR))
      CALL settextposition(SIT,58,curpos)
      CALL Outtext('      ')
      CALL settextposition(SIT,58,curpos)
      READ (*,205) Rough
    END IF

    IF (VAR.EQ.14) THEN
      dummy=settextcolor(14)
      CALL settextposition(SIT,5,curpos)
      CALL outtext(text(VAR))
      CALL settextposition(SIT,58,curpos)
      CALL Outtext('      ')
      CALL settextposition(SIT,58,curpos)
      READ(*,205) choice
    END IF

    IF (VAR.EQ.26) THEN
      dummy=settextcolor(14)
      CALL settextposition(SIT,5,curpos)
      CALL outtext(text(VAR))
      CALL settextposition(SIT,58,curpos)
      CALL Outtext('                ')
      CALL settextposition(SIT,58,curpos)
      READ(*,'(A)') Coating
    END IF
    dummy=settextcolor(7)
    CALL settextposition(SIT,5,curpos)
    CALL outtext(text(VAR))
    CALL settextposition(1,60,curpos)
    READ (*,100) VAR
    SIT=VAR-7
    ELSE
    CALL settextposition(1,60,curpos)
    READ (*,100) VAR
  END IF
```

```
    END DO
   DUMMY= SETTEXTCOLOR(7)
   GOTO 5

   CASE(99)
C Saving data to Filename.DNC
      OPEN(1,FILE=Filenam//'.dnc',STATUS='UNKNOWN')
      Rewind(1)
      Write(1,600)Date
      Write(1,606)job
      Write(1,610)customer
      Write(1,610)Material
      Write(1,615) Special
      Write(1,410)d
      Write(1,410)Pitch
      Write(1,410) dia
      Write(1,605) Rough
      Write(1,605)Choice
      Write(1,410) Hardn
      Write(1,450) Chip
      Write(1,410)Speed
      Write(1,410)Lfeed
      Write(1,410) Lcomp
      Write(1,410)Lmet
      Write(1,410) Bar
      Write(1,460) Hmet
      Write(1,460)e
      Write(1,460) First
      Write(1,460) Overall
      Write(1,420)Coating
      Close(1)
C Saving data to Camjob).inp
      OPEN(2,FILE='camjob0.inp',STATUS='UNKNOWN')
      Write(2,*)'            '
      Write(2,*)'            '
      Write(2,700)Date
      Write(2,706)job
      Write(2,710)customer
      Write(2,710)Material
      Write(2,715) Special
      Write(2,*)'            '
      Write(2,*)'            '
      Write(2,510)d
      Write(2,510)Pitch
      Write(2,510) dia
      Write(2,505) Rough
      Write(2,505)Choice
      Write(2,510) Hardn
      Write(2,550) Chip
      Write(2,510)Speed
      Write(2,510)Lfeed
      Write(2,510) Lcomp
      Write(2,510)Lmet
      Write(2,510) Bar
      Write(2,580) Hmet
```

```
      Write(2,580)e
      Write(2,580) First
      Write(2,580) Overall
      Write(2,520)Coating
      Close(2)
    GOTO 99

    CASE(88)
    GOTO 99

    CASE DEFAULT
    GOTO 10

    END SELECT
C Format definitions.
100  FORMAT(BN,I3\\)
105  FORMAT(BN,I2\\)
110  FORMAT(f6.1\\)
150  FORMAT(F4.2\\)
160  FORMAT(f4.1\\)
200  FORMAT(A8\\)
205  FORMAT(BN,I1\\)
206  FORMAT(BN,I5\\)
210  FORMAT(A15\\)
215  FORMAT(A20\\)
220  FORMAT(BN,I2\\)
300  FORMAT(1X,I6,2X,A15,2X,A20)
310  FORMAT(1X,A20,2X,A15)
400  FORMAT(I3)
405  FORMAT(I2)
410  FORMAT(f6.1)
420  FORMAT(A1)
450  FORMAT(f4.2)
460  FORMAT(f4.1)
C500  FORMAT(49X,I3)
505  FORMAT(49X,I1)
510  FORMAT(49X,f6.1)
520  FORMAT(49X,A1)
550  FORMAT(49X,f4.2)
580  FORMAT(49X,f4.1)
600  FORMAT(A8)
605  FORMAT(I1)
606  FORMAT(I5)
610  FORMAT(A15)
615  FORMAT(A20)
620  FORMAT(I2)
700  FORMAT(49X,A8)
705  FORMAT(49X,I1)
706  FORMAT(49X,I5)
710  FORMAT(49X,A15)
715  FORMAT(49XA20)

99   END

C  *****************************************************************
```

```
CC  INTRODUCTORY SCREEN
    SUBROUTINE intscreen
    CALL clearscreen($GCLEARSCREEN)
    CALL settextposition(5,20,curpos)
    CALL outtext('WELCOME TO THE SIMULATION PROGRAM THAT INTEGRATES')
    CALL settextposition(6,20,curpos)
    CALL outtext('THE MELTING AND G-codes Generator PROGRAMS')

    CALL settextposition(9,20,curpos)
    CALL outtext('IF YOU HAVE ALREADY OPTIMISED THE SCREW DESIGN')
    CALL settextposition(10,20,curpos)
    CALL outtext('USING THE MELTING PROGRAM,')
    CALL settextposition(12,20,curpos)
    CALL outtext('       OR ')
    CALL settextposition(14,20,curpos)
    CALL outtext('IF YOU HAVE ALREADY INTRODUCED "G-codes Generator"')
    CALL settextposition(15,20,curpos)
    CALL outtext('PROGRAM DATA, ')
    CALL settextposition(17,20,curpos)
    CALL outtext('THIS DATA CAN BE INTERNALLY TRANSFERRED ')
    CALL settextposition(18,20,curpos)
    CALL outtext('TO THIS PROGRAM')
    READ(*,*)
    END

C  ***************************************************************


CC  FIRST QUESTION
    SUBROUTINE Firstquest
    CALL clearscreen($GCLEARSCREEN)
    CALL settextposition(10,20,curpos)
    CALL outtext('DO YOU WANT TO TRANSFER DATA?')
    CALL settextposition(11,20,curpos)
    CALL outtext('Press Y or N:  ')
    END

C  ***************************************************************


CC  SECOND QUESTION
    SUBROUTINE Secondq(Filenam)

    INCLUDE 'FGRAPH.FD'

    CHARACTER*20 Filenam
    INTEGER*2 Dummy
    CALL clearscreen($GCLEARSCREEN)
    CALL settextposition(10,20,curpos)
    Dummy=settextcolor(11)
    CALL outtext('Your current file is:   ')
    CALL outtext(filenam)
    CALL settextposition(13,20,curpos)
```

```
    Dummy=settextcolor(7)
    CALL outtext('TO CHANGE IT PRESS "C"')
    CALL settextposition(15,20,curpos)
    CALL outtext('TO CONTINUE PRESS RETURN')
    CALL settextposition(17,20,curpos)
    CALL outtext('   >> ')
    END

C   ******************************************************************


CC  MAIN MENU SCREEN

    SUBROUTINE mainmenu
    INCLUDE 'FGRAPH.FD'
       CALL clearscreen($GCLEARSCREEN)
       DUMMY=SETTEXTCOLOR(7)
       CALL settextposition(6,20,curpos)
       CALL outtext('MAIN MENU')
       CALL settextposition(7,19,curpos)
       CALL outtext('===========')
       CALL settextposition(9,20,curpos)
       CALL outtext('1. GENERAL INFORMATION  ')
       CALL settextposition(11,20,curpos)
       CALL outtext('2. WHIRLING DETAILS  ')
       CALL settextposition(13,20,curpos)
       CALL outtext('88. EXIT  ')
       CALL settextposition(15,20,curpos)
       CALL outtext('99. SAVE AND EXIT  ')
       CALL settextposition(18,20,curpos)
       CALL outtext('SELECT AND PRESS RETURN: ')
    END
C   ******************************************************************


CC  CHARACTER - To convert a real value to a character string.


         SUBROUTINE kar(s,fin)

         DOUBLE PRECISION  s, s2, s1, st
         INTEGER           i, j, k, fl, n, x1, x2
         CHARACTER*20      c, fin
         CHARACTER*1  num(10) /
    *   "0", "1", "2", "3", "4", "5", "6", "7", "8", "9" /

         s=s+0.0000001
         s1=DINT(s)
         s2=(s-s1)

         st=s-255555555
         IF(st.GT.0) THEN
           fin(1:20)='Number out of range '
           GOTO 22
         END IF
```

```
c  First part (s1)

        i=15
        j=1
        fl=0

9    n=DINT(s1/10**(i-1)) - 10*DINT(s1/10**i)

        IF ((fl.EQ.1) .OR. (n.NE.0) .OR. (i.EQ.1))THEN
          c(j:j)=num(n+1)
          j=j+1
          fl=1
        END IF

        i=i-1
        IF(i.GT.0) GOTO 9

        c(j:j)='.'
        j=j+1

c  Second half (s2)

        i=6
        k=j+5
        fl=0

20     x1=DINT(s2*10**i)
        x2=10*DINT(s2*10**(i-1))
        n=x1-x2
        IF ((fl.EQ.1) .OR. (n.NE.0) .OR. (i.EQ.1))THEN
          c(k:k)=num(n+1)
          fl=1
        END IF

        k=k-1
        i=i-1
        IF(i.GT.0) GOTO 20

c  Write characters to output array and clean character arrays.

        DO n=1,20
          fin(n:n)=' '
        END DO

        DO m=1,j+6
          fin(m:m)=c(m:m)
        END DO

        DO n=1,20
          c(n:n)=' '
        END DO

22     END
```

WELCOME TO THE SIMULATION PROGRAM THAT INTEGRATES
THE MELTING AND G-codes Generator PROGRAMS

IF YOU HAVE ALREADY OPTIMISED THE SCREW DESIGN
USING THE MELTING PROGRAM,

OR

IF YOU HAVE ALREADY INTRODUCED "G-codes Generator"
PROGRAM DATA,

THIS DATA CAN BE INTERNALLY TRANSFERRED
TO THIS PROGRAM

DO YOU WANT TO TRANSFER DATA?
Press Y or N: Y

Your current file is: MOPB24

TO CHANGE IT PRESS "C"

TO CONTINUE PRESS RETURN

>>

MAIN MENU
===========

1. GENERAL INFORMATION

2. WHIRLING DETAILS

88. EXIT

99. SAVE AND EXIT

SELECT AND PRESS RETURN:

MAIN MENU
===========

1. GENERAL INFORMATION

2. WHIRLING DETAILS

88. EXIT

99. SAVE AND EXIT

SELECT AND PRESS RETURN: 1

Select option by entering the corresponding number.99

1. DATE (DD MM YY).......................... 01 12 96
2. JOB NUMBER (MAXIMUM 5 DIGITS)............ 12
3. CUSTOMER NAME............................ N.T.U.
4. MATERIAL NAME............................ PP
5. SPECIAL INSTRUCTIONS.....................

99. GO TO MAIN MENU

```
MAIN MENU
===========

 1. GENERAL INFORMATION

 2. WHIRLING DETAILS

 88. EXIT

 99. SAVE AND EXIT

SELECT AND PRESS RETURN: 2
```

```
Select option by entering the corresponding number.   99

    **Whirling details**
10. INTERNAL(SCREW) BARREL DIAMETER (mm)..........    63.5
11. SCREW PITCH (mm)..............................    63.5
12. ROOT (Feed) DIAMETER (mm).....................    43.7
13. No. OF ROUGHING TOOLS (4 or 6)................  4
14. CHOICE OF STEEL: 1, 2,3, 4, OR 5 (OTHER)......  1
15. STEEL HARDNESS (BRINELL)......................  140.0
16. CHIP THICKNESS................................   .20
17. MATERIAL CUTTING SPEED (m/min)................  150.0
18. LENGTH OF FEED (mm)...........................   349.3
19. LENGTH OF COMPRESSION ZONE (mm)...............   698.5
20. LENGTH METERING ZONE (mm).....................   539.8
21. DIAMETER OF THE BLANK BAR (mm)................    69.5
22. DEPTH OF METERING(mm).........................   4.0
23. FLIGHT WIDTH (mm).............................   6.9
24. WIDTH OF THE FIRST TOOL'S TIP (mm)............  10.0
25. OVERALL WIDTH OF THE LAST TOOL (mm)...........  8.0
26. COATING ALLOWANCE (Y or N)....................  Y


99. GO TO MAIN MENU
```

MAIN MENU
===========

1. GENERAL INFORMATION

2. WHIRLING DETAILS

88. EXIT

99. SAVE AND EXIT

SELECT AND PRESS RETURN: 99

MOPB24.DNC

Listed below is the data saved to the file *Mopb24.Dnc*. This file contains all the required data to generate the G-codes to manufacture the screw previously optimised using The MELTING program under *Mopb24* file-name.

```
25 09 96
1
N.T.U.
PP

63.5
 63.5
 43.7
4
1
 200.0
 .15
 160.0
 349.3
 698.5
 539.8
  65.0
 4.0
 6.9
 8.0
10.0
Y
```

CAMJOB0.INP

This file contains all the required data to run the G-codes Generator Program in a format that the G-codes Generator Program can read. In this case the data shown below, is the data to generate the G-codes for the screw optimised using the MELTING Program under *Mopb24* file name.

```
25 09 96
1
N.T.U.
PP
No heater required


 63.5
 63.5
 43.7
4
1
200.0
.15
160.0
349.3
698.5
539.8
 65.0
4.0
6.9
8.0
10.0
Y
```

CAMJOB.INP

Camjob.inp file is the file that the G-codes Generator Program reads in order to generate the G-codes.

General information

1. DATE (DD MM YY)............................. 25 09 96
2. Job number (Maximum 5 digits)............ 1
3. Customer Name...................................... N.T.U.
4. Material Name....................................... PP
5. Special Instructions................................

Whirling details

10. Internal(Screw) Barrel Diameter (mm)........ 63.5
11. Screw pitch (mm).. 63.5
12. Root (Feed) Diameter (mm)........................ 43.7
13. No. of Roughing Tools (4 or 6).................. 4
14. Choice of Steel: 1, 2,3, 4, or 5 (other)......... 1
15. Steel Hardness (Brinell).............................. 200.0
16. Chip Thickness.. .15
17. Material Cutting Speed (m/min)................. 200.0
18. Lenght of Feed (mm)................................. 349.3
19. Length of Compression Zone (mm)........... 698.5
20. Length Metering Zone (mm)....................... 539.8
21. Diameter of the Blank Bar (mm)................. 70.0
22. Depth of Metering(mm).............................. 4.0
23. Flight Width (mm)...................................... 6.9
24. Width of the fist tool's tip (mm).................. 10.0
25. Overall Width of the last tool(mm)............. 8.0
26. Coating allowance (Y or N)......................... Y

1.GCD

Listed below the G-codes generated by *STEP3* G-codes Generator Program, to manufacture the "*Mopb24" screw.*

```
%   1
N   0 G71
N   5 G97                       S    1.431 M 3
N  10 G90 G00      X    2.000
N  15 G00                Z  -59.500
N  20 G91 G33 G05  X   61.500 Z   43.980 K    63.500
N  25           X   -7.760 Z   15.520 K   63.500
N  30                   Z    8.000 K    63.500
N  35           X    7.640 Z     .000 K   63.500
N  40                   Z   -8.000 K    63.500
N  45 G90 G00      X    2.000
N  50                            M 0
N  55 G97                       S    1.431 M 3
N  60 G90 G00      X    2.000
N  65 G00                Z  -51.500
N  70 G91 G33 G05  X   61.500 Z   35.980 K    63.500
N  75           X   -7.760 Z   15.520 K   63.500
N  80                   Z    8.000 K    63.500
N  85           X    7.640 Z     .000 K   63.500
N  90                   Z   -8.000 K    63.500
N  95 G90 G00      X    2.000
N 100                            M 0
N 105 G97                       S    1.431 M 3
N 110 G90 G00      X    2.000
N 115 G00                Z  -43.500
N 120 G91 G33 G05  X   61.500 Z   27.980 K    63.500
N 125           X   -7.760 Z   15.520 K   63.500
N 130                   Z    8.000 K    63.500
N 135           X    7.640 Z     .000 K   63.500
N 140                   Z   -8.000 K    63.500
N 145 G90 G00      X    2.000
N 150                            M 0
N 155 G97                       S    1.431 M 3
N 160 G90 G00      X    2.000
N 165 G00                Z  -35.500
N 170 G91 G33 G05  X   61.500 Z   19.980 K    63.500
N 175           X   -7.760 Z   15.520 K   63.500
N 180                   Z    8.000 K    63.500
N 185           X    7.640 Z     .000 K   63.500
N 190                   Z   -8.000 K    63.500
N 195 G90 G00      X    2.000
```

```
N 200                              M 0
N 205 G97                      S    1.431 M 3
N 210 G90 G00      X    2.000
N 215 G00                  Z   -27.500
N 220 G91 G33 G05  X    61.500 Z    11.980 K    63.500
N 225              X   -7.760 Z   15.520 K   63.500
N 230                  Z    8.000 K   63.500
N 235              X    7.640 Z      .000 K   63.500
N 240                  Z   -8.000 K   63.500
N 245 G90 G00      X    2.000
N 250                              M 0
N 255 G97                      S    1.431 M 3
N 260 G90 G00      X    2.000
N 265 G00                  Z   -19.500
N 270 G91 G33 G05  X    61.500 Z     3.980 K    63.500
N 275              X   -7.760 Z   15.520 K   63.500
N 280                  Z    8.000 K   63.500
N 285              X    7.640 Z      .000 K   63.500
N 290                  Z   -8.000 K   63.500
N 295 G90 G00      X    2.000
N 300                              M 0
N 305 G97                      S    1.431 M 3
N 310 G90 G00      X    2.000
N 315 G00                  Z   -11.500
N 320 G91 G33 G05  X    61.500 Z    -4.020 K    63.500
N 325              X   -7.760 Z   15.520 K   63.500
N 330                  Z    8.000 K   63.500
N 335              X    7.640 Z      .000 K   63.500
N 340                  Z   -8.000 K   63.500
N 345 G90 G00      X    2.000
N 350                              M 0
N 355 G97                      S    1.431 M 3
N 360 G90 G00      X    2.000
N 365 G00                  Z    42.000
N 370 G91 G33 G05  X    61.500 Z   -57.520 K    63.500
N 375              X   -7.760 Z   15.520 K   63.500
N 380                  Z    8.000 K   63.500
N 385              X    7.640 Z      .000 K   63.500
N 390                  Z   -8.000 K   63.500
N 395 G90 G00      X    2.000
N 400                              M 0
%
```

APPENDIX V

BATCH FILES

SCREWOPT.BAT

```
@ECHO OFF
MENU1.EXE
```

10.BAT Batch File

```
@ECHO OFF
CLS
C:\PRENTP\FORTRAN\MELTING\DATAINP.EXE
CLS
echo.
echo.
echo.
echo.
echo.
ECHO DO YOU WANT TO RUN GCODES PROGRAM?
echo.
PROMPT  (Type YES  or NO and press Return):
```

YES.BAT Batch File

```
@echo off
cls
COPY c:\prentp\fortran\melting\camjob0.inp
c:\prentp\fortran\gcodes\camjob.inp
cd c:\prentp\fortran\gcodes
step3.exe
prompt $p$g
dir *.gcd
echo.
echo.
cd c:\prentp\fortran\melting
prompt $p$g
```

NO.BAT Batch File

```
@echo off
cls
cd c:\prentp\fortran\melting
prompt $p$g
```