Using 100% Recycled ABS (rABS) in Plastic Products (Phase 1, Background Research and Initial Concept Design)

Using 100% Recycled ABS in Plastic Products (Phase 1 Background Research and Initial Concept Design)

Outputs Contents

Summary of findings and design proposal

Aim of the research (at this time BT were part of the Ellen Macarthur Foundation

Improve the ease of reuse and recovery of materials

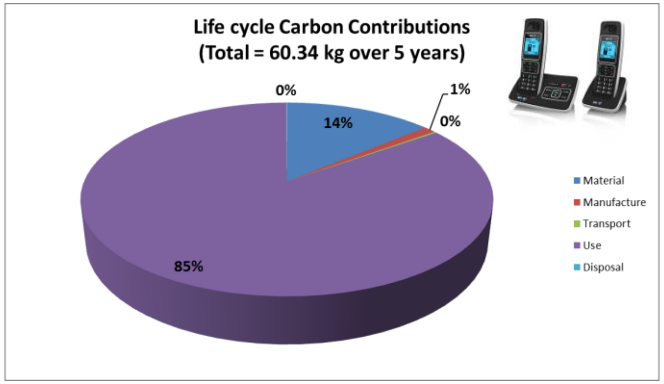
Reduce materials supply risks

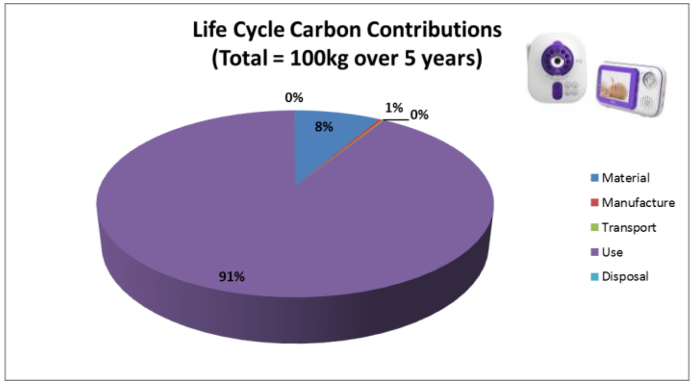
Match the durability requirements of the product to the durability of the design

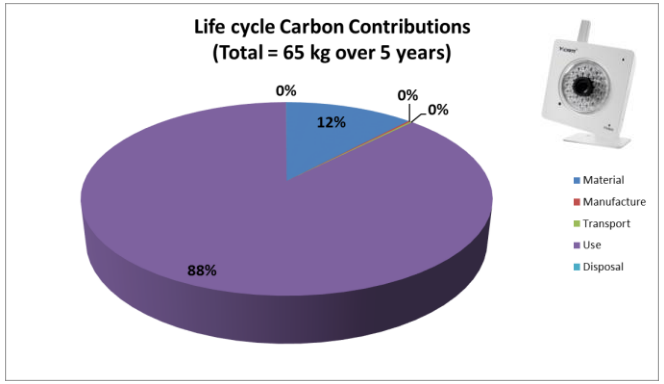
Shift to renewable energy sources

Build in modularity

Think in systems rather than specific physical products

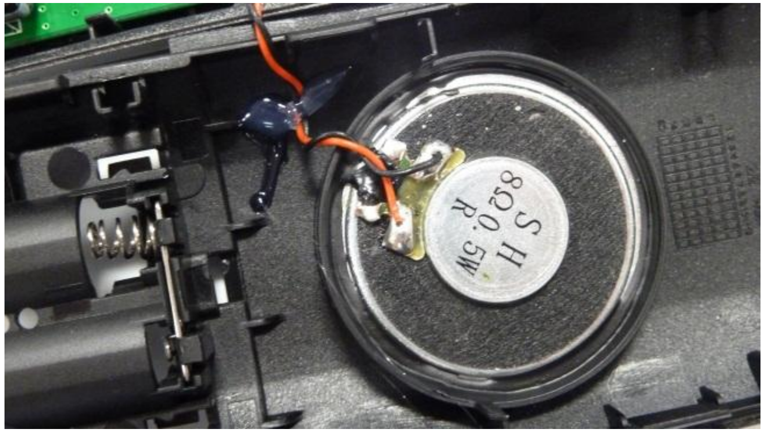






LCA's of three products (two BT products and one other brand)

THE DESIGN UNIT



Headline risks in materials used in current products

Risk analysis of materials used:

Three main risk areas:

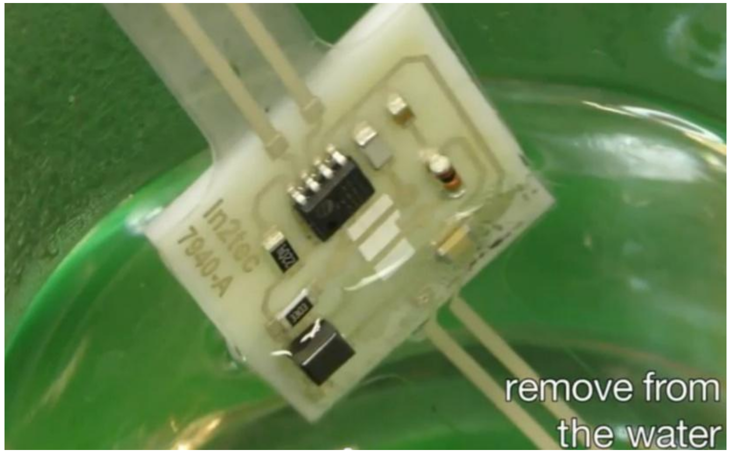
- *Oil-derived materials: price increases, ultimate restriction of supply, non-renewable resource*
- *Rare Earths: rare metallic elements used in electronics, some essential, restricted supply controlled by small number of countries. Restricted supply risks and increasing prices*
- *Conflict Minerals: Sourcing materials (tin, tantalum gold etc.) from area of conflict e.g. DRC. Supply risk and CSR risks associated with these,*

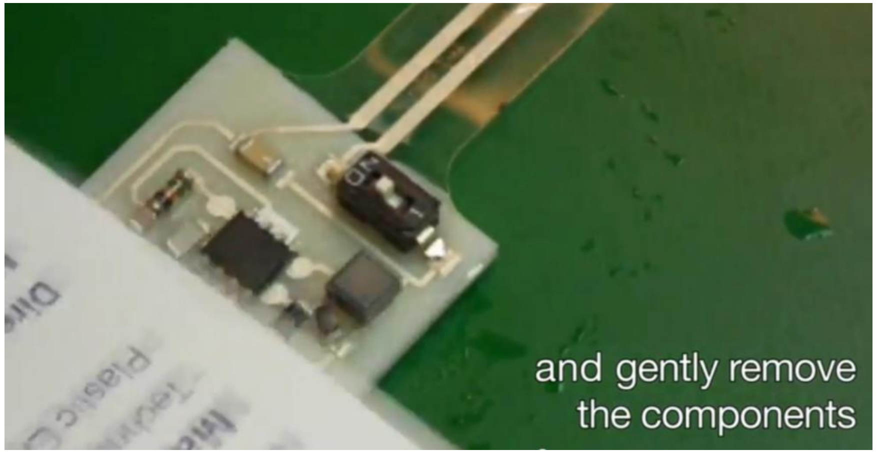
All products assessed have the same basic risk from these issues as they are very similar in their material content

Alternative materials and construction

Thoughts on Components and Assembly

- *Dissolvable PCB's*

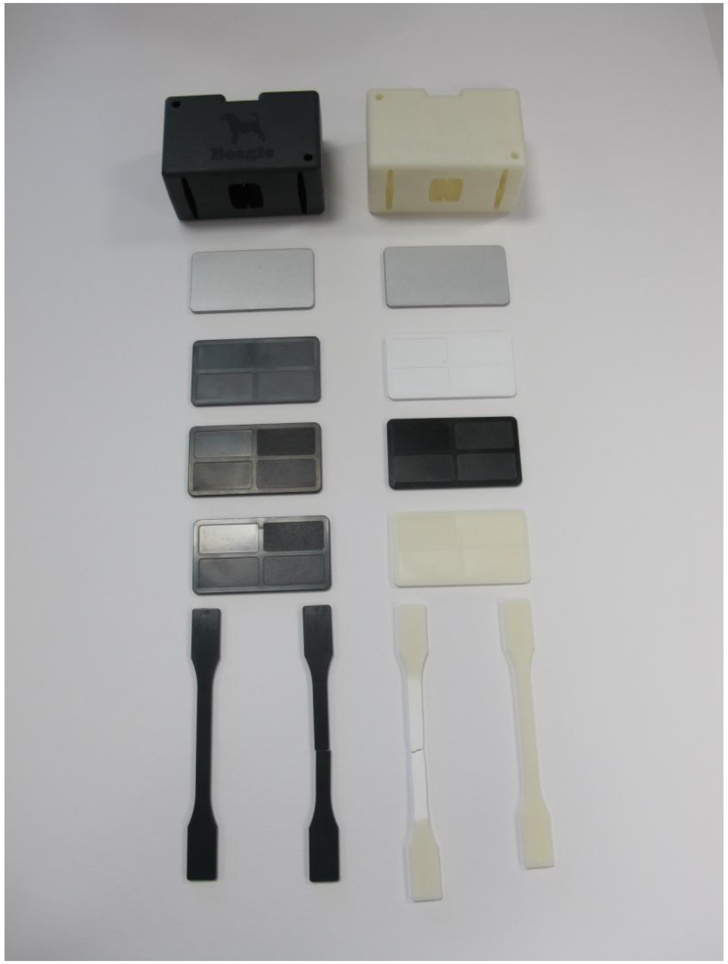




Colour, texture and strength comparisons between virgin and 100% recycled ABS

100% Recycled Versus Virgin Material:

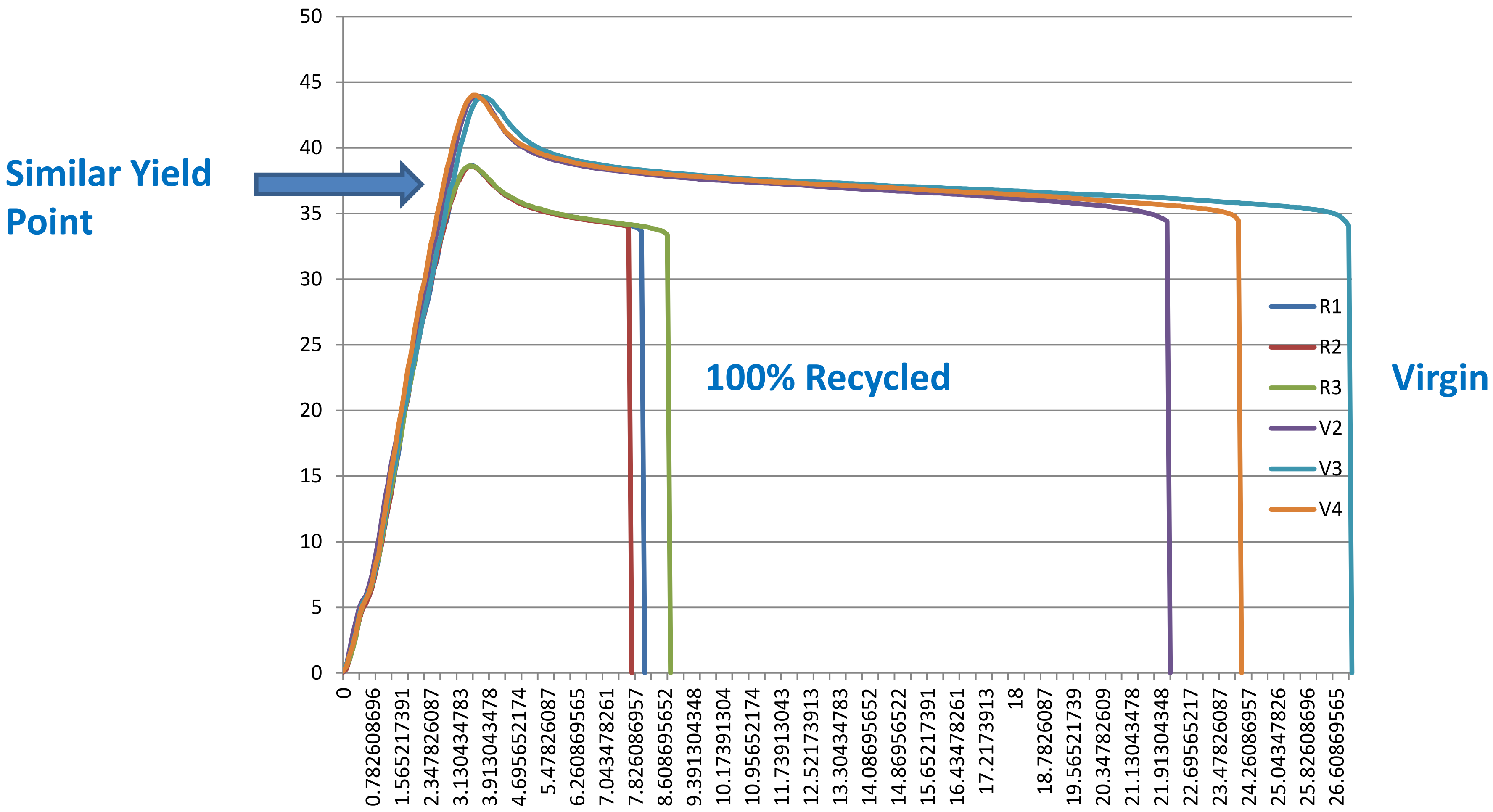
100% Recycled



Virgin

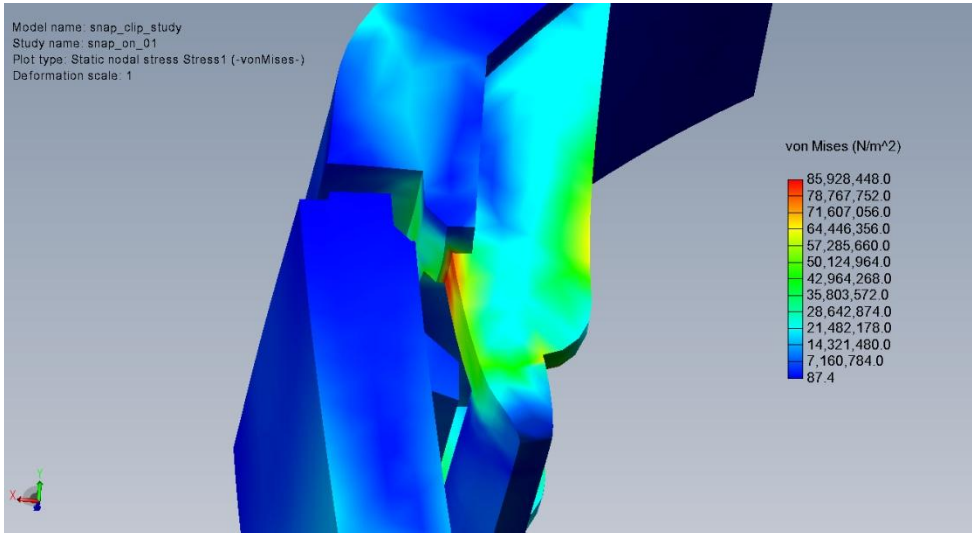
Strength comparison between Virgin and 100% recyled ABS

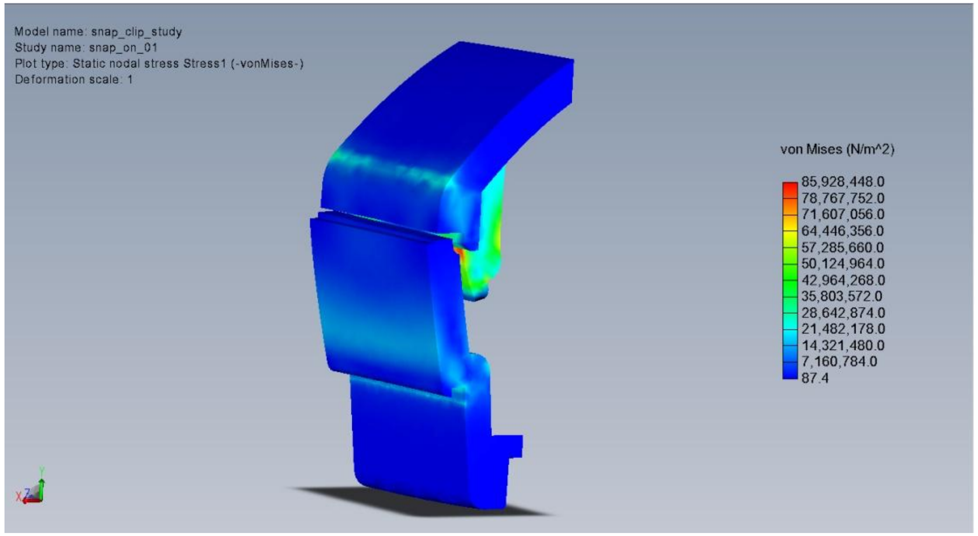
100% Recycled Versus Virgin Material:



Finite element analysis of clip on existing BT DECT phone using 100% recycled ABS charactersitics

100% Recycled Versus Virgin Material:





Although there is a clear area of high stress, this could be kept within the yield point

Using capacitive touch technology to reduce keyboard componentry

THE DESIGN UNIT

Thoughts on Components and Assembly

- *Capacitive touch to replace conventional keypad*

Using heat shrink technology to provide colour, texture and assembly features

Thoughts on Components, Assembly - Materials

- *Heat shrink for assembly, colouring and the ability to customise/personalise*

New concept using 'e-ink' dispaly, capacitive touch keyboard and shrink sleeve colour/graphics and outer assembly method

BT Material Strategy and Risk Assessment

31st January 2014


3.59pm
Handset 1
MENU
CALLS
Volume
OK
Calls
ECO

EXECUTIVE SUMMARY

This research has taken 2 mainstream products from BT's range and 1 competitor's product and assessed them in a way that highlights issues in relation to the circular economy. It has also shown that many of these issues can be relatively easily address through some lateral thinking at the design stage and the application of a number of simple practical design rules. These rules relate to material choices, manufacturing practices and supply chain concerns as well as in-use impacts and the eventual end-of-life of products.

All three products basically consist of plastic casings which contain a range of electronics (PCBs, batteries etc.) and LCD screens. The components are of difference sizes but in essence they are the same things. They also both contain similar type power supplies and each has a keyboard/keypad.

With all these products the overall recycled content of the current materials used is extremely low (% by weight). The plastics contain no recycled content (as far as can be established) and the metals have been allocated the average recycled content that is in current supply chains. The majority of the recycled material content is in fact in the cardboard packaging. Only 33% of the weight of the material used can actually be recycled.

On this basis the environmental credentials for the 2 BT products is not great. Indeed if BT continues to develop or brand products of this type (business as usual) they may well find themselves lagging behind their competitors in terms of environmental product impact.

This research has identified ways in which the negatives associated with using recycled materials can be mitigated against in approaches to design which will not add cost or have a negative impact on the user experience. In addition, via these design approaches, improvements can be made to end of life disassembly, enabling them to become genuinely circular; this, coupled with careful use of modular and systems approaches can make for updatable and repairable products that the meet the needs of the consumer who are looking for quality products that can last them 10 years or more.

These approaches will address both an incremental and component (change, update, replace) to new product development that will keep BT very much in the environmental agenda and in a position to such developments not having a negative impact on them achieving their 'Net Good', 'North Star' goal.

To address more transformational requirements the research also highlights the need to collaborate with competitors on applying pressure for change on their sub-contractors and suppliers to research into the development of new materials, technologies and new uses of energy.

CONTENTS

AIMS and CONTEXT

Background

This report has been undertaken in the context of BT's Better Future initiative, the pan-BT programme to deliver on BT's strategic aim to be a responsible and sustainable business leader. In this context the report aims to make a contribution to the three directives of building stronger communities through the power of their technology and people, reducing carbon emissions and their impact on the environment through BT's operations and products, and to behave responsibly towards BT's customers (people) and their suppliers.

In particular the report presents material in the context of one of BT's key three 'North Star Goals' that is 'Net Good' where BT's products will achieve three times the carbon saving for their customers than they emit over their lifetime (a 5 to 15 year target). An enabler of Net Good is implementation of the Circular Economy (CE) principles (see 'Towards the Circular Economy' reports 1 and 2 - Ellen MacArthur Foundation 2013). BT's overall goal being to make good quality, inclusively-designed products that exceed customer expectations, while minimising the environmental impacts inherent in their manufacture and use and therefore going beyond mere 'compliance'.

In the context of Net Good impact, three products have been used as the basis for this study, a wholly BT generated product, a VTec – BT 'badged' product and another brand product (see approach), all of which embody generic elements (packaging, PSUs, casing, PCBs, screens etc.), yet provide opportunity to compare and contrast.

How products are made, what they are made of, where they are made, and what happens at the End of Life (EoL) will be crucial to BT's new product development strategies. The commodities market and working environment legislation are just two factors impacting on People, Planet, and Profit aspects of consumer electronics which present an out-of-control WEEE problem; for a successful future BT will need to place itself in a position to manage this situation.

For further context it should be noted this research has been undertaken in parallel with an additional project commissioned by BT Group relating to **'Sustainability and Consumer Behaviour'**, the findings of which have been provided in an August 2013 report. This research has addressed the questions:

1. BT does not believe that consumers are willing to pay more for a DECT handset product with higher sustainability credentials than another. However, given a choice of products which are the same price and quality, they are confident that the one with greater visibility and plausibility of environmental labels/messaging will be the most popular.

2. Consumers of DECT handsets are creatures of habit, BT are not confident that users would be willing to revolutionise their behaviour beyond a certain level. BT also believes that any changes in user behaviour would be driven by the technological improvements in a device rather than improving sustainability credentials.

3. Consumers are caught in the habit of the ‘buy-use-throw’ model, BT believe that many would consider exploring other models of ownership based on the circular economy.

Underlying anecdotal findings in this research have revealed that consumers look for quality and durability in their DECT phones, many keeping them for ten years or more. In addition many are totally confused by green messaging and the various icons and tags that relate to it. There was no negativity to more environmentally sustainable devices provided this did not impact on quality and durability. In addition it was found there was little to moderate appetite for systems rental or leasing.

PROJECT BRIEF

The goal of this project is, where possible, to provide evidence-based recommendations to BT on a number of key materials’ areas and manufacturing processes, and provide a risk analysis in the form of:

1. **Business as usual** (BAU or do nothing)
2. **Incremental** (BAU+ small changes here and there)
3. **Component** (Mostly BAU, but swap out parts/processes)
4. **Transformational** (Making a big step, adopting total supply chain approach, Circular Economy principles)

Underpinning much of the CE approach is chemistry of materials, appropriate use, and costs. This context, this study was to evaluate a number of key materials and constructions that if used will contribute toward BT achieving circular economy goals but will provide design challenges in so doing. This study was therefore to evaluate the impact of using these materials and constructions on BT’s Materials Strategy, and the impact on industrial design, and cost-effectiveness for manufacture in China or the UK.

In each case, the feasibility and suitability of materials and processes was to be taken into account; recommendations were to be proposed in terms of incremental, component and transformational.

TASKS

Specific tasks were as follows:

T1 Risk analysis of current materials – which materials and method of ranking the associated risk?

T2 Alternative materials – measuring evidence-based pros & cons.

T3 Alternatives to existing components.

T4 Impact on industrial design of component or materials change.

T5 How can EoL impacts be improved?

T6 What are the key barriers to improvements and suggestions to overcome these?

T7 Propose best strategy to significantly move forward.

APPROACH

The approach has been to:

- Provide information on materials and constructions by evaluating three current telecoms related products (a ‘physical teardown’ of these products to provide quantitative information for material content, recycled content and recyclability, energy use and CO_2 emissions), in terms of their CE credentials in order to determine possible improvements for component change, material use, alternative constructions and design improvements and to identify/highlight areas of material risk

- Look at the current state of play of materials risk, typically rare earth metals and conflict minerals

- Undertake a thorough comparative analysis between non recycled and %100 recycled material for use in the caseworks of telecoms style products

- Evaluate broader opportunities for component and materials change

- Propose design opportunities based on the research findings

All evaluations and recommendations have been made in the context of currently accessible or near accessible materials and manufacturing technologies and potentially cost effective solutions.

As mentioned above three different products were selected for evaluation:

The BT 6500 DECT phone
The BT (VTec manufactured) Baby Monitor 1000 (DECT based)
The Y-Cam Night Wi-Fi based home monitoring product

This has enabled comparative, quantitative, evaluations between a product designed and manufactured by BT, a product designed and manufactured by VTec (but branded BT) and non BT branded or manufactured product; this third product also being more home computer/Wi-Fi orientated providing opportunity to determine if this technology generates any significant CE improvement over DECT.

PRODUCT ANALYSIS SUMMARY

BT 6500 DECT Telephones

BT Digital Video Baby Monitor 1000

'Y-Cam' Knight Internet Security System

Evaluation Context - The Circular Economy and Product Design

The circular economy is an alternative to a traditional linear economy (make, use, dispose) in which resources are kept in use for as long as possible, the maximum value is extracted from them whilst in use and they are recovered and regenerate at the end of each service life. When considering products in respect of this over-arching goal designers must consider the materials they use, the physical form of the product, the way in which different materials and components are joined together and the possibilities for extracting materials and value at end of life.

Applying CE principles to product design requires a number of design changes that can help make a tangible difference in the overall life cycle impact. These are best considered in the context of the goals listed in 'Towards the Circular Economy' [1]which was published in 2013 by the Ellen MacArthur Foundation.

The reports suggest that manufacturers should 'specify the purpose and performance of the end-products, more than those of the input materials'. It goes on to suggest that designers should specify 'pure materials in their production process since they are easier to sort at end of life'. The report also highlights that besides material selection, other areas important for economically successful circular design are standardised components, designed-to-last products, design for easy end-of-life sorting, separation or reuse of products and materials, and design-for-manufacturing criteria that take into account possible useful applications of by-products and wastes.

The goals of the CE highlighted in the report that are relevant to physical product design, manufacture and use can be summarised as follows:

- Improve the easy of reuse and recovery of materials
- Reduce materials supply risks
- Match the durability requirements of the product to the durability of the design
- Shift to renewable energy sources
- Build in modularity
- Think in systems rather than specific physical products

It was with these goals in mind that the teardown and assessment of the 2 BT products was undertaken. The aim was to identify design characteristics (possibly common to both products) that either aid or hinder the achievement of the goals. Once the characteristics had been identified and explained, solutions to the possible issues were developed and proposed.

Although the products are from different market sectors and fulfil dissimilar functions, their physical characteristics are very similar. They are also similar to many other electrical and electronics products on the market. Therefore the issues identified and solutions proposed in this report should be applicable to a much wider range of products than the specific telephones and baby monitor assessed in this work.

[1] Towards the Circular Economy Reports 1 and 2. Ellen MacArthur Foundation 2013

Product Assessment Methodology

There are many ways in which to assess the overall life cycle environmental impacts of a product. The most well-known is Life Cycle Assessment (LCA). LCA is a technique used to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Undertaking a full and scientifically rigorous LCA is very time consuming and expensive. The main stages are:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

A full LCA requires the collection of specific data related to the exact materials and manufacturing practices used and the results of such studies are usually complex and for non-experts, difficult to understand.

There is a much more practical method of undertaking assessments known as an abridged LCA. These types of studies us the same principles of full LCA in that they consider the whole life cycle of a product but they use secondary data (from published datasets) and usually consider a limited number of impacts such as Carbon and energy footprints.

The two BT products assessed in this work were done so using an abridged LCA technique through the use of the Eco Audit function of the Cambridge Engineering Selector (CES) software[2]. These assessments require the input of a bill of materials for the product in question and the definition of generic processing routes as well as information relating to energy consumption during use and likely disposal routes at end of life. The assessment also takes into account the impacts of shipping the finished item at end of life.

As well as the use of software to assess the overall carbon and energy impacts of the products in question a design review in respect of CE principles was also undertaken. This involved the physical teardown and examination of the product to identify areas of concern / good practice.

Physical Teardown and Assessment

Detailed bills of materials containing list of materials, components and weights were not available for the products being assessed. Therefore each product was physically disassembled. This allowed the identification of material types, the measurement of their weights and the assessment of processing routes used. The teardown included the packaging as well as the product itself.

Each product was broken down into its constituent parts. Each part was weighed, materials identified and, where possible, the processing routes identified. Where components or materials were joined together they were separated if possible. Where multi-material components were impossible to separate estimates were made in regard if the weights of the different constituent materials.

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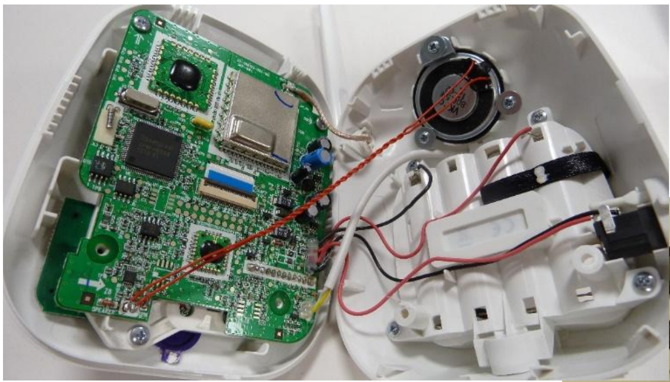
[2] http://www.grantadesign.com/products/ces

As well as assessing quantifiable parameters the products were considered in respect of use of recycled content, ease of recyclability and design features that affect the CE principles.

Many of the design features exist as they fulfil a functional and / or aesthetic requirement. When the assessment was undertaken these issues were taken into account and considered when alternative solutions were proposed.

The physical teardown gives and invaluable insight into the design, form and function of a product. The process of disassembly shows how easy materials and components are to separate, highlights issues relating to materials, processes, design and the implications these have on durability, use patterns and end of life options.



Use of CES Software

The quantitative information gained form the physical teardown stage was used to undertake a whole-life impact assessment using Granta CES Software. This software uses a database of materials properties (which included environmental measures such as Energy and CO_2e) to generate a whole life cycle impact and communicate how each life cycle stage contributes to this.

For each of the products the bill of materials was entered and estimates of energy consumption during use were also added. Both products are manufactured in China so the transport of the products to the UK by sea freight was included in the assessment. Finally, the expected end of life scenario for the products was described in CES. As these products are small electrical item which come under the requirements of the WEEE Directive it is anticipated that they would be returned or collected for recovery and recycling. In the majority of cases these types of products are shredded and material recover is undertaken where possible. For the assessment an end of life scenario of ‘downcycling’ was specific for the majority of materials in both products as it is very unlikely that they would go through a closed loop recycling process and the materials be re-used in similar products.

The expected life of both products was set at 5 years. The assumptions made in respect of energy consumption for each product are shown in detail in Appendix 1 and Appendix 2.

The results were exported into MS Excel to allow manipulation of the figures and presentation in a pie-chart format.

The full assessment for the 6500 DECT telephones and the Digital Baby Monitor can be seen in Appendix 1b and 2b respectively. A summary of the overall life cycle impacts of each product is shown in figures 1 and 2 below.

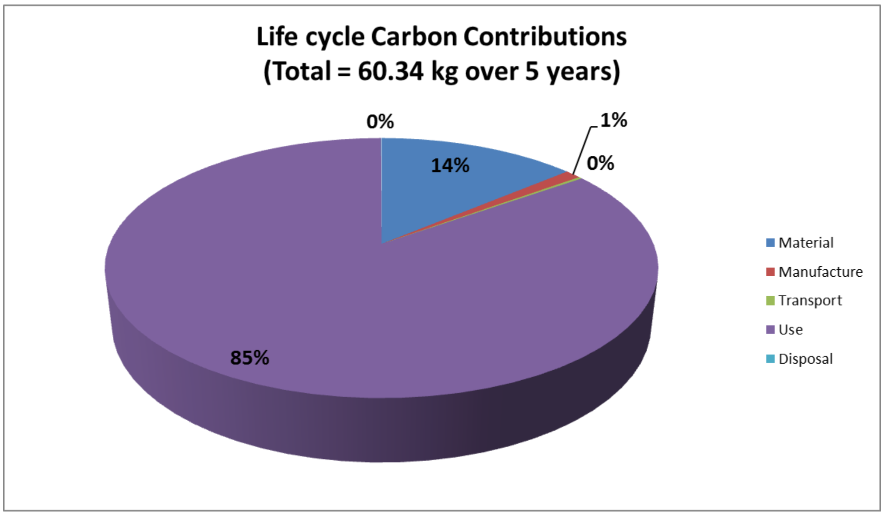


Figure 1 - Life cycle CO_2e impact of BT 6500 DECT Telephone

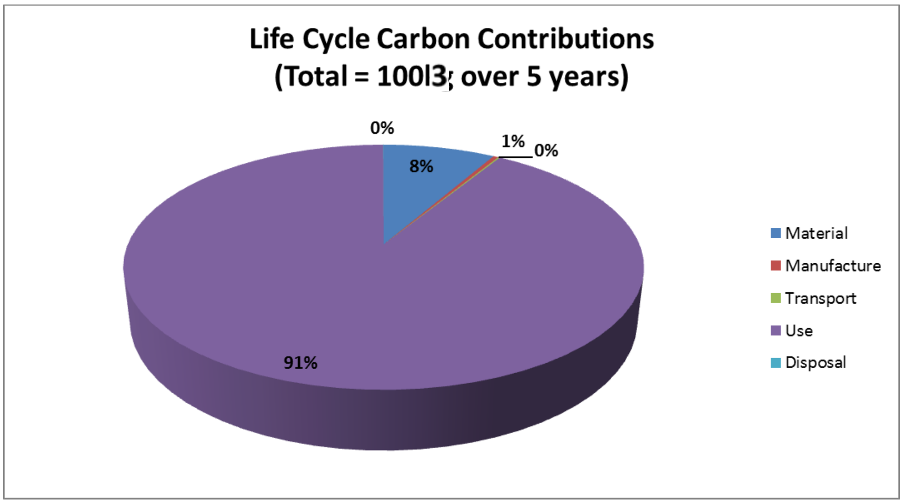


Figure 2 - Life cycle CO_2e impact of BT Digital Video Baby Monitor 1000

As well as the overall CO_2e for the 5 year product life other key KPIs were also measured (show in Table 1). These include total material intensity and energy use as well as estimated of the current level of recycled materials content (all figures include product and packaging).

	Total Materials Intensity (kg)	Total Recycled Content (%)	Total materials easily recycled (%)	Overall energy use (kWh)	Overall Life Cycle CO_2e
BT 6500	0.690	22	57	57	60.3

Baby Monitor	**0.680**	**10**	**27**	**175**	**103**

Table 1 - Product Life Cycle KPIs

Analysis of results and identification of issues

Although the 2 products serve a different purpose and are aimed at different segments of the market they are very similar in many ways. Both basically consist of plastic casings which contain a range of electronics (PCBs, batteries etc.) and LCD screens. The components are of difference sizes but in essence they are the same things. They also both contain similar type power supplies and each has a keyboard/keypad.

For both products the largest contributor to CO_2e impact is the use phase (over 5 years). Over 80% in the case of the Phone and over 90% for the baby monitor. If this study was purely focusing on reducing CO_2e then the use phase would be the focus for improvements as it offers the biggest scope for reductions.

From the CES EcoAudit assessment it can also be seen that over the 5 years both products embody a similar amount of materials. The carbon footprint of the Baby Monitor is higher overall mainly due to the estimated energy use being higher.

In both cases the overall recycled content of the current materials used (% by weight) is low. The plastics contain no recycled content (as far as can be established) and the metals have been allocated the average recycled content that is in current supply chains. The majority of the recycled material content in both products is in the cardboard of the packaging materials.

Only approximately 1/3 of the weight of the materials used in these products can be easily recycled (closed loop). This comes mainly from the materials used in the packaging and any metallic content of the products. A larger proportion could be 'downcycled' but this is not a key aim of the circular economy. It is much better to recover materials in a closed loop system and to be able to extract value from waste products.

From the assessment undertaken of the 2 products a set of common issues related to material use and products design can be drawn out.

Common Issues in respect of the Circular Economy

Improving the ease of reuse and recovery of materials and using recycled materials

Issues Identified

The products use a number of components which are manufactured from different materials. Some are bonded together and are not compatible for recycling. This means that the recovery of the materials at end of life becomes very difficult is not impossible.

Practices observed included; bonding foam to plastic components, bonding electronic components to plastic casings, bonding different types of plastics together, coating screws with sealant. The key pads used in the products are particularly complex and would be all but impossible to recover high grade materials for closed-loop recycling from them.

Coatings (paint) are used to add specific colours to polymer mouldings. The use of paint does not affect the recyclability of polymers. Soft touch surfaces and co-moulded inserts should be avoided where possible as this make material recycling almost impossible.

The use of recycled plastic materials in consumer electronics is not common. Apart from a small number of PCs and similar products there are very few that utilize any recycled content. In many cases this is down to the aesthetic requirements of the design. The use of light colours (such as the white plastic used in the Baby Monitor) and high gloss finishes mean that the inclusion of recycled materials has not been possible.

Possible Design Solutions

- Use either single materials or compatible materials – reducing the number of types of materials used in a particular product will make recycling and recovery easier as less separation is required.
- Eliminate the use of permanent joining techniques for incompatible materials. Reduce the use of glues, ultrasonic and heat joining techniques if materials are not compatible. Do not glue speakers into casings, do not glue foam to plastic casings.
- Use darker colours in polymer mouldings – it is much easier to introduce recycled content into darker coloured plastics. This can then be painted over to achieve the required colour and / or gloss finish.
- If the surface finish and colour has to be of a certain type that can only be achieved through the use of virgin polymers consider the use of 'layered' mouldings. The main core of the moulding can be made from recycled materials and it can be skinned with virgin material of the required colour and finish. The approach has been used in many sectors from packaging to automotive.
- Use 'removable' skinning technologies to colour and texture plastics. These could range from stretch material covers to heat shrink coatings that can be removed at end of life.
- Texture moulded surfaces – a high gloss finish is very difficult to achieve with recycled plastics. Texturing the surface of moulding addresses many of the issues apparent in the colouring and surface finish of plastics with high recycled content.
- Utilise alternative technologies – by using different technologies to perform certain functions some of the issues of materials recovery can be addresses. For example using a touch screen in place of a physical keypad (bonding together a range of materials in this case) will eliminate the issues of recycling the multi-material keypad. As LCD screens are used in the products this option is not introducing new materials or components.
- Investigate the use of new 'recyclable' printed circuit board technologies – new developments and research in the materials and design of PCBs. One example is the printed circuit board that falls apart when immersed in hot water developed by the National Physical Laboratory (NPL)[3]. The board itself is composed of "unzippable polymeric layers." While

[3] http://www.npl.co.uk/news/recyclable-printed-circuit-boards

these layers are able to withstand prolonged thermal cycling and damp heat stressing, they separate from one another when exposed to hot water. The conventional components mounted on the boards – such as resistors, capacitors and integrated circuits – can then simply be scraped off, fully intact and ready for reuse. Additionally, the material can be used not only for flat, rigid boards, but also for flexible electronics and three-dimensional structures.

Reducing Materials Supply Risks

Issues Identified

As with most consumer electronic products, the products assessed in this work consist of plastic moldings and electronic components. The use of these materials brings with it a number of possible supply chain risks.

The use of oil based polymers means the risks over ever-rising prices as the supply of oil becomes more constrained.

A number of 'rare earth' metals are used in the manufacture of electronics. Antimony is used in LCD screens, and lithium in batteries. Supply of these materials may become restricted in the future due to their scarcity and their increased use in products. Also many materials used in electronics such as Tin (solder) and Tantalum (capacitors) can be sourced from areas of conflict. The supply of these materials could be affected by political events and is becoming an issue for larger companies in respect of CSR reporting in countries such as the USA (Dodd Frank Conflict minerals)[4].

There is growing concern over the toxicity and environmental impact of some of the materials used in printed circuit boards and solders. The move away from leaded solder towards lead-free alternatives has meant an increase in the use of materials such as silver and also the use of rare earth alloying elements such as indium. The toxicity of silver is now being highlighted as a possible issue in the use of such solders. There is also considerable concern building over the use of brominated flame retardants that are the norm in FR$ board as used in both the Dect phones and the baby monitor. It is not inconceivable that these materials may be restricted of completely banned in the future.

Possible Design Solutions

- Investigate the use of plant-based polymers - In the past most plant based polymers have been sugar or starch derived and have not had the chemical and mechanical properties required to be able to de used in durable consumer products. However recent developments in polymer technologies mean that plastics that are chemical and mechanically identical to petroleum-based materials can be derived from plant materials. The plants are used as a renewable source of carbon and hydrogen which is isolated and used to make monomer molecules. The molecules are then polymerised. This is an emerging technology but one that should be watched closely.

[4] http://www.sec.gov/spotlight/dodd-frank/speccorpdisclosure.shtml

- Recycled materials – one way of ensuring the continued supply of non-renewable and scarce materials is to recover your own product and extract the materials for use in mew products. By following the proposed design solutions relating to increasing recyclability and instigating a product collection / return system, companies can help to secure a supply of known quality materials into the future.
- Utilise new electronics manufacturing technologies – as well as the recyclable circuit board technology discussed in the previous section there are other technologies that can help reduce reliance on conflict minerals such as Tin. The most notable of which is the use of conductive inks. Conductive inks can be a more economical way to lay down conductive traces when compared to traditional industrial standards such as etching copper from copper plated substrates to form the same conductive traces on relevant substrates, as printing is a purely additive process producing little to no waste streams which then have to be recovered or treated. This developing technology could ultimately be used to deliver much simpler and less polluting boards that use much less tin and silver and could be easier to recover at end of life.

Matching the durability requirements of the product to the durability of the design

Issues Identified

There are no apparent issues in relation to durability of the design of the products assessed. However consideration does need to be given to issues such as:

1. Real use patterns of the product
2. Longevity (consumer expectations and technological lifespan)
3. Update and repair the product (costs, expected life etc.)

If these issues are considered the products should be 'appropriate' in terms of durability and expected life. It is possible to 'overdesign' products and make them more robust and more material intensive than they actually need to be. There may be a case to answer in respect of this in some parts / components / modules of the products assessed.

Possible Design Solutions

- Try and gain as much information as possible on the actual 'real-life' use patterns of the product. Design according to the requirements of these. There may be an opportunity to remove materials from products as they do not need to be as robust as first thought.
- Consider the durability versus the life of the technology and maturity of the market. If a product is in a sector where fast technological change is happening is it appropriate to make it to last 10 years when it's likely useful life might only be 2-3 years? Also consider if the product is a system in its own right or if it is part of another system that might change over time.
- Design for repair and upgradability may be appropriate form products with a long useful life but for those with relatively short lives this may not be the case.

Shifting to renewable energy sources

Issues Identified

Although the products use relatively small amounts of energy on an hourly basis. The use patterns required almost constantly power use of some degree. This means that the overall energy requirement across the whole life of the products is by far the largest impact. No renewable energy is used in the products in their current format.

The use of renewable energy may cause some challenges in that both products require a feed of power constantly (both day and night) and therefore continuity of power supply is very important.

Possible Design Solutions

- Use of solar technology to charge batteries with the inclusion of smart switching to mains power when batteries run low. During daylight hours or when lighting is on in the house the units could trickle charge their own batteries. If the current drops below a preset value the unit could automatically switch back to the mains power. In this way overall reliance on mains power could be reduced whilst still maintaining the continuity of power supply needed.
- Other renewable energy sources could be utlised, such as wind-up chargers etc. However it is unlikely that these would be accepted by mainstream consumers in this type of product.
- Self-charging batteries are beginning to come to market. These are small power cells (which can be the same size as standard batteries such as AA cells) that charge when the device in which they are placed is moved. Technology in the cell converts the movement to a charging current. There is a possibility of use for the telephones as they are in motion when in use. Otherwise the user can physically shale the unit to charge it up.
- Miniature fuel cells have been used to power small electrical devices and it is an area that is benefiting from research and development at the current time. Into the future it may become a viable way to provide cleaner energy for consumer electronics.

Building in modularity

Issues Identified

Modularity can help extend a product's life, reduce repair costs and allow for easy upgrading. The effectiveness and appropriateness of this approach will depend on a number of factors such as:

1. Expected life of the product – is modularity a sensible approach for short life products?
2. Advantages offered by modularity

One of the products (the telephone) already demonstrates the use of some modularity principles. The handsets are interchangeable and there are some common parts used in the bases. The ability to replace just a handset (should one fail) would be a move towards are more circular approach. Currently if a user needs a new handset it can only be purchased together with a new base unit. Supplying just a handset, if that is all that is required, would reduce the material burden.

Possible Design Solutions

- Design the product from the viewpoint of allowing sub-assemblies and components to be replaced. Allow easy removal and replacement of parts that are likely to be the 'weak point' in terms of reliability.
- Provide a backup of spare parts at reasonable prices so that repair is a financially viable option. Sell replacement parts rather than whole products. For example, supply single handsets, charger units or separate camera / receiver units.
- Design out redundancy. Allow the insertion of new components / modules and the upgrading of aesthetic parts to keep the product in use for longer.

Thinking in systems rather than specific physical products

Issues Identified

Both the products considered in this assessment are sold as 'standalone' systems. This means that each system has an amount of embodied materials and energy and a range of other impacts link to manufacturing and transportation of the physical product.

Modern technology and advances in computing, communications technology and home networking mean that in many cases the functions traditionally supplied by a range of standalone products can now be supplied by an integrated system.

The functions performed by both the products could be integrated into current and future IT and communication network systems. They could be incorporated into mobile phone networks, wireless LANs and integrated with existing hardware such as smartphones, laptops, tablets and smart TVs. This could considerably reduce overall resource use for the delivery of a range of the functions.

As an indicator of the type of savings that might be achievable through integration of products into existing systems a further assessment of a digital wireless camera was undertaken as part of this work. This can be seen in Appendix 3. The unit in question (a Y-cam Knight S Camera) was assessed in exactly the same way as the BT products using a physical teardown and analysis with CES Eco Audit software.

This camera could be integrated into an existing system of wireless LAN and smartphone/tablet/laptop in place of the baby monitor. The camera would be placed in the room to be monitored and the pictures and sound relayed over the LAN to a phone/tablet/laptop thus removing the need for the bespoke receiver unit.

The full analysis is shown in Appendix 3. A summary of the total lifecycle CO_2e and other KPIs is shown in Figure 3 and Table 2.

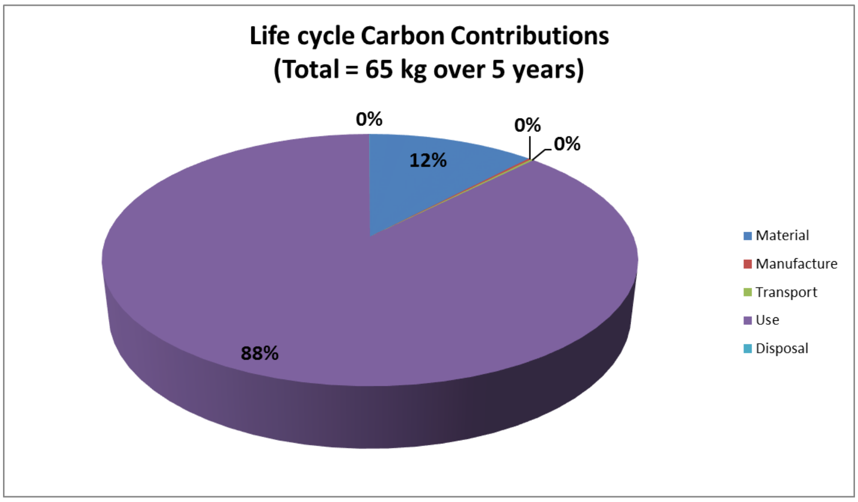


Figure 3 - Life cycle CO_2e impact of Y-Cam Knight S Wireless Camera[5]

	Total Materials Intensity (kg)	Total Recycled Content (%)	Total materials easily recycled (%)	Overall energy use (kWh)	Overall Life Cycle CO_2e
Baby Monitor	0.680	10	27	175	100
Y-cam	0.570[6]	27	39	110	65.89
Potential savings	16% reduction	17% increase	12% increase	37%	34%

Table 2 – Comparison of Product Life Cycle KPIs of standalone product versus product integration into existing systems.

By integrating a unit into an existing system to provide the same functionality as a standalone baby monitor considerable savings can be made in terms of materials and energy consumption to deliver the function. All the main CE aims are positively addressed. Less material is used, less energy is consumed and the resulting 'waste' at end of life is also less. If the design principles discussed earlier in respect of recovery and recycling of material are implemented in such units those materials will also be easier to recover for use in other products.

Summary and Conclusions

For many years companies have adopted a linear model in the approach to the design, manufacture, use and disposal of products. Various pieces of legislation from the EU (and more recently other

[5] Energy use of the 'system' into which the Y-cam is integrated is not included as the addition of the Y-cam into the system would not result in extra energy use by that system.

[6] The y-cam as assessed included a very large heavy steel wall bracket that was not necessary in this comparison. It was therefore not included in the calculation of these KPIs – it is included in the full assessment in Appendix 3.

areas of the world) have led to the restriction of the use of certain materials and a legal requirement to collect and recycle certain types of products; most notably vehicles and electrical and electronic equipment. Although this has some effect on product design practices we are still a long way from considering the full life cycle impacts of products at the design stage and addressing them though considered design decisions.

If we are to move towards a truly circular approach to product manufacture, it requires a new way of undertaking product design. This move is not as complex or challenging as it may first appear. The main aims of a circular economy are clearly defined and the benefits they bring are clear from both and environmental and cost perspective.

This report has taken 2 mainstream products from BT's range and assessed them in a way that highlights issues in relation to the circular economy. It has also shown that many of these issues can be relatively easily address through some lateral thinking at the design stage and the application of a number of simple practical design rules. These rules relate to material choices, manufacturing practices and supply chain concerns as well as in-use impacts and the eventual end-of-life of products.

The continual development of new technologies affords a number of opportunities to move towards a more circular economy. The use of these technologies can reduce the impact of products, ensure materials are easier to recover and ultimately reduce the overall resource burden required to deliver the functions and services provided by the products we buy, use and dispose of.

Product design is a key part of the circular economy and if undertaken in the correct manner it can contribute considerably to the overall reduction of resource use in modern society.

See Appendices:

Appendix 1a – BT 6500 DECT Telephone Circular Economy Product Design Assessment

Appendix 1b – BT 6500 DECT Telephone CES EcoAudit Assessment

Appendix 2a – BT Digital Video Baby Monitor 1000 Circular Economy Product Design Assessment

Appendix 2a – BT Digital Video Baby Monitor 1000 CES EcoAudit Assessment

Appendix 3a - Y-cam Knight S Camera Circular Economy Product Design Assessment

Appendix 3b - Y-cam Knight S Camera CES EcoAudit Assessment

MATERIALS at RISK

Materials at risk have been referred to specifically in the context of the three product analyses, it is clear that rare earth and conflict mineral issues are very much the concern of the larger global economies.

For companies such as BT it is very much a case of monitoring the situation typically through IAMGOLD style reports and British Geological Survey findings (see appendix 4).

Clearly it is in the interest of all in the supply chains to mitigate against the use of these at risk materials and to continually research into alternatives. Typically it will be for companies such as BT to prompt and support their suppliers and manufacturers to this end.

Perhaps more importantly it will be for companies such as BT to collaborate with their competitors to provide greater resource in these research efforts with the supplier base.

With regard to a method of ranking the associated risk, a suggestion would be to build links to the latest risk lists in the proposed online design tool 'Designing our Tomorrow (DoT) toolkit; the collaboration between the University of Cambridge, BT Group and BT Technology, Service & Operations.

Within the 'Understand it' section in the 'Performance Indicators' subsection of this tool there is a link to a report of the type mentioned above.

http://www.designingourtomorrow.com/business/UND_outcome_measures/critical_materials_for_the_EU.pdf

This is indeed a detailed 80 page report, but it is over 3 years old, it does discuss 'critical materials' but there is no mention of 'conflict minerals'; indeed if the term Conflict Minerals is used in the search facility for the DoT site, it does not come up at all.

Ideally at risk and conflict minerals should be explained in a tool kit of this type, it should identify these elements and where they are commonly used, help in undertaking a risk assessment and aid in identifying alternatives.

Recent research on UK Product design consultancy industry has also highlighted the need for tools to be simple and very accessible; expecting a busy designer to link to and read through an 80 page report is unlikely to yield a positive result.

Also see product evaluations summary – reducing materials supply risk, page 15

MATERIALS ANALYSIS

Next to internal components/assemblies, product casework parts generally constitute the majority of product content; therefore any improvement to the End of Life (EOL) 'credentials' of these items would represent worthwhile improvement on the 'circular' impact of any product.

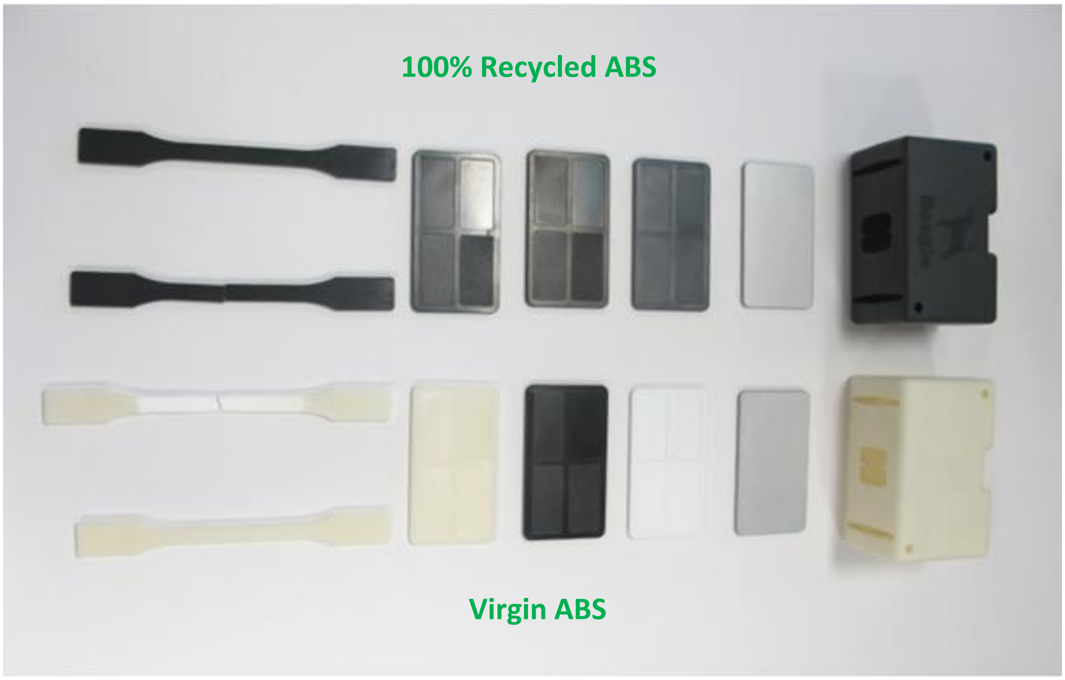
As such, to be in a position to use % 100 recycled materials would be highly desirable in this context; understanding the limits in the using such material is therefore essential.

This aspect of the research has therefore been based largely on undertaking a direct comparative analysis between non recycled (virgin) and 100% recycled ABS (the injection moulding polymer used predominantly for product caseworks being considered in this market sector under evaluation). Criteria being investigated were finish (surface texture), ability to colour (paint, print, etc.) and strength.

Materials under specific consideration were Tairilac AG 15A1 (by Formosa Chemicals) – virgin ABS (appendix 5) and 4124 100% recycled ABS from MBA Polymers (appendix 6).

Test parts (plaques) for finish and stress testing were not available for these materials so an injection moulding tool was commissioned to produce required test plaques to observe differences in surface finish (from gloss to coarse texture) and test strips to undertake stress/elongation testing (on industry standard test equipment).

Test parts were then produced on manufacturing quality injection moulding machines (see appendix 7 for set-up data).



Group of test samples

Finish

From the test plaques (with 3% black 'master batch' colouring added) it can be seen that with a glossy surface finish contaminants (inclusions) in the 100% recycled ABS can be seen with the naked eye, however once a texture is applied these inclusions are not noticeable.

Texture samples with 3% black master batch added

A recommendation when using 100% recycled material is not to design products with a gloss surface finish.

Colour

Colouring 100% recycled ABS does appear to present a problem. White master batch was used to produce samples in both virgin and 100% recycled grades.

With 4% white master batch added, the 100% recycled material could only achieve a mid grey at best.

Adding white master batch to test plaques

A similar result would almost certainly be achieved with the master batching of colours when added to the 100% recycled material, producing grey toned reds, greens, blues etc.

An evaluation was also undertaken of basic paint finish adhesion, in this case simply silver, cellulose based, spray applied paint (just clean parts, no primer preparation). There did not appear to be any obvious difference between the two materials in terms of finish and wear characteristics (although this was not done over time to any industry standard).

Cellulose based, silver spray paint applied to both materials

In summary it would appear that 100% recycled ABS is problematic to colour using the industry standard master batch colouring process, but that (subject to further evaluation) it can 'accept' a paint finish to a similar standard as virgin ABS.

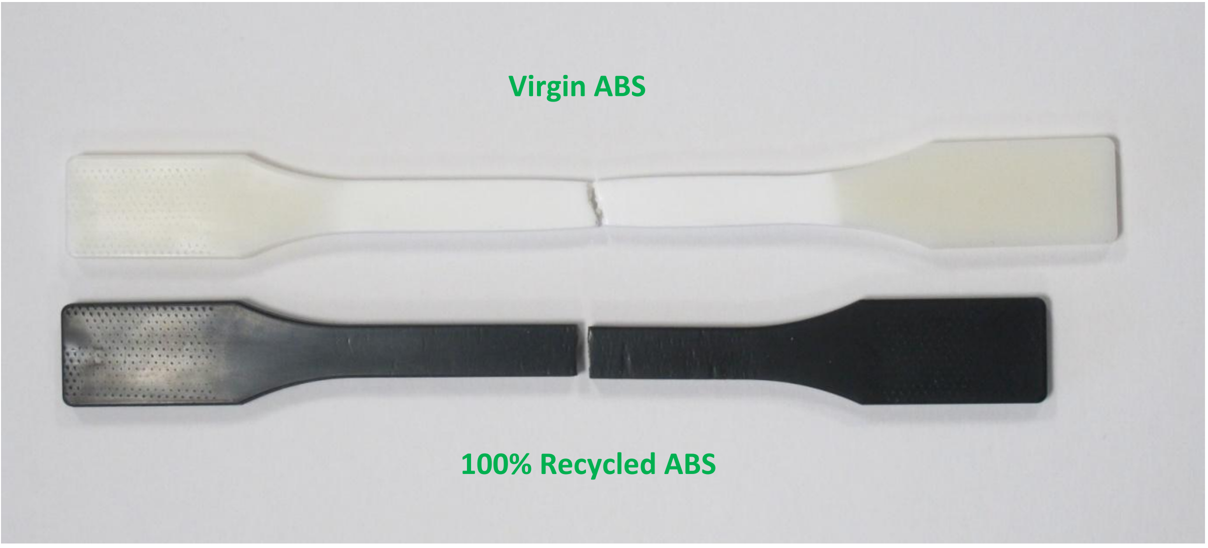
It is therefore recommended that the 100% recycled material (without colouring) be used for black or dark to mid grey products only, or is finished (post process) using an appropriate paint surface treatment (or similar).

It should be noted however that paint finishing is an additional process (therefore adding cost) and adds 'contamination' (in effect) to the substrate material (a negative for further recycling). It should also be noted many paint finishing processes (including water based acrylics), emit volatile elements into the atmosphere and without adequate processing are a pollutant.

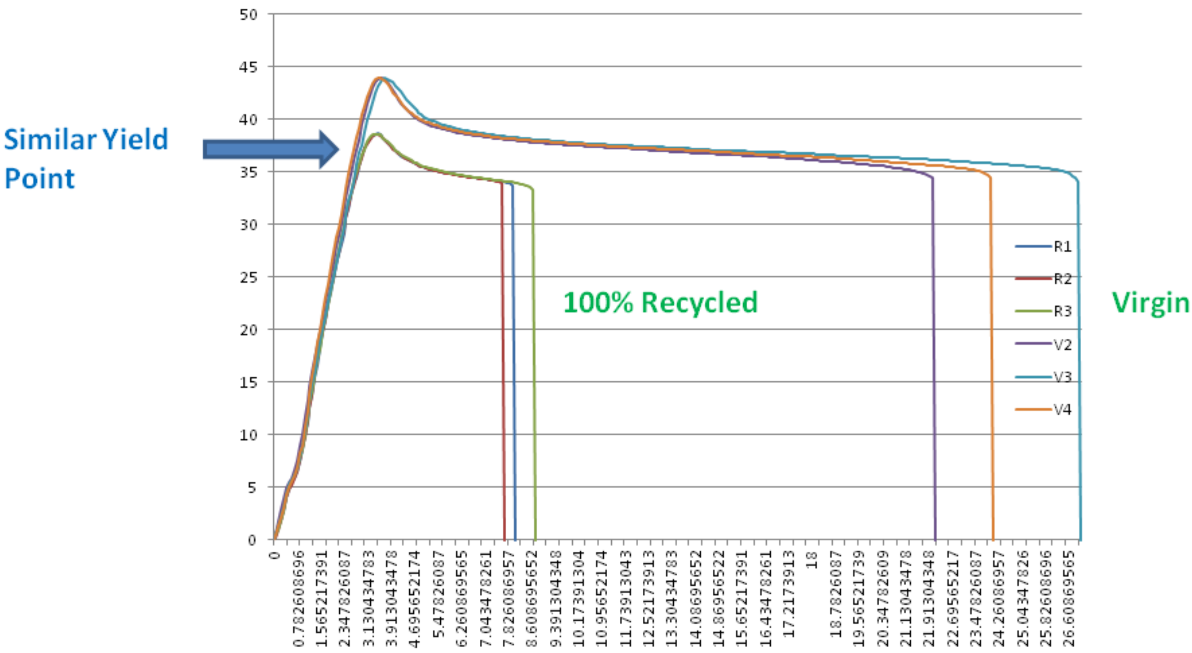
Strength – Tested

Standard stress to elongation evaluations were undertaken on a number of test strips (see appendix 8 for full stress/strain elongation results).

Results indicated that both materials had similar yield points but that the 100% recycled ABS was stiffer, failing after considerably less extension than the virgin ABS.



Elongation to break evaluation

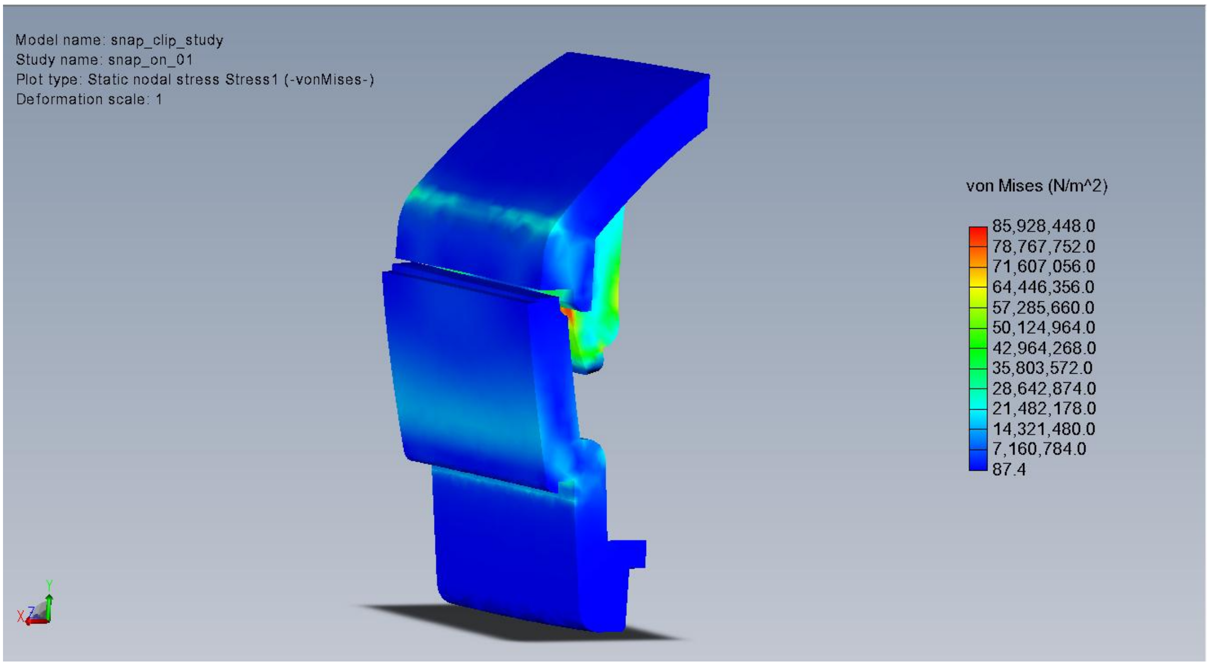


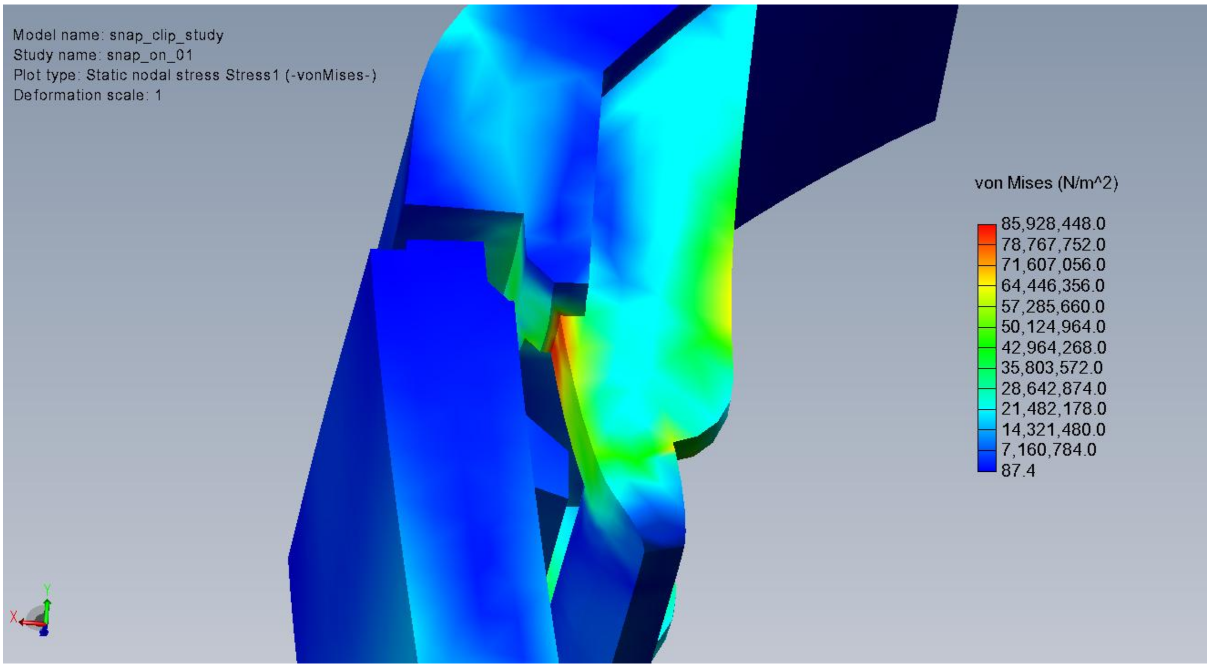
Stress to elongation showing similar yield points but differing elongation to break characteristics

Strength Finite - Element Analysis

The above results are encouraging, as the two materials have similar yield points; it will just be a requirement to ‘work around’ the stiffer nature of the 100% recycled material, typically with clip fittings and similar assembly features.

Using the data obtained from the stress/strain to elongation measurements, finite element analysis was undertaken to evaluate the stress on the clip design (to hold body halves together) of the DECT 6500 handset, this did indicate a stress concentration (red element) at the root of the clip half.





Stress/strain in DECT 6500 handset clip

However this red element does not occur right the way through the feature. Although not ideal, this is not be a major cause for concern.

In terms of design, due to the stiffer nature of the 100% recycled ABS, it would be prudent to avoid clip features subject to significant stress, or at least to use design features (predominantly root radii) that minimise/avoid stress raisers.

In addition when subject to loads beyond its yield point, %100 recycled ABS will fail far more abruptly than virgin ABS. It would therefore be wise to design products to be manufactured in 100% ABS, to withstand higher impact, or to utilise an assembly method that could compensate for this failure characteristic.

Also see product evaluations summary – common issues, page 13

RELATED TECHNOLOGIES and FACTORS

To complement the detailed investigation of the virgin and 100% recycled ABS, a brief study was also undertaken on various aspects of complementary areas such as:

- Touch keys
- Printed circuit technology
- Displays
- Shrink wrapping
- Recycled polymers
- Packaging
- Modularity
- Systems
- Energy

Capacitive Touch Keys

As highlighted in the product analyses, current keypad construction is often complex, being manifest as a number of layers often bonded together or attached in such a way so as to make for significant difficulty in disassembly.

Capacitive touch technology has improved at a pace in recent years and as such should be considered as a cost effective alternative to the current, more complicated keypad systems (see appendix 9 for full information). As they can be incorporated on the main product printed circuit board (PCB) they don't necessitate a layered construction and therefore, inherently, de construction.

Current use of capacitive touch technology in automotive applications

A downside of this technology is the lack of tactile feedback through the touch (this is however being perused by developers, but not to a useable end result at present). However end users are now very used to the capacitive touch of smart phones, the lack of tactile feedback here has done little to halt the uptake of these devices.

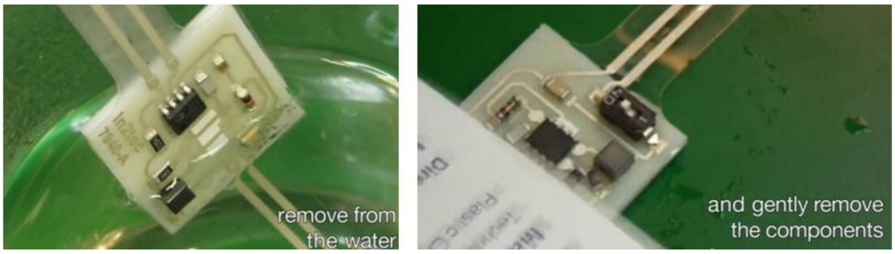
Capacitive touch with other forms of subtle use of tactile feedback (visual display change, sound, vibration), should be considered as a credible alternative to mechanically complex, difficult to assemble, mechanical keypads.

Printed Circuit Technology

A significant road block in the ability to fully re cycle and re use products is the PCB, not only do they use significant amounts of at risk materials but via their construction, they 'lock up' these elements for easy future use. Current methods for recycling PCB's are expensive, energy hungry and generate harmful waste in processing.

This area is a typical example of where new product developers should collaborate with their competitors to force and fund research for change.

A typical example would be The National Physical Laboratory (NPL), along with partners In2Tec Ltd (UK) and Gwent Electronic Materials Ltd, who have developed a PCB whose components can be easily separated by immersion in hot water.
http://www.zeitnews.org/natural-sciences/materials-science/recyclable-electronics-just-add-hot-water

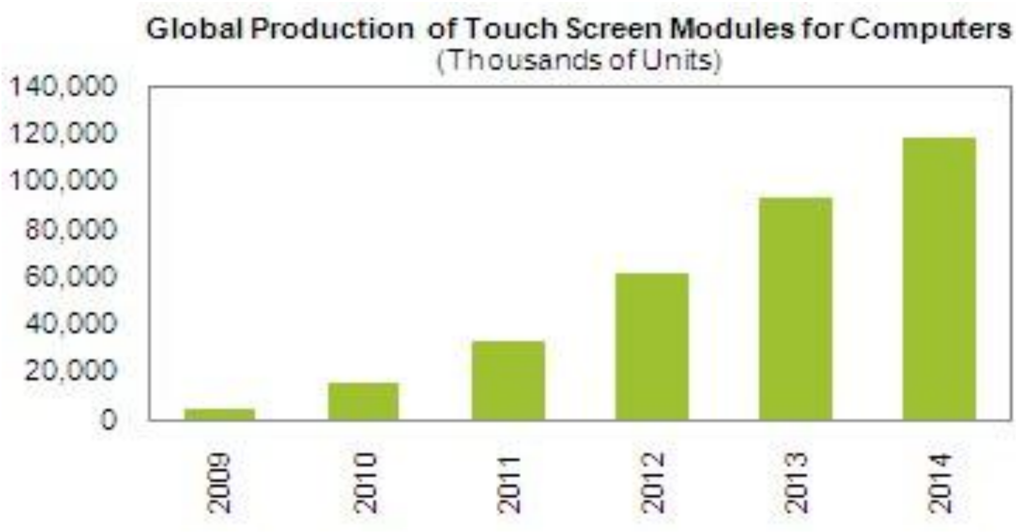


PCB dissolvable in warm water

Also see product evaluations summary – common issues page 13

Visual Displays

As the chart below illustrates there has been a rapid increase in the uptake of touch screens and visual displays for technology related products in recent years.



But the adoption of this technology for products such as DECT phones is still limited by cost.

Whereas a comprehensive, reasonably sized touch screen maybe appropriate for a £300 smart device, it would not be cost effective for a £50 DECT phone.

For example the capacitive touch display on the right is currently 40% more expensive than the high quality TFT display on the left. Small capacitive touch displays are not readily available at present and are not available in sizes less than 3.5’’.

However this situation is likely to rapidly change and should be monitored, though whether this technology will become economically viable within the lifetime of DECT technology is debateable.

Shrink Wrapping

Given the problematic nature of colouring 100% recycled ABS and the need to consider alternative constructions to clipping, the notion of providing colour, graphic application, and assembly and disassembly benefits through the use of shrink film, is intriguing.

Heat shrink wrap

Normally associated with the graphic applications and tamper evidence sleeving on liquids packaging, this technology does have potential in more hi-technology applications.

Higher quality grades of material that can be produced in a range of foil thicknesses and in materials that are suitable for recycling are already available (see appendix 10).

This manufacturing technology would also be complementary to the capacitive touch key technology, where there are no articulating parts.

It is a recommendation of this research report that this technology be investigated further.

Use of Recycled Polymers – Supply/Demand

The development of polymers from recycled and waste materials is a rapidly growing industry (and quite rightly so) as is the development of polymers produced by synthesizing hydrocarbons from plant products.

But the area is becoming a minefield of confusion. There are those who would pioneer and champion the development of bio degradable polymers produced from plant starch (see appendix 11 - Lu, Xiao, Xu paper Mach 2009), Lu at al stated in 2009 that ’This means someday it is unnecessary to rely on petroleum’, four years later, there has been progress but these polymers are not available in large quantities an still do not possess the mechanical properties of conventionally produced polymers.

Starch based packaging (including foil wrap) for plant seeds

In a recent study into sustainability and the supply chain, one aspect of the study looked at alternatives to medium density fibre board (MDF) for the retail display industry in the East Midlands – UK. A number of alternatives were indeed identified but none were available in the quantities that this sector demanded and therefore the cost was not viable (see Ford, P. Radlovic, P. (2013) Design, Sustainability and the Supply Chain. *The International Journal of Sustainability Policy and Practice*. V8 :1 pp 233 -245).

It is therefore critical to monitor these supply and demand relationships to determine when availability and economic viability has been achieved.

In addition there are those companies who purport to be environmentally conscious but unwittingly get it wrong.

A classic example being with a leading manufacturer of clothing, who marketed a range of men's shirts made entirely from polyester produced from recycled PET drinks bottles. Demand was so great that the supply of used drinks bottles was insufficient to meet it. The manufacturer had to resort to obtaining bottles directly from the manufacturer that had never been used to ship drinks!!, hardly a sustainable situation.

Supply and demand

Another example is with Pepsi and Coke who are promoting drinks bottle made from plants, however if transpires (no pun intended) that this polymer is merely being synthesised from Bio Ethanol (resulting from plant waste fermentation). These synthesised polymers are therefore identical to conventionally produced polymers, offering no end of life benefits in terms of sustainability apart for an argument for carbon neutrality (see appendix 12).
http://www.greenpacks.org/2011/06/20/plant-based-bottles-by-pepsico-and-coke-are-plastic/

It would appear that a controlled loop for the recycling and re use of polymers at end of life has significant merit whatever the original source of that polymer. The Circular Economy approach to re use of polymers is therefore extremely valid in this context, but supply, demand and cost have to be carefully managed.

Also see product evaluations summary – reducing materials supply risk, page 13

Packaging

Packaging has to be considered as an integrated element of the product offering and the CE goals.

There are now a growing number of alternatives to the unsustainable use of expanded polystyrene, typically, various types of compostable card packaging made from recycled materials, to durable packaging which can have a secondary use, to new developing alternatives such as mycelium in for literally growing packaging solutions.

In all cases the will be a need to be smart in terms of designing pack and product combinations than can make for environmentally (heat, moisture etc.) resistant solutions.
Typically this will be needed given the growth in online sales and the design of product/pack combinations that (where possible) can fit a standard post box.

Unsustainable use of polystyrene packaging

Creative use of recycled card

Lateral use of recycled materials

Reusable packaging concept for BT

Mycelium based packaging solutions

Standard letterbox size

Modularity

As part of a co ordained approach to circular product/packaging combinations modularity could yield significant benefits in terms of economies of scale, component assembly and end of life disassembly.

In addition it would also facilitate future upgrading of product or the easy replacement of failed components providing products with a longer 'in use' life, a characteristic known to appeal to consumers of DECT products (BT Group research relating to **'Sustainability and Consumer Behaviour' research**), that is to design out redundancy.

Far from reducing product sales, this could enable a new form of product revenue with regard to upgrading, repair and maintenance.

Also see product evaluations summary – build in modularity, page 17

Also s ee section on design opportunities, page 35

Systems

Based on the product analysis there was only moderate environmental gain to be seen between the BT 1000 DECT baby monitor and Y-Cam Knight Wi-Fi home monitoring system, particularly when you take into consideration the need for a computer or Smart Phone required to work with the system.

The BT Group research relating to **'Sustainability and Consumer Behaviour' research'** has indicated that any systems orientated solution would have to be incredibly simple to install and operate. The Y-Cam Knight is not, in fact it was impossible to set it up to operate during this research exercise.

In addition the BT Group research relating to **'Sustainability and Consumer Behaviour'** research has also indicated only limited interest in rental or leasing, probably closely related to the fact that consumers will keep their DECT phone for 10 years or more.

However a system that does not appear as rental or leasing possibly linked to an upgradeable, modular approach to provide a quality system may have merit.

Also see product evaluations summary – thinking in systems, page 18

Energy

Based on the BT Group research relating to **'Sustainability and Consumer Behaviour'**, the use of solar power to charge batteries was of interest but only if the financial (energy) benefits are clear and worthwhile (which is likely to be problematic).

Smart switching to mains power when batteries are running low, the use of wind up charging proved to be of low customer acceptance in the study.

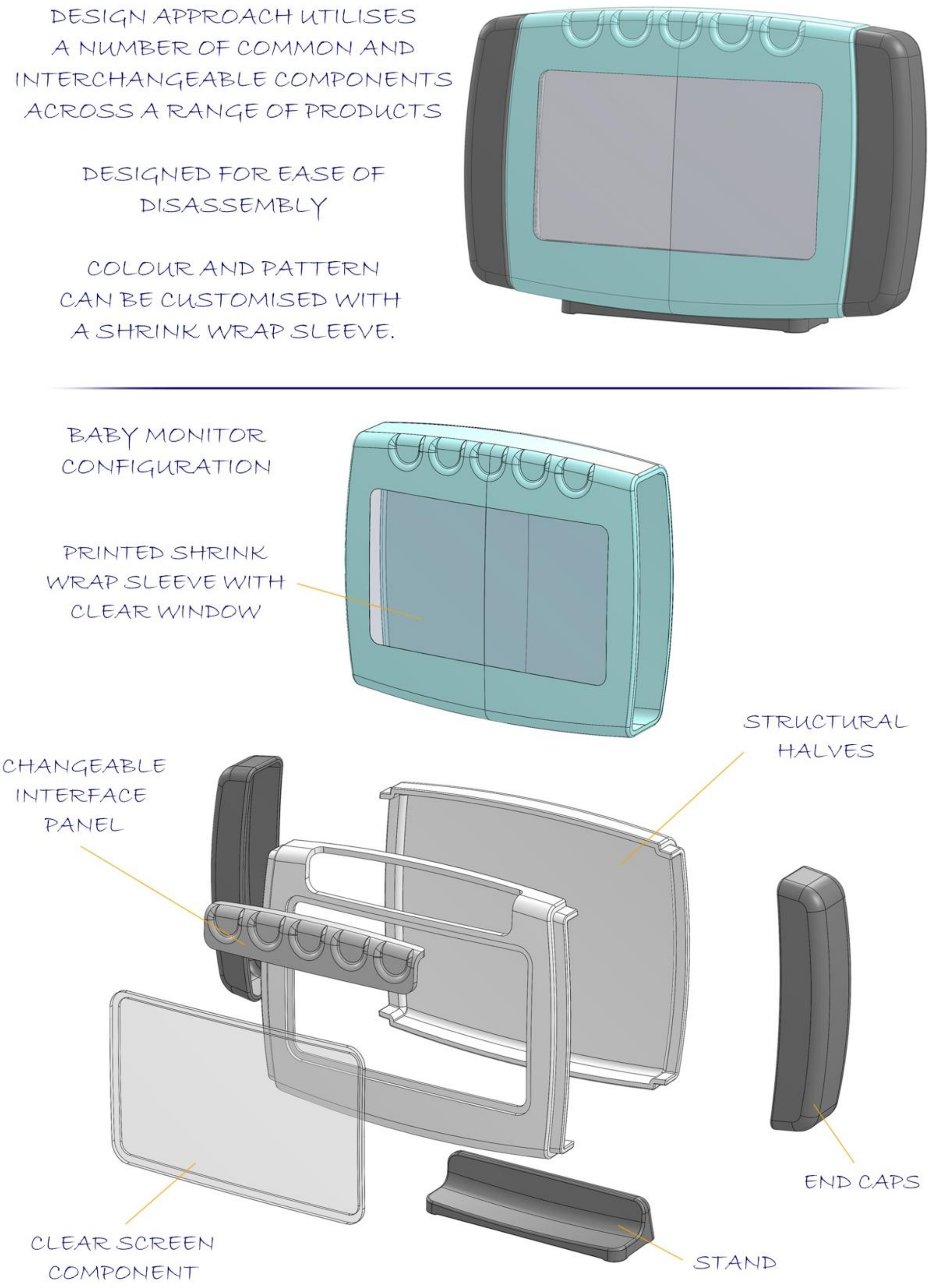
Self-charging batteries through movement and even the use of miniature fuel cells are both possibilities but neither are viable at this point in time.

Also see product evaluations summary – shifting to renewable energy, page 17

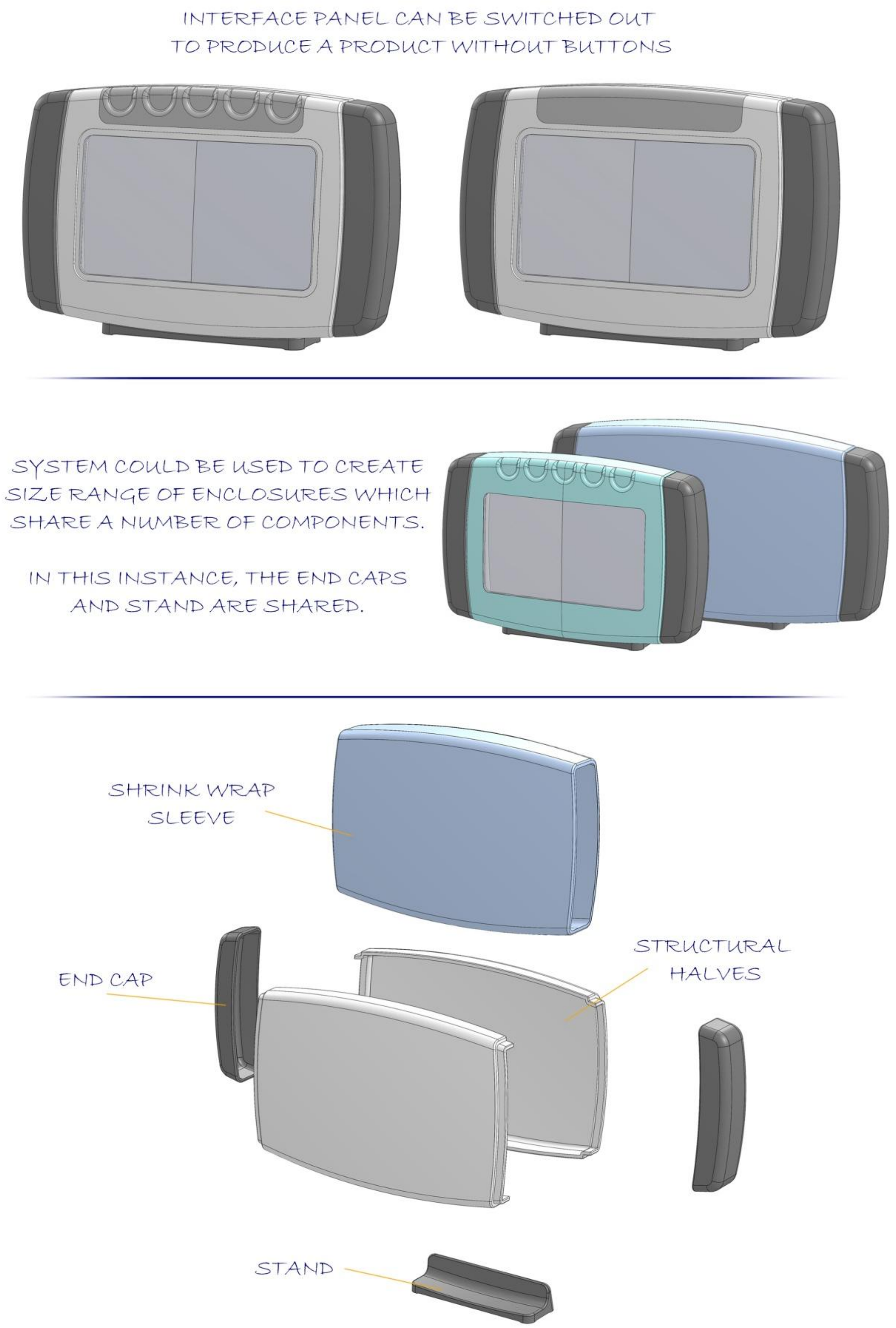
DESIGN OPPORTUNITIES

Modular Construction

Potential for modular construction approach:



Modular approach for smaller products (with shrink wrap construction)



Modular approach for larger products using commonality of parts (also based on shrink wrap construction)

The Use of Shrink – Foil Wrap

The following shrink wrap design options are based on a modified DECT 6500 design constructed in 100% recycled, charcoal grey, textured ABS with a shrink wrapped exterior providing colour options and graphics over a capacitive switch technology incorporated into the main PCB

White themed option

Black themed option

Multi (coloured) possibly customer specified graphics

Design Opportunities for Foil Wrapping:

- Ability to colour
- Ability to customise/personalise
- Opportunity to simplify assembly
- Opportunity to simplify disassembly
- Opportunity to improve drop protection
- Foil wrapping could work in conjunction with modular systems

FORWARD STRATEGY – RECOMMENDATIONS

The following summarises the findings and recommendations of this research and groups the findings in terms of what can be achieved now, what could be achieved subject to some design modification and what could be achieved longer with longer term collaboration.

These are as follows:

Can do Know

Construction:

- Use either single materials or compatible materials – reducing the number of types of materials used in a particular product will make recycling and recovery easier as less separation is required.
- Eliminate the use of permanent joining techniques for incompatible materials. Reduce the use of glues, ultrasonic and heat joining techniques if materials are not compatible. Do not glue speakers into casings, do not glue foam to plastic casings.

Near Application Based on Design Modifications

Using Recycled Polymers:

- Use darker colours in polymer mouldings – it is much easier to introduce recycled content into darker coloured plastics. This can then be painted over to achieve the required colour and / or gloss finish.
- If the surface finish and colour has to be of a certain type that can only be achieved through the use of virgin polymers consider the use of 'layered' mouldings. The main core of the moulding can be made from recycled materials and it can be skinned with virgin material of the required colour and finish. The approach has been used in many sectors from packaging to automotive.
- Use 'removable' skinning technologies to colour and texture plastics. These could range from stretch material covers to heat shrink coatings that can be removed at end of life.
- Texture moulded surfaces – a high gloss finish is very difficult to achieve with recycled plastics. Texturing the surface of a moulding addresses many of the issues apparent in the colouring and surface finish of plastics with high recycled content.

Alternative Technologies:

- Utilise alternative technologies – by using different technologies to perform certain functions some of the issues of materials recovery can be addresses. For example using a touch screen in place of a physical keypad (bonding together a range of materials in this case) will eliminate the issues of recycling the multi-material keypad. As LCD screens are used in the products this option is not introducing new materials or components.

Modularity:

- Design for repair and upgradability may be appropriate form products with a long useful life but for those with relatively short lives this may not be the case.
- Design the product from the viewpoint of allowing sub-assemblies and components to be replaced. Allow easy removal and replacement of parts that are likely to be the 'weak point' in terms of reliability.
- Provide a backup of spare parts at reasonable prices so that repair is a financially viable option. Sell replacement parts rather than whole products. For example, supply single handsets, charger units or separate camera / receiver units.
- Design out redundancy. Allow the insertion of new components / modules and the upgrading of aesthetic parts to keep the product in use for longer.

Energy:

- Use of solar technology to charge batteries with the inclusion of smart switching to mains power when batteries run low could be used if proven to be energy viable.

New Technologies and Materials

Materials:

- Investigate the use of plant-based polymers - In the past most plant based polymers have been sugar or starch derived and have not had the chemical and mechanical properties required to be able to de used in durable consumer products.
- Recycled materials – one way of ensuring the continued supply of non-renewable and scarce materials is to recover your own product and extract the materials for use in mew products. By following the proposed design solutions relating to increasing recyclability and instigating a product collection / return system, companies can help to secure a supply of known quality materials into the future.

Technology:

- Investigate the use of new 'recyclable' printed circuit board technologies – new developments and research in the materials and design of PCBs, typically the printed circuit board that falls apart when immersed in hot water developed by the National Physical Laboratory
- Utilise new electronics manufacturing technologies, typically conductive inks.

Energy:

- Self-charging batteries are beginning to come to market. These are small power cells (which can be the same size as standard batteries such as AA cells) that charge when the device in which they are placed is moved. Technology in the cell converts the movement to a charging current. There is a possibility of use for the telephones as they are in motion when in use. Otherwise the user can physically shale the unit to charge it up.

- Miniature fuel cells have been used to power small electrical devices and it is an area that is benefiting from research and development at the current time. Into the future it may become a viable way to provide cleaner energy for consumer electronics.

KEY BARRIERS to IMPROVEMENTS and SUGGESTIONS to OVERCOME THESE

The following summarises the findings and recommendations of this research and groups the findings in terms of what can be achieved now, what could be achieved subject to some design modification and what could be achieved longer with longer term collaboration.

Can do Know

To address those issues that could be achieved now will require designers and manufacturers to co-ordinate with each other in the development and manufacture of any new product to ensure commonality materials and ease of disassembly at end of life.

It is unlikely theta the consumer would perceive any change in the product, their reaction to the product is unlikely to be an issue therefore at this level.

Barriers to achieving at this level are the degree of collaborations and communications between BT's designers and manufacturers. This would have to be managed by BT.

Near Application Based on Design Modifications

To achieve progress in the area that requires greater design modification will have an impact on hoe the product will manifest itself to the consumer; it is therefore possible that the consumer could have a negative reaction to:

- The use of 100% recycled polymer in black or grey tones only
- The use of a foil/wrap overlay to provide colour and product protection
- The use of capacitive touch technology with reduced tactile feedback
- The impact of modularity
- The option to upgrade and repair over a longer product lifetime

An evaluation of the above reactions could be achieved through a series of carefully produced prototypes and end user evaluations.

It has been observed during the sustainability and consumer behaviour research, that consumer may keep their DECT devices for more than ten years and look for quality products that will last.

It has also been noted that consumers are confused by the sustainability message.

It would be proposed that consumer reaction work on prototypes of this type present a quality product with and circular or sustainability aspect to the designs kept hidden form the consumer.

If the consumer will accept these products on their own design and functionality merits, then the fact that they are circular would be a bonus to the consumer.

New Technologies and Materials – Supporting Research, Driving Change

Developments in materials, manufacturing, component technology and energy sources that are to have significant environmental impact are likely to go beyond capacity of any single manufacturer to achieve.

For companies like BT it will be a requirement for them to collaborate with competitors to apply pressure to the manufacturing and supplier base to research into the development of new materials, technologies and new uses of energy.

It will be a requirement therefore for companies who develop new products to create demand for change and support research in achieving that change.

If this is done actively as a continual set of support initiatives, it will keep BT at the forefront of these developments, keeping them in a valuable position to take advantage of them when they become viable.

Appendix 1a

Circular Economy Assessment Product Design Assessment

Part 1 – Abridged LCA

Product: BT6500 DECT Phones

Sub-Contents

1 Introduction & Aims

Better Future is the name of a pan-BT programme to deliver on BT's strategic aim to be a responsible and sustainable business leader.

BT Group's Better Future strategy has three dimensions; Building stronger communities through the power of their technology and people, reducing carbon emissions and their impact on the environment through their operations and products, and behaving responsibly towards their customers, people and their suppliers.

One of BT's goals is 'Net Good' where BT's products will achieve three times the carbon saving for their customers than they emit over their lifetime. An enabler of Net Good is implementation of the Circular Economy (CE) principles.

How products are made, what they are made of, where they are made, and what happens at the End of Life (EoL) is crucial to the Net Good strategy.

By undertaking an abridged Life cycle Assessment (LCA) design review on a **BT6500 DECT Phone**

The goal of this work is to provide evidence-based recommendations to BT on a number of key materials' areas and manufacturing processes, and provide a risk analysis in the form of:

1. **BAU** (do nothing)
2. **Incremental** (BAU+ small changes here and there)
3. **Component** (Mostly BAU, but swap out parts/processes)
4. **Transformational** (Making a big step, adopting total supply chain approach, Circular Economy principles)

A BT6500 DECT phone has been used as an example to outline the different options that should be considered during the product design process and how these options and choices might affect the products overall life-cycle impacts.

2 Product Assessment Methodology

There are many ways in which to assess the overall life cycle environmental impacts of a product. The most well-known is Life Cycle Assessment (LCA). LCA is a technique used to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Undertaking a full and scientifically rigorous LCA is very time consuming and expensive. The main stages are:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

A full LCA requires the collection of specific data related to the exact materials and manufacturing practices used and the results of such studies are usually complex and for non-experts, difficult to understand.

There is a much more practical method of undertaking assessments known as an abridged LCA. These types of studies us the same principles of full LCA in that they consider the whole life cycle of a product but they use secondary data (from published datasets) and usually consider a limited number of impacts such as Carbon and energy footprints.

The two BT products assessed in this work were done so using an abridged LCA technique through the use of the Eco Audit function of the Cambridge Engineering Selector (CES) software[1]. These assessments require the input of a bill of materials for the product in question and the definition of generic processing routes as well as information relating to energy consumption during use and likely disposal routes at end of life. The assessment also takes into account the impacts of shipping the finished item at end of life.

As well as the use of software to assess the overall carbon and energy impacts of the products in question a design review in respect of CE principles was also undertaken. This involved the physical teardown and examination of the product to identify areas of concern / good practice.

2.1 Physical Teardown and Assessment

Detailed bills of materials containing list of materials, components and weights were not available for the product being assessed. Therefore the product was physically disassembled. This allowed the identification of material types, the measurement of their weights and the assessment of processing routes used. The teardown included the packaging as well as the product itself.

The product was broken down into its constituent parts. Each part was weighed, materials identified and, where possible, the processing routes identified. Where components or materials were joined together they were separated if possible. Where multi-material components were impossible to separate estimates were made in regard if the weights of the different constituent materials.

As well as assessing quantifiable parameters the product were considered in respect of use of recycled content, ease of recyclability and design features that affect the CE principles.

Many of the design features exist as they fulfil a functional and / or aesthetic requirement. When the assessment was undertaken these issues were taken into account and considered when alternative solutions were proposed.

The physical teardown gives and invaluable insight into the design, form and function of a product. The process of disassembly shows how easy materials and components are to separate, highlights issues relating to materials, processes, design and the implications these have on durability, use patterns and end of life options.

[1] http://www.grantadesign.com/products/ces

2.2 Use of CES Software

The quantitative information gained from the physical teardown stage was used to undertake a whole-life impact assessment using Granta CES Software. This software uses a database of materials properties (which included environmental measures such as Energy and CO_2e) to generate a whole life cycle impact and communicate how each life cycle stage contributes to this.

The bill of materials were entered and estimates of energy consumption during use were also added. The product is manufactured in China so the transport of the products to the UK by sea freight was included in the assessment. Finally, the expected end of life scenario for the product was described in CES. As this product is a small electrical item which come under the requirements of the WEEE Directive it is anticipated that it would be returned or collected for recovery and recycling. In the majority of cases these types of products are shredded and material recovery is undertaken where possible. For the assessment an end of life scenario of 'downcycling' was specific for the majority of materials in both products as it is very unlikely that they would go through a closed loop recycling process and the materials be re-used in similar products.

The expected life of the product was set at 5 years. The assumptions made in respect of energy consumption is shown later in this report.

The results were exported into MS Excel to allow manipulation of the figures and presentation in a pie-chart format.

3 Product Assessment Results

3.1 Summary of Lice Cycle Impacts

Using the bill of materials generated form a teardown of the product and certain assumptions about the end-of-life scenarios for the materials and components a simplified life cycle assessment was undertaken using CES Selector software. This is an 'indicative' study that allows the identification of the largest areas of life cycle impact in terms of energy and carbon. It is not a scientifically rigorous study but can be used to identify areas where changes can be made in the product's design to allow overall life cycle impacts to be reduced. A product life of 5 years has been presumed for this assessment.

The overall life cycle carbon footprint is just over 60kg. Figure 1 details the different life cycle contributions to this overall figure.

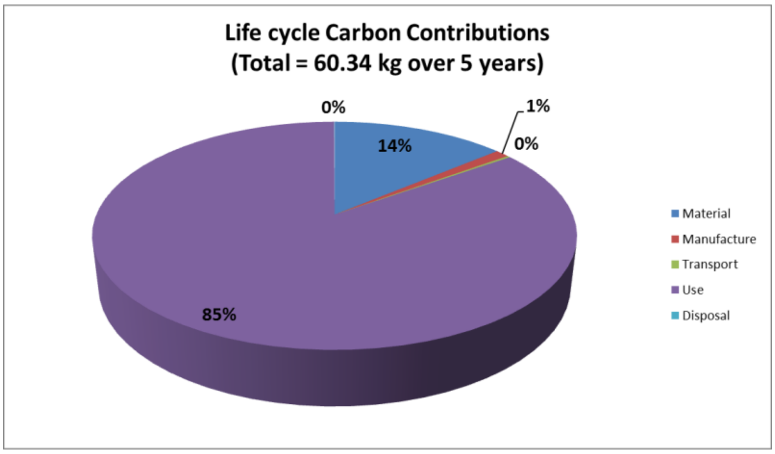


Figure 1 - Overall Life Cycle carbon impact of the BT6500

As can be seen the vast majority of the impact of the product comes from the use of energy during its use.

3.2 Total material intensity

To deliver its function over its 5 year life the produce uses a total of 0.690 kg of materials in terms of the physical product manufacture. It does not account for any materials and wastage apparent in the extraction/refining/processing stages. This includes packaging and batteries but does not include any repairs or accessories that are added during the product's life.

In respect of circular economy goals a number of issues can be highlighted.

3.2.1 Total recycled content

The total recycled content of the product is currently very low. Only the metals content will contain recyclate as the supply chains of these materials use an amount of recyclate as standard practice. All the polymers used are currently 100% virgin. Therefore it is estimated that only 22% of the current product (by weight) is made from recycled materials.

3.2.2 Total easily recyclable

The design of the product and the manufacturing operations used to make it have an effect on how easy it is to recycle at the end-of-life and recovery materials for re-use. This product contains a number of different materials and components, some of which are permanently bonded together. This will compromise the ability to recover materials for recycling and may mean that the product ends up being 'downcylced'. In downcycling a material is processed into a material of lower quality. Typical examples include the conversion of: PET drink bottles into fibres for fleece clothing, crushing concrete and brick for use as an aggregate replacement, and reprocessing PP packaging as a wood replacement (decking, park benches). Although it does recover materials, value is much reduced when compared to recycling (where material is reprocessed into a material of similar quality).

Currently is it estimated that the opportunities to recycle, downcycle and landfill the products are as shown in figure 2.

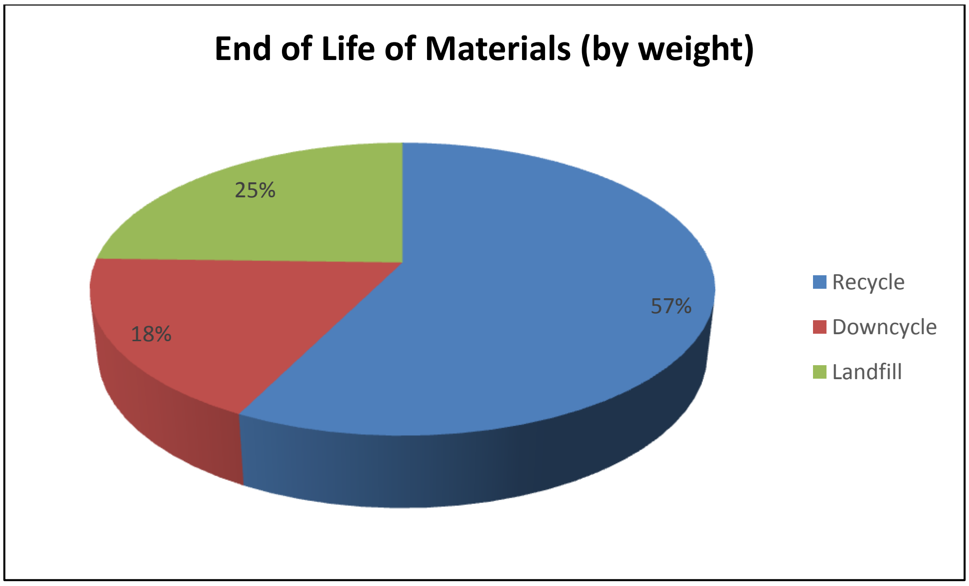


Figure 2 - Estimated end of life routes for materials (by weight)

These figures are a 'best case' scenario, based on the assumption that any clean easily separated non-contaminated plastics will be recycled as will the metals as they can be easily separated even after a product has been shredded. The majority of the materials and components will be downcycled through a shredding process, which is the most likely route for small electrical products like this.

3.2.3 Overall Energy consumption

The product requires energy to function. The phones are battery powered and need recharging, and the main base acts as the main connection for the phones and has a powered answer phone function.

The power supplies for the bases are rated as 7.5v at 300 mA and therefore will draw 2.25w at full power. The trickle change / standby power use is unknown but expected to be in the region of 0.25w which is similar to that of a mobile phone charger. If we presume that the use of the phones will be split as follows (based on 8760 hours in a year and a 5 year life):

Full power use 20% main unit / 0% slave unit

Full power charge 10% main unit / 10% slave unit

Standby / trickle charge 70% main unit / 90% slave unit

The overall energy use will be as shown in Table 1.

	Percentage use		**Number of hours**		**Watts per hour**		**Total Watts**	
	Main	*Slave*	*Main*	*Slave*	*Main*	*Slave*	*Main*	*Slave*
Full power use	**20%**	**0%**	8,760	0	2.25	0	19,710	0
Full power charge	**10%**	**10%**	4,380	4,380	2.25	2.25	9,855	9,855

Standby / Trickle	**70%**	**90%**	30,660	39,420	0.25	0.25	7,665	9,855

Table 1 - In use energy consumption over phone's lifecycle (5 years)

Total in-use energy consumption over 5 years is approximately 57 kWh.

If this energy is supplied by the UK grid the associated carbon impacts[2] would be 33.62kg CO_2e. *NB the CES model uses a more simplified approach to energy use and therefore produces slightly different figures.*

3.2.4 Conflict minerals

Conflict minerals are minerals mined in conditions of armed conflict and human rights abuses, notably in the eastern provinces of the Democratic Republic of the Congo. The profits from the sale of these minerals finance continued fighting in wars, and control of lucrative mines becomes a focus of the fighting as well. The most commonly mined minerals are cassiterite, wolframite, coltan, and gold, which are extracted from the Eastern Congo, and passed through a variety of intermediaries before being purchased by multinational electronics companies.

- Coltan is the metal ore from which the element tantalum is extracted. Tantalum is used primarily for the production of capacitors, particularly for applications requiring high performance, a small compact format and high reliability, ranging widely from hearing aids and pacemakers, to airbags, GPS, ignition systems and anti-lock braking systems in automobiles, through to laptop computers, mobile phones, video game consoles, video cameras and digital cameras.
- Cassiterite is the chief ore needed to produce tin, essential for the production of tin cans and solder on the circuit boards of electronic equipment. Tin is also commonly a component of biocides, fungicides and as tetrabutyl tin/tetraoctyl tin, an intermediate in polyvinyl chloride (PVC) and high performance paint manufacturing.
- Wolframite is an important source of the element tungsten. Minimal amounts are used in electronic devices, including the vibration mechanism of mobile phones.
- Gold is used in jewellery, electronics, and dental products. It is also present in some chemical compounds used in certain semiconductor manufacturing processes.

The telephones will contain tantalum in the capacitors used in the electronics, tin in the solder used for the printed circuit boards and gold as a solderable coating on some of the circuit boards. It is unlikely that the phone contains tungsten.

3.3 Bill of materials Assessment

3.3.1 Component 1 – Packaging

The packaging used for this product comprised sole of paper and cardboard. A corrugated cardboard outer box contains die cut corrugated cardboard inserts. Separate components are wrapped in tissue paper to protect their surface finishes.

[2] UK Grid electricity CO_2e is 0.58982 kg per kWh (Source DEFRA GHG Conversion Factors 2012)

Figure 3 - BT6500 Consumer Packaging

- Material – Cardboard / Paper
- Recycled content - ??
- Weight – 94g
- Renewable / sustainable – Yes
- Conflict Minerals? - No
- Marked for recycling? - ??
- Coatings – Varnish and print
- Readily recyclable - YES
- Removal – N/A

3.3.2 Component 2 – Handset (x 2)

The phone set assessed contained 2 identical handsets. Theses comprise of plastic mouldings, printed circuit boards and other components.

Figure 4 - BT6500 Handset

3.3.2.1 Handset Battery Cover

The cover is a relatively simple injection moulded piece. It has a spark eroded finish on the outside and is not coated. It is marked for recycling, using the Mobius loop and the letters <ABS>. It is easily removed from the phone and will be easily recycled as it is a single material

Figure 5 - Handset Battery cover

- Material – ABS
- Recycled content – 0%
- Weight – 8.7g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - YES
- Coatings – NONE
- Readily recyclable - YES
- Removal – clips off

3.3.2.2 Handset Casing

The handset consists of 2 parts; and upper and lower casing. These are held together with 2 screws and moulded in clips.

Figure 6 - Phone casings

The lower part of the handset casing is injection moulded in ABS. It contains a speaker unit as well as steel battery contacts. It has a spark eroded finish on the outside and is not coated. It is marked for recycling, using the Mobius loop and the letters <ABS>. The speaker is bonded into the moulding and is not easy to separate. It also utilises a foam pad – presumably to reduce vibrations. This component would be difficult to recycle due to 'contamination' of polymer with the bonded in speaker and foam.

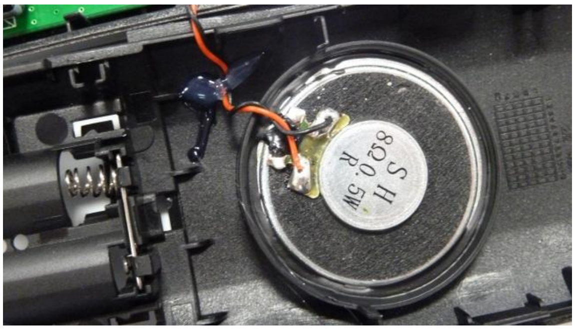


Figure 7 - Speaker bonded into lower handset moulding

Figure 8 - Handset lower casing components

Lower casing

- Material – ABS / speaker unit / foam
- Recycled content – 0%
- Weight – (22.1g/7.6g/0.3g) – total 30g
- Renewable / sustainable – NO
- Conflict Minerals? - No
- Marked for recycling? - YES
- Coatings – none
- Readily recyclable - NO
- Removal – removal of 2 screws to separate the 2 halves of the casing. Then clips apart. Battery contacts clip out. Speaker unit has to be broken out as it is bonded in.

The upper part of the handset casing is again injection moulded in ABS. This is a more complex moulding than the lower part as it contains a ‘window’ for a screen, a keypad and a printed circuit board. It has a spark eroded finish and is painted in some areas to give a silver colour. It is marked for recycling on the inside, using the Mobius loop and the letters <ABS>. It contains foam pads bonded to the plastic which would compromise the recyclability of the piece. The screen is bonded / ultrasonically welded in to the casing.

Figure 9 - Handset Upper Casing Moulding

Figure 10 - Details of silver paint on upper handset casing

Upper Casing

- Material – ABS / foam
- Recycled content – 0%
- Weight – 22.1g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - YES
- Coatings – painted
- Readily recyclable - NO
- Removal – removal of 2 screws to separate the 2 halves of the casing. Then clips apart. Screen has to be broken out as it is bonded in.

3.3.2.3 Handset key pad

The keypad used in the handset consists of various components made form silicone, steel and ABS. The back on the pad is made from flexible silicone and the ABS buttons are bonded (as separate pieces) to this. A steel spacer is used between the keypad and the circuit board. Due to the use of differing materials that are permanently bonded together this component could not be recycled back into its constituent materials.

Figure 11 - Handset Keypad

Figure 12 - Handset keypad component parts

- Material – Silicone / ABS / Steel
- Recycled content – 0%
- Weight – (5.6g / 6.5g / 2.9g) Total 15g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – printed buttons
- Readily recyclable - NO
- Removal – simply sits into the handset, so very easily removed one the casing of the handset are separated.

3.3.2.4 Handset circuit board assembly

The circuit board assembly used in the handset consists of a number of components. The main PCB, and LCS screen assembly, a speaker and wires. It is easily removed as a whole unit from the handset casing as it is simply clipped in. Once the assembly is removed the component parts are more difficult to separate as some of them are bonded in. The speaker is bonded into the 'frame' of the LCD screen and the LCD screen itself is also bonded into the 'frame'

Figure 13 - Circuit board assembly components

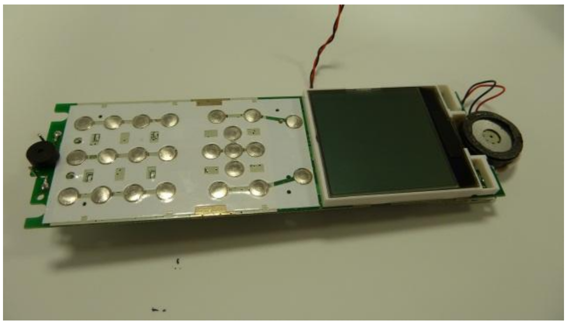


Figure 14 - Front of PCB showing LCD screen and frame and switch pads for buttons

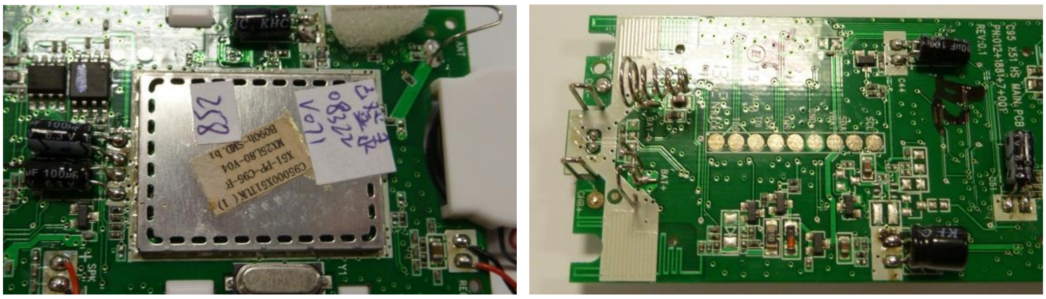


Figure 15 - Details of rear of PCB

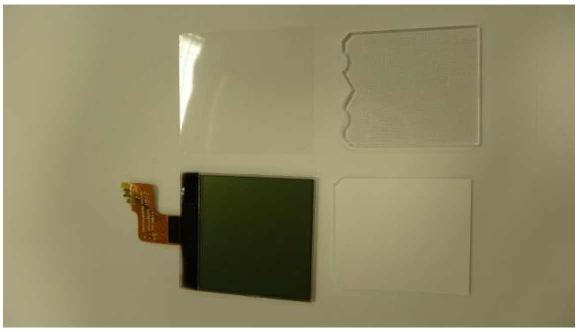


Figure 16 - Details of LCD screen and diffuser components

- Material – PCB/LCD/PC/ABS/other
- Recycled content – 0%
- Weight – (17.7g / 6.9g / 2.8g / 2.3g / 4.05g) Total 33.75g
- Renewable / sustainable – NO
- Conflict Minerals? – Potentially (LCD and others)
- Marked for recycling? - NO

- Coatings – conformal coating on PCB
- Readily recyclable – NO – not with all different materials bonded together. PCB should be able to go for precious metal recovery.
- Removal – PCB assembly clips into the casing and is easily removed. Speaker and LCD unit are bonded into the PCB assembly

3.3.2.5 Handset screws

The handset contains only 2 screws. These are sued to hold the two main halves of the casings together. Everything else is clipped in to the casing or bonded to other components.

3.3.3 Component 3 – Main Base Unit

The two handsets have a base each. The main base unit is the larger of the 2 and contains the answer phone facility and is therefore more complex than the other 'salve' base unit. It consists of an upper and lower casing, a separately moulded 'cradle' in which the phone sits, circuit boards and a keypad assembly.

Figure 17 - Main base unit

Figure 18 - Main base unit casings

Figure 19 - Main base upper case components

3.3.3.1 *Main Base Casings*

The main base unit consists of two casings moulded from ABS, a further ABS moulding that screws into the top casing (where the phone sits), 2 circuit boards and 2 metal connectors. The cases are injection moulded and have a spark eroded finish the same as used on the handsets. Areas of the upper casing are painted silver and it also contains a logo 'button' of an unknown material which is bonded onto the casing. The cradle in which the phone sits is a separate ABS moulding which is screwed into the upper casing. The casings are held together with 2 screws and once these are removed they clip apart. The circuit board in the lower half is clipped in place, whereas the circuit board in the upper half is screwed in place as this also supports the keypad.

The lower part of the casing has 4 rubber (EPDM) feet stuck on. This is done to help create friction between the base and the surface on which it is standing. The bonding of this material to the ABS will cause contamination and difficulties in recycling.

Both halves of the casing are marked for recycling.

Figure 20 - Main base lower casing and circuit board

Figure 21 - Underside of main base lower casing showing feet

Figure 22 - Details of base showing silver paint and logo 'button'

Figure 23 - Phone cradle moulding and contacts

Lower Casing

- Material – ABS/EPDM
- Recycled content – 0%
- Weight – (48g / 0.7g) Total 48.7g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – ABS component Yes, Feet No
- Coatings – None
- Readily recyclable – NO – EPDM feet contaminate
- Removal – remove 2 screws and separated from upper part. Feet needs to be prized off as bonded.

Upper casing

- Material – ABS/Unknown
- Recycled content – 0%
- Weight – (28g / 0.1g) Total 28.1g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – Yes (does not include button)
- Coatings – Sliver paint and printing
- Readily recyclable – Unknown – possible contamination from logo ‘button’

- Removal – remove 2 screws and separated from lower part. Logo 'button' needs to be prized off as bonded.

Phone 'cradle'

- Material – ABS/steel
- Recycled content – 0%/Typical
- Weight – (4.8g / 0.4g) Total 48.4g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – Yes
- Coatings – None
- Readily recyclable – Yes but removal of contact would make it easier
- Removal – remove 2 screws and separated from upper casing. Steel spring contact clip out of the moulding.

3.3.3.2 Main Base Circuit Boards

The circuit boards used in the upper and lower sections of the main base differ from each other in the materials used. The one in the lower part is an FR4 type glass-reinforced epoxy laminate double-sided board whereas the one used in the upper casing seems to be a single side board.

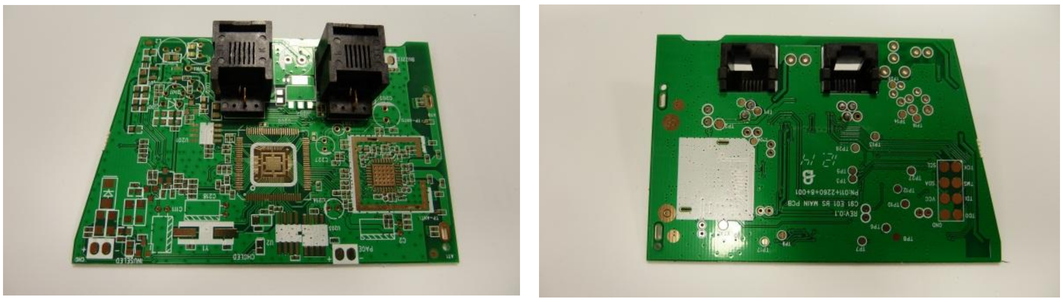


Figure 24 - Main base Lower PCB

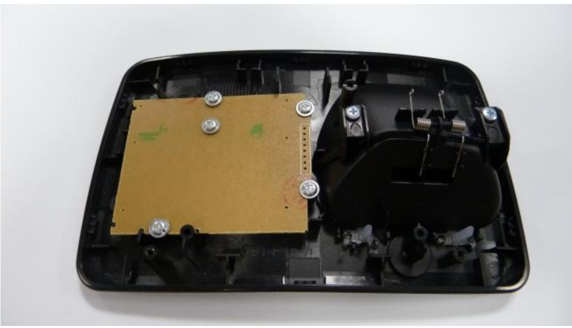


Figure 25 - Main base upper PCB in-situ

Lower PCB

- Material – Double side PCB
- Recycled content – 0%

- Weight – 13.3g
- Renewable / sustainable – NO
- Conflict Minerals? - Possibly
- Marked for recycling? - NO
- Coatings – conformal coating on PCB
- Readily recyclable – Yes (precious metal recovery)
- Removal – clips into lower base casing, so very easily removed one the 2 halves of the base are separated.

Upper PCB

- Material – Single side PCB
- Recycled content – 0%
- Weight – 4.9g
- Renewable / sustainable – NO
- Conflict Minerals? - Possibly
- Marked for recycling? - NO
- Coatings – None
- Readily recyclable – Yes (precious metal recovery)
- Removal – need to remove 5 screws to separate the PC from the upper case moulding.

3.3.3.3 Main Base Keypad

The keypad used in main base is the same format as that used in the handset. It consists of various components made form silicone, steel and ABS. The back on the pad is made from flexible silicone and the ABS buttons are bonded (as separate pieces) to this. There is also an ABS ‘frame’ around the buttons. Unlike the keypad in the handset there is no steel spacer is used between the keypad and the circuit board. In this case it is a very thin polymer spacer. The edges of some of the buttons / frame are painted silver and the buttons are printed. Due to the use of differing materials that are permanently bonded together this component could not be recycled back into its constituent materials.

Figure 26 – Front of the main base unit keypad assembly

Figure 27 - Rear of the main base unit keypad assembly

- Material – Silicone / ABS / Unknown
- Recycled content – 0%
- Weight – (6.4g / 8.5g / 0.05g) Total 14.95g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – silver paint and printed buttons
- Readily recyclable - NO
- Removal – simply sits into the base but is held behind a circuit board that needs 5 screws removing to allow access to the keypad.

3.3.4 Component 4 - Slave Base

The second handset is used in conjunction with a 'slave' base unit. This unit is smaller and simpler than the main base and serves as a cradle and charging station. It has no other functions (such as answer phone).

Figure 28 - Salve base unit

Figure 29 - Slave base unit casings

3.3.4.1 Slave Base casings

The slave base unit consists of two casings moulded from ABS, an additional ABS moulding to cradle the phone, 1 small circuit board, a metal weight and various wires connectors and screws. The cases are injection moulded and have a spark eroded finish the same as used on the handsets. Areas of the upper casing are painted silver and it also contains a logo ‘button’ of an unknown material which is bonded onto the casing. The casings are held together with 2 screws and once these are removed they clip apart. The cradle is removed from the lower casing by the extraction of 2 further screws. The circuit board in the upper half is fixed in place with 2 screws. The weight in the base is screwed in and a sealant is applied over the screws to lock them in place. The lower part of the casing has 4 rubber (EPDM) feet stuck on. This is done to help create friction between the base and the surface on which it is standing. The bonding of this material to the ABS will cause contamination and difficulties in recycling.

Both halves of the casing are marked for recycling.

Figure 30 - Underside of slave base lower casing showing feet

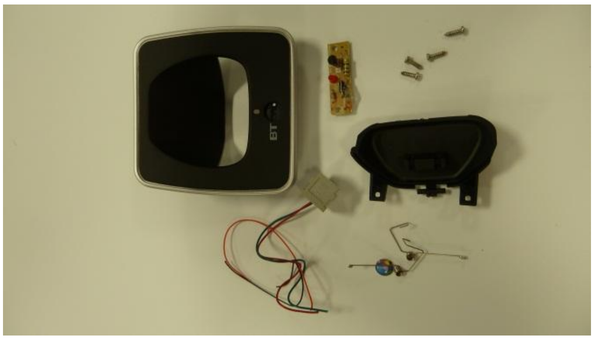


Figure 31 - Slave base upper casing components

Figure 32 - Detail of weight in slave base and sealant on screws

Figure 33 - Detail of silver paint on slave base

Lower Casing

- Material – ABS/EPDM/Steel
- Recycled content – 0%
- Weight – (33.4g / 0.7g / 31.2) Total 65.3g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – ABS component Yes, Feet No
- Coatings – None
- Readily recyclable – NO – EPDM feet contaminate, steel weight and screws are sealed in.
- Removal – remove 2 screws and separated from upper part. Feet needs to be prized off as bonded.

Upper casing

- Material – ABS/Unknown
- Recycled content – 0%/0%
- Weight – (21.8g / 0.05g) Total 21.85g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – Yes (does not include button)
- Coatings – Sliver paint and printing
- Readily recyclable – Unknown – possible contamination from logo ‘button’

- Removal – remove 2 screws and separated from lower part. Logo 'button' needs to be prized off as bonded.

Phone 'cradle'

- Material – ABS/steel
- Recycled content – 0%/Typical
- Weight – (4.8g / 0.4g) Total 48.4g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – Yes
- Coatings – None
- Readily recyclable – Yes but removal of contact would make it easier
- Removal – remove 2 screws and separated from upper casing. Steel spring contact clip out of the moulding.

3.3.4.2 Slave Base circuit boards

The circuit board used in the upper sections of the slave base is an FR4 type glass-reinforced epoxy laminate double-sided board. It is held in place with 2 screws and contains 3 'trailing' wires whose soldered connections to the board are strengthened with the use of silicone.

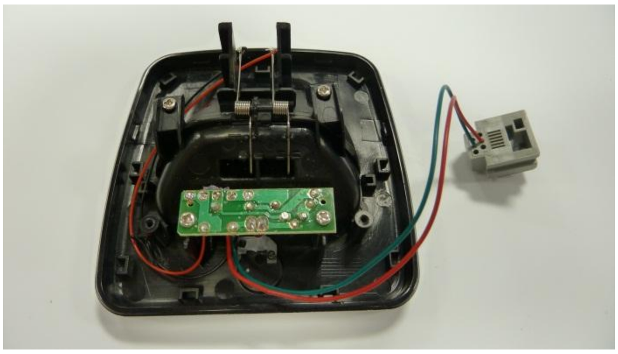


Figure 34 - Salve base circuit board in situ

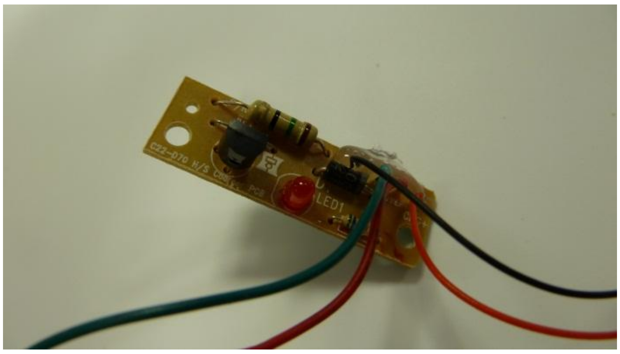


Figure 35 - Detail of slave base circuit board components

Salve base PCB

- Material – Double side PCB

- Recycled content – 0%
- Weight – 4.9g (includes wires and connector)
- Renewable / sustainable – NO
- Conflict Minerals? - Possibly
- Marked for recycling? - NO
- Coatings – conformal coating on PCB
- Readily recyclable – Yes (precious metal recovery)
- Removal – remove 2 screws to separate the board from the lower base casing

3.4 Proposed Design Changes

To propose appropriate design changes that will help make a tangible different in the overall life cycle impacts of the phone these changes need to be considered in respect of the goals of a 'circular economy' Two reports[3], published in 2013 by the Ellen Macarthur Foundation explain these principles in detail.

The reports suggest that manufacturers should 'specify the purpose and performance of the end-products, more than those of the input materials'. It goes on to suggest that designers should specify 'pure materials in their production process since they are easier to sort at end of life'. The report also highlights that besides material selection, other areas important for economically successful circular design are standardised components, designed-to-last products, design for easy end-of-life sorting, separation or reuse of products and materials, and design-for-manufacturing criteria that take into account possible useful applications of by-products and wastes.

The principles relevant to this particular product can be summarised as follows:

- Improve the easy of reuse and recovery of materials
- Match the durability requirements of the product to the durability of the design
- Shift to renewable energy sources
- Build in modularity
- Think in systems rather than specific physical products

These will apply to general design themes observed in this product and can be addresses in the following ways:

3.4.1 Improving materials recovery and recycling

The telephone uses a number of components which are manufactured from different materials which are not compatible for recycling. This means that the recovery of the materials at end of life becomes very difficult is not impossible.

Practices observed in this product included, bonding foam to plastic components, bonding electronic components to plastic casings, bonding different types of plastics together, coating screws with sealant.

In order to address this, new designs should:

[3] Towards the Circular Economy Reports 1 and 2. Ellen Macarthur Foundation 2013

1. Ensure materials are clearly marked to aid recycling
2. Attempt to reduce the mix of incompatible materials to a minimum
3. If there are incompatible materials they should be east to separate and bonding them together should be avoided at all costs
4. Carefully consider the use of any coatings and how they might affect the recyclability of the materials to which they are applied.
5. Try to group similar materials together to allow easier recovery and minimal separation operations.
6. Can new technologies be used to reduce the complexity of current components? E.g. a touch screen as part of the current LCD panel rather than a spate complex keypad.
7. Consider designing components in a way that allows their re-use (if appropriate and viable in the particular product system).

3.4.2 Durability of design

When considering how durable the product needs to be, designers should consider a number of different factors such as:

1. What are the real use patterns of the product
2. How long should it last (consumer expectations)
3. What is its useful technological life – will it become obsolete due to changes in technology?
4. Is it appropriate to update and repair the product (costs, expected life etc.?)
5. I the product a system in its own right or is it part of another system that might change over time

If these issues are considered the products should be ‘appropriate’ in terms of durability and expected life. It I possible to ‘overdesign’ products and make them more robust and more material intensive than they actually need to be.

3.4.3 Renewable Energy Sources

The product only uses a small amount of energy in terms of the power requirement to run the system. However the power is required constantly. There are a number of options in terms of renewable energy such as solar for this particular product but the following issues need to be considered:

1. How reliable is the supply of renewable energy?
2. Does it need to be stored?
3. Can it supply the required level of power / energy
4. Does it mean that the product will have to be placed in a specific position (e.g. near a window).

3.4.4 Modularity

Designing in modularity can bring be to product in respect of the circular economy. Modularity can help extend a product’s life, reduce repair costs and allow for easy upgrading. The effectiveness and appropriateness of this approach will depend on a number of factors:

1. What is the expected life of the product – is modularity a sensible approach for short life products?

2. What advantages does modularity offer?
3. Consider how this will affect the way spare parts and upgrades are sold.

This telephone already demonstrates the use of some modularity principles. The handsets are interchangeable and there are some common parts used in the bases. The ability to replace just a handset (should one fail) would be a move towards are more circular approach. Currently if a user needs a new handset it can only be purchased together with a new base unit. Supplying just a handset, if that is all that is required, would reduce the material burden.

3.4.5 Systems

Many products are sold as 'standalone' systems. Modern technology and advances in computing, communications technology and home networking mean that in many cases the functions traditionally supplied by a range of standalone products can now be supplied by an integrated system.

For example the pone has a built in answer phone facility that requires the use of components and materials. Many communication providers now offer a 'virtual' answer machine as part of the provision therefore it is likely that the majority of users of the BT6500 will ever utilise the built in answer phone.

Also many people now use a mobile phone as their main means of contact and are using landlines less and less. The integration of mobiles, via connection systems such as Bluetooth, into a landline 'server' would allow a landline number but would not require the use of all the hardware needed for separate handsets. Only a small base transmitter / receiver would be needed.

The integration of products into new emerging IT and communication systems will mean that the form of many products as we currently know them will change dramatically over the coming years. This could considerably reduce overall resource use for the delivery of a range of services.

See the main summary report for more detailed design proposals.

Appendix 1b

Circular Economy Assessment Product Design Assessment

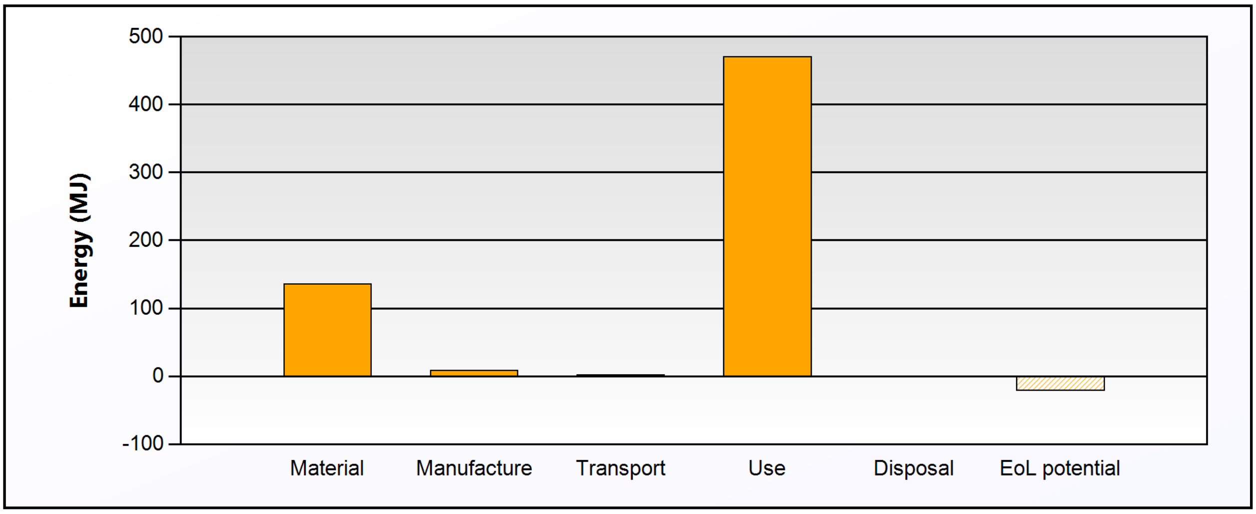
Part 2 – LCA Data

Product: BT6500 DECT Phones

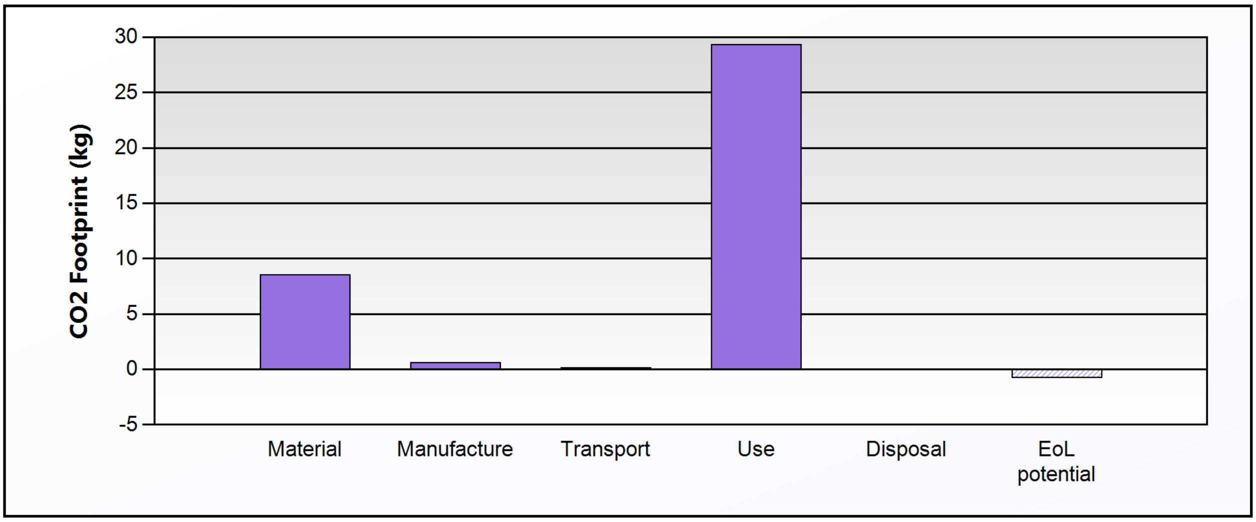
Eco Audit Report

Product Name	BT 6500 Twin Handset DECT Phone
Product Life (years)	5

Energy and CO2 Footprint Summary:



Energy Details...



CO2 Details...

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	137	22.1	8.59	22.1
Manufacture	8.89	1.4	0.667	1.7
Transport	2.7	0.4	0.192	0.5
Use	471	76.0	29.4	75.6
Disposal	0.506	0.1	0.0354	0.1
Total (for first life)	**620**	**100**	**38.9**	**100**
End of life potential	-21		-0.769	

Eco Audit Report

Energy Analysis

Energy and CO2 Summary

	Energy (MJ)/year
Equivalent annual environmental burden (averaged over 5 year product life):	124

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	Energy (MJ)	%
Packaging (outer box)	Cardboard	50.0%	0.084	1	0.088	2.8	2.0
Packaging inner box	Paper (cellulose based)	75.0%	0.14	1	0.15	4.4	3.2
Handset upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.021	2	0.042	4	2.9
Hanndset lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.022	2	0.044	4.2	3.1
Handset battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.087	2	0.17	17	12.1
Handset PCB	Printed circuit board assembly	Virgin (0%)	0.018	2	0.035	4.6	3.4
Handset LCD	LCD panel (liquid crystal display)	Virgin (0%)	0.0069	2	0.014	3.3	2.4
Handset LCD Diffuser	PC (high viscosity, molding and extrusion)	Virgin (0%)	0.0028	2	0.0056	0.61	0.4
Hanset LCD 'frame'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0023	2	0.0046	0.44	0.3
Handset Speaker	Carbon steel, AISI 1010, annealed	Typical %	0.0035	2	0.007	0.13	0.1
Main base lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.048	1	0.048	4.6	3.3
Main base upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.028	1	0.028	2.7	1.9
Main base phone 'cradle'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0048	1	0.0048	0.46	0.3
Main base upper circuit board	Printed circuit board assembly	Virgin (0%)	0.013	1	0.013	1.7	1.3
Main base lower circuit borad	Printed circuit board assembly	Virgin (0%)	0.0049	1	0.0049	0.64	0.5
Main base feet	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0007	1	0.0007	0.066	0.0
Screws and metal contatcs	Carbon steel, AISI 1010, annealed	Typical %	0.0029	1	0.0029	0.053	0.0
Main base keypad frame	ABS (medium-impact, injection molding)	Virgin (0%)	0.0039	1	0.0039	0.37	0.3
Main base keypad buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.0049	1	0.0049	0.47	0.3
Main base keypad 'pad'	Silicone (VMQ, heat cured, low hardness)	Virgin (0%)	0.0064	1	0.0064	0.89	0.6
Slave base upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.022	1	0.022	2.1	1.5
Slave base lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.033	1	0.033	3.2	2.3
Slave base phone 'cradle'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0048	1	0.0048	0.46	0.3
Slave base circuit board	Printed circuit board assembly	Virgin (0%)	0.0016	1	0.0016	0.21	0.2
Slave base wires	Cable	Virgin (0%)	0.0033	1	0.0033	0.3	0.2
Slave base weight connectors and screws	Carbon steel, AISI 1010, annealed	Typical %	0.033	1	0.033	0.6	0.4
Slave base feet	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0007	1	0.0007	0.066	0.0
Power supply	Power supply unit	Virgin (0%)	0.085	2	0.17	77	56.3
Total				**37**	**0.95**	**1.4e+02**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	Energy (MJ)	%
Packaging (outer box)	Cutting and trimming	5	0.0044 kg	0.0013	0.0
Packaging inner box	Cutting and trimming	5	0.0075 kg	0.0023	0.0
Handset upper casing	Polymer molding	-	0.042 kg	0.87	9.8
Hanndset lower casing	Polymer molding	-	0.044 kg	0.91	10.3
Handset battery cover	Polymer molding	-	0.17 kg	3.6	40.4
Handset LCD Diffuser	Polymer molding	-	0.0056 kg	0.11	1.2
Hanset LCD 'frame'	Polymer molding	-	0.0046 kg	0.095	1.1
Main base lower casing	Polymer molding	-	0.048 kg	0.99	11.2
Main base upper casing	Polymer molding	-	0.028 kg	0.58	6.5
Main base phone 'cradle'	Polymer molding	-	0.0048 kg	0.099	1.1
Main base feet	Polymer molding	-	0.0007 kg	0.012	0.1
Screws and metal contatcs	Rough rolling, forging	-	0.0029 kg	0.0078	0.1
Main base keypad frame	Polymer molding	-	0.0039 kg	0.081	0.9
Main base keypad buttons	Polymer molding	-	0.0049 kg	0.1	1.1
Main base keypad 'pad'	Polymer molding	-	0.0064 kg	0.095	1.1
Slave base upper casing	Polymer molding	-	0.022 kg	0.45	5.1
Slave base lower casing	Polymer molding	-	0.033 kg	0.69	7.8
Slave base phone 'cradle'	Polymer molding	-	0.0048 kg	0.099	1.1
Slave base weight connectors and screws	Rough rolling, forging	-	0.033 kg	0.089	1.0
Slave base feet	Polymer molding	-	0.0007 kg	0.012	0.1
Total				**8.9**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage

Total product mass = 0.94 kg

Stage name	Transport type	Distance (km)	Energy (MJ)	%
Transport from China	Sea freight	1.8e+04	2.7	100.0
Total		**1.8e+04**	**2.7**	**100**

Breakdown by components

Component	Component mass (kg)	Energy (MJ)	%
Packaging (outer box)	0.084	0.24	8.9
Packaging inner box	0.14	0.41	15.2
Handset upper casing	0.042	0.12	4.5
Hanndset lower casing	0.044	0.13	4.7
Handset battery cover	0.17	0.5	18.5
Handset PCB	0.035	0.1	3.8
Handset LCD	0.014	0.04	1.5
Handset LCD Diffuser	0.0056	0.016	0.6
Hanset LCD 'frame'	0.0046	0.013	0.5
Handset Speaker	0.007	0.02	0.7
Main base lower casing	0.048	0.14	5.1
Main base upper casing	0.028	0.081	3.0
Main base phone 'cradle'	0.0048	0.014	0.5
Main base upper circuit board	0.013	0.038	1.4
Main base lower circuit borad	0.0049	0.014	0.5
Main base feet	0.0007	0.002	0.1
Screws and metal contatcs	0.0029	0.0084	0.3
Main base keypad frame	0.0039	0.011	0.4
Main base keypad buttons	0.0049	0.014	0.5
Main base keypad 'pad'	0.0064	0.018	0.7
Slave base upper casing	0.022	0.063	2.3
Slave base lower casing	0.033	0.096	3.6
Slave base phone 'cradle'	0.0048	0.014	0.5
Slave base circuit board	0.0016	0.0046	0.2
Slave base wires	0.0033	0.0095	0.4
Slave base weight connectors and screws	0.033	0.094	3.5
Slave base feet	0.0007	0.002	0.1
Power supply	0.17	0.49	18.0
Total	**0.94**	**2.7**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	1.3
Usage (hours per day)	24
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	**Energy (MJ)**	**%**
Static	4.7e+02	100.0
Mobile	0	
Total	**4.7e+02**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	Energy (MJ)	%
Packaging (outer box)	Recycle	100.0	0.059	11.6
Packaging inner box	Recycle	100.0	0.1	19.8
Handset upper casing	Downcycle	100.0	0.021	4.2
Hanndset lower casing	Recycle	100.0	0.031	6.1
Handset battery cover	Recycle	100.0	0.12	24.1
Handset PCB	Downcycle	100.0	0.018	3.5
Handset LCD	Landfill	100.0	0.0028	0.5
Handset LCD Diffuser	Downcycle	100.0	0.0028	0.6
Hanset LCD 'frame'	Downcycle	100.0	0.0023	0.5
Handset Speaker	Landfill	100.0	0.0014	0.3
Main base lower casing	Recycle	100.0	0.034	6.6
Main base upper casing	Landfill	100.0	0.0056	1.1
Main base phone 'cradle'	Recycle	100.0	0.0034	0.7
Main base upper circuit board	Downcycle	100.0	0.0067	1.3
Main base lower circuit borad	Downcycle	100.0	0.0025	0.5
Main base feet	Downcycle	100.0	0.00035	0.1
Screws and metal contatcs	Recycle	100.0	0.002	0.4
Main base keypad frame	Landfill	100.0	0.00078	0.2
Main base keypad buttons	Landfill	100.0	0.00098	0.2
Main base keypad 'pad'	Landfill	100.0	0.0013	0.3
Slave base upper casing	Downcycle	100.0	0.011	2.2
Slave base lower casing	Downcycle	100.0	0.017	3.3
Slave base phone 'cradle'	Downcycle	100.0	0.0024	0.5
Slave base circuit board	Downcycle	100.0	0.0008	0.2
Slave base wires	Downcycle	100.0	0.0017	0.3
Slave base weight connectors and screws	Recycle	100.0	0.023	4.5
Slave base feet	Downcycle	100.0	0.00035	0.1
Power supply	Landfill	100.0	0.034	6.7
Total			**0.51**	**100**

EoL potential:

Component	End of life option	% recovered	Energy (MJ)	%
Packaging (outer box)	Recycle	100.0	-1.1	5.4
Packaging inner box	Recycle	100.0	-1	5.0
Handset upper casing	Downcycle	100.0	-0.53	2.5
Hanndset lower casing	Recycle	100.0	-2.8	13.2
Handset battery cover	Recycle	100.0	-11	52.0
Handset PCB	Downcycle	100.0	0	0.0
Handset LCD	Landfill	100.0	0	0.0
Handset LCD Diffuser	Downcycle	100.0	-0.08	0.4
Hanset LCD 'frame'	Downcycle	100.0	-0.058	0.3
Handset Speaker	Landfill	100.0	0	0.0
Main base lower casing	Recycle	100.0	-3	14.3
Main base upper casing	Landfill	100.0	0	0.0
Main base phone 'cradle'	Recycle	100.0	-0.3	1.4
Main base upper circuit board	Downcycle	100.0	0	0.0
Main base lower circuit borad	Downcycle	100.0	0	0.0
Main base feet	Downcycle	100.0	0	0.0
Screws and metal contatcs	Recycle	100.0	-0.032	0.2
Main base keypad frame	Landfill	100.0	0	0.0
Main base keypad buttons	Landfill	100.0	0	0.0
Main base keypad 'pad'	Landfill	100.0	0	0.0
Slave base upper casing	Downcycle	100.0	-0.27	1.3
Slave base lower casing	Downcycle	100.0	-0.42	2.0
Slave base phone 'cradle'	Downcycle	100.0	-0.06	0.3
Slave base circuit board	Downcycle	100.0	0	0.0
Slave base wires	Downcycle	100.0	0	0.0
Slave base weight connectors and screws	Recycle	100.0	-0.36	1.7
Slave base feet	Downcycle	100.0	0	0.0
Power supply	Landfill	100.0	0	0.0
Total			**-21**	**100**

Notes:

Energy and CO2 Summary

Eco Audit Report

CO2 Footprint Analysis

Energy and CO2 Summary

	CO2 (kg)/year
Equivalent annual environmental burden (averaged over 5 year product life):	7.77

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	CO2 footprint (kg)	%
Packaging (outer box)	Cardboard	50.0%	0.084	1	0.088	0.087	1.0
Packaging inner box	Paper (cellulose based)	75.0%	0.14	1	0.15	0.18	2.1
Handset upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.021	2	0.042	0.16	1.9
Hanndset lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.022	2	0.044	0.17	2.0
Handset battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.087	2	0.17	0.67	7.8
Handset PCB	Printed circuit board assembly	Virgin (0%)	0.018	2	0.035	0.34	4.0
Handset LCD	LCD panel (liquid crystal display)	Virgin (0%)	0.0069	2	0.014	0.25	2.9
Handset LCD Diffuser	PC (high viscosity, molding and extrusion)	Virgin (0%)	0.0028	2	0.0056	0.034	0.4
Hanset LCD 'frame'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0023	2	0.0046	0.018	0.2
Handset Speaker	Carbon steel, AISI 1010, annealed	Typical %	0.0035	2	0.007	0.009	0.1
Main base lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.048	1	0.048	0.18	2.1
Main base upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.028	1	0.028	0.11	1.2
Main base phone 'cradle'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0048	1	0.0048	0.018	0.2
Main base upper circuit board	Printed circuit board assembly	Virgin (0%)	0.013	1	0.013	0.13	1.5
Main base lower circuit borad	Printed circuit board assembly	Virgin (0%)	0.0049	1	0.0049	0.048	0.6
Main base feet	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0007	1	0.0007	0.0031	0.0
Screws and metal contatcs	Carbon steel, AISI 1010, annealed	Typical %	0.0029	1	0.0029	0.0037	0.0
Main base keypad frame	ABS (medium-impact, injection molding)	Virgin (0%)	0.0039	1	0.0039	0.015	0.2
Main base keypad buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.0049	1	0.0049	0.019	0.2
Main base keypad 'pad'	Silicone (VMQ, heat cured, low hardness)	Virgin (0%)	0.0064	1	0.0064	0.057	0.7
Slave base upper casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.022	1	0.022	0.083	1.0
Slave base lower casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.033	1	0.033	0.13	1.5
Slave base phone 'cradle'	ABS (medium-impact, injection molding)	Virgin (0%)	0.0048	1	0.0048	0.018	0.2
Slave base circuit board	Printed circuit board assembly	Virgin (0%)	0.0016	1	0.0016	0.016	0.2
Slave base wires	Cable	Virgin (0%)	0.0033	1	0.0033	0.022	0.3
Slave base weight connectors and screws	Carbon steel, AISI 1010, annealed	Typical %	0.033	1	0.033	0.042	0.5
Slave base feet	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0007	1	0.0007	0.0031	0.0
Power supply	Power supply unit	Virgin (0%)	0.085	2	0.17	5.8	67.3
Total				**37**	**0.95**	**8.6**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	CO2 footprint (kg)	%
Packaging (outer box)	Cutting and trimming	5	0.0044 kg	0.0001	0.0
Packaging inner box	Cutting and trimming	5	0.0075 kg	0.00017	0.0
Handset upper casing	Polymer molding	-	0.042 kg	0.065	9.8
Hanndset lower casing	Polymer molding	-	0.044 kg	0.068	10.3
Handset battery cover	Polymer molding	-	0.17 kg	0.27	40.4
Handset LCD Diffuser	Polymer molding	-	0.0056 kg	0.0082	1.2
Hanset LCD 'frame'	Polymer molding	-	0.0046 kg	0.0071	1.1
Main base lower casing	Polymer molding	-	0.048 kg	0.074	11.1
Main base upper casing	Polymer molding	-	0.028 kg	0.043	6.5
Main base phone 'cradle'	Polymer molding	-	0.0048 kg	0.0074	1.1
Main base feet	Polymer molding	-	0.0007 kg	0.00097	0.1
Screws and metal contatcs	Rough rolling, forging	-	0.0029 kg	0.00059	0.1
Main base keypad frame	Polymer molding	-	0.0039 kg	0.006	0.9
Main base keypad buttons	Polymer molding	-	0.0049 kg	0.0076	1.1
Main base keypad 'pad'	Polymer molding	-	0.0064 kg	0.0076	1.1
Slave base upper casing	Polymer molding	-	0.022 kg	0.034	5.1
Slave base lower casing	Polymer molding	-	0.033 kg	0.052	7.8
Slave base phone 'cradle'	Polymer molding	-	0.0048 kg	0.0074	1.1
Slave base weight connectors and screws	Rough rolling, forging	-	0.033 kg	0.0067	1.0
Slave base feet	Polymer molding	-	0.0007 kg	0.00097	0.1
Total				**0.67**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 0.94 kg

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
Transport from China	Sea freight	1.8e+04	0.19	100.0
Total		**1.8e+04**	**0.19**	**100**

Breakdown by components

Component	Component mass (kg)	CO2 footprint (kg)	%
Packaging (outer box)	0.084	0.017	8.9
Packaging inner box	0.14	0.029	15.2
Handset upper casing	0.042	0.0086	4.5
Hanndset lower casing	0.044	0.009	4.7
Handset battery cover	0.17	0.036	18.5
Handset PCB	0.035	0.0072	3.8
Handset LCD	0.014	0.0028	1.5
Handset LCD Diffuser	0.0056	0.0011	0.6
Hanset LCD 'frame'	0.0046	0.00094	0.5
Handset Speaker	0.007	0.0014	0.7
Main base lower casing	0.048	0.0098	5.1
Main base upper casing	0.028	0.0057	3.0
Main base phone 'cradle'	0.0048	0.00098	0.5
Main base upper circuit board	0.013	0.0027	1.4
Main base lower circuit borad	0.0049	0.001	0.5
Main base feet	0.0007	0.00014	0.1
Screws and metal contatcs	0.0029	0.00059	0.3
Main base keypad frame	0.0039	0.0008	0.4
Main base keypad buttons	0.0049	0.001	0.5
Main base keypad 'pad'	0.0064	0.0013	0.7
Slave base upper casing	0.022	0.0045	2.3
Slave base lower casing	0.033	0.0068	3.6
Slave base phone 'cradle'	0.0048	0.00098	0.5
Slave base circuit board	0.0016	0.00033	0.2
Slave base wires	0.0033	0.00067	0.4
Slave base weight connectors and screws	0.033	0.0067	3.5
Slave base feet	0.0007	0.00014	0.1
Power supply	0.17	0.035	18.0
Total	**0.94**	**0.19**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	1.3
Usage (hours per day)	24
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	29	100.0
Mobile	0	
Total	**29**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	CO2 footprint (kg)	%
Packaging (outer box)	Recycle	100.0	0.0041	11.6
Packaging inner box	Recycle	100.0	0.007	19.8
Handset upper casing	Downcycle	100.0	0.0015	4.2
Hanndset lower casing	Recycle	100.0	0.0022	6.1
Handset battery cover	Recycle	100.0	0.0085	24.1
Handset PCB	Downcycle	100.0	0.0012	3.5
Handset LCD	Landfill	100.0	0.00019	0.5
Handset LCD Diffuser	Downcycle	100.0	0.0002	0.6
Hanset LCD 'frame'	Downcycle	100.0	0.00016	0.5
Handset Speaker	Landfill	100.0	9.8e-05	0.3
Main base lower casing	Recycle	100.0	0.0024	6.6
Main base upper casing	Landfill	100.0	0.00039	1.1
Main base phone 'cradle'	Recycle	100.0	0.00024	0.7
Main base upper circuit board	Downcycle	100.0	0.00047	1.3
Main base lower circuit borad	Downcycle	100.0	0.00017	0.5
Main base feet	Downcycle	100.0	2.5e-05	0.1
Screws and metal contatcs	Recycle	100.0	0.00014	0.4
Main base keypad frame	Landfill	100.0	5.5e-05	0.2
Main base keypad buttons	Landfill	100.0	6.9e-05	0.2
Main base keypad 'pad'	Landfill	100.0	9e-05	0.3
Slave base upper casing	Downcycle	100.0	0.00076	2.2
Slave base lower casing	Downcycle	100.0	0.0012	3.3
Slave base phone 'cradle'	Downcycle	100.0	0.00017	0.5
Slave base circuit board	Downcycle	100.0	5.6e-05	0.2
Slave base wires	Downcycle	100.0	0.00012	0.3
Slave base weight connectors and screws	Recycle	100.0	0.0016	4.5
Slave base feet	Downcycle	100.0	2.5e-05	0.1
Power supply	Landfill	100.0	0.0024	6.7
Total			**0.035**	**100**

EoL potential:

Appendix 2a

Circular Economy Assessment Product Design Assessment

Part 1 – Abridged LCA

Product: **Digital Video Baby Monitor 1000**

Sub-Contents

1 Introduction & Aims

Better Future is the name of a pan-BT programme to deliver on BT's strategic aim to be a responsible and sustainable business leader.

BT Group's Better Future strategy has three dimensions; Building stronger communities through the power of their technology and people, reducing carbon emissions and their impact on the environment through their operations and products, and behaving responsibly towards their customers, people and their suppliers.

One of BT's goals is 'Net Good' where BT's products will achieve three times the carbon saving for their customers than they emit over their lifetime. An enabler of Net Good is implementation of the Circular Economy (CE) principles.

How products are made, what they are made of, where they are made, and what happens at the End of Life (EoL) is crucial to the Net Good strategy.

By undertaking an abridged Life cycle Assessment (LCA) design review on a **Digital Video Baby Monitor 1000**

The goal of this work is to provide evidence-based recommendations to BT on a number of key materials' areas and manufacturing processes, and provide a risk analysis in the form of:

1. **BAU** (do nothing)
2. **Incremental** (BAU+ small changes here and there)
3. **Component** (Mostly BAU, but swap out parts/processes)
4. **Transformational** (Making a big step, adopting total supply chain approach, Circular Economy principles)

A Digital Video Baby Monitor 1000 phone has been used as an example to outline the different options that should be considered during the product design process and how these options and choices might affect the products overall life-cycle impacts.

2 Product Assessment Methodology

There are many ways in which to assess the overall life cycle environmental impacts of a product. The most well-known is Life Cycle Assessment (LCA). LCA is a technique used to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Undertaking a full and scientifically rigorous LCA is very time consuming and expensive. The main stages are:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;
- Interpreting the results to help make a more informed decision.

A full LCA requires the collection of specific data related to the exact materials and manufacturing practices used and the results of such studies are usually complex and for non-experts, difficult to understand.

There is a much more practical method of undertaking assessments known as an abridged LCA. These types of studies us the same principles of full LCA in that they consider the whole life cycle of a product but they use secondary data (from published datasets) and usually consider a limited number of impacts such as Carbon and energy footprints.

The two BT products assessed in this work were done so using an abridged LCA technique through the use of the Eco Audit function of the Cambridge Engineering Selector (CES) software[1]. These assessments require the input of a bill of materials for the product in question and the definition of generic processing routes as well as information relating to energy consumption during use and likely disposal routes at end of life. The assessment also takes into account the impacts of shipping the finished item at end of life.

As well as the use of software to assess the overall carbon and energy impacts of the products in question a design review in respect of CE principles was also undertaken. This involved the physical teardown and examination of the product to identify areas of concern / good practice.

2.1 Physical Teardown and Assessment

Detailed bills of materials containing list of materials, components and weights were not available for the product being assessed. Therefore the product was physically disassembled. This allowed the identification of material types, the measurement of their weights and the assessment of processing routes used. The teardown included the packaging as well as the product itself.

The product was broken down into its constituent parts. Each part was weighed, materials identified and, where possible, the processing routes identified. Where components or materials were joined together they were separated if possible. Where multi-material components were impossible to separate estimates were made in regard if the weights of the different constituent materials.

As well as assessing quantifiable parameters the product were considered in respect of use of recycled content, ease of recyclability and design features that affect the CE principles.

Many of the design features exist as they fulfil a functional and / or aesthetic requirement. When the assessment was undertaken these issues were taken into account and considered when alternative solutions were proposed.

The physical teardown gives and invaluable insight into the design, form and function of a product. The process of disassembly shows how easy materials and components are to separate, highlights issues relating to materials, processes, design and the implications these have on durability, use patterns and end of life options.

[1] http://www.grantadesign.com/products/ces

2.2 Use of CES Software

The quantitative information gained from the physical teardown stage was used to undertake a whole-life impact assessment using Granta CES Software. This software uses a database of materials properties (which included environmental measures such as Energy and CO_2e) to generate a whole life cycle impact and communicate how each life cycle stage contributes to this.

The bill of materials were entered and estimates of energy consumption during use were also added. The product is manufactured in China so the transport of the products to the UK by sea freight was included in the assessment. Finally, the expected end of life scenario for the product was described in CES. As this product is a small electrical item which come under the requirements of the WEEE Directive it is anticipated that it would be returned or collected for recovery and recycling. In the majority of cases these types of products are shredded and material recover is undertaken where possible. For the assessment an end of life scenario of 'downcycling' was specific for the majority of materials in both products as it is very unlikely that they would go through a closed loop recycling process and the materials be re-used in similar products.

The expected life of the product was set at 5 years. The assumptions made in respect of energy consumption is shown later in this report.

The results were exported into MS Excel to allow manipulation of the figures and presentation in a pie-chart format.

3 Product Assessment Results

3.1 Summary of Lice Cycle Impacts

Using the bill of materials generated form a teardown of the product and certain assumptions about the end-of-life scenarios for the materials and components a simplified life cycle assessment was undertaken using CES Selector software. This is an 'indicative' study that allows the identification of the largest areas of life cycle impact in terms of energy and carbon. It is not a scientifically rigorous study but can be used to identify areas where changes can be made in the product's design to allow overall life cycle impacts to be reduced. A product life of 5 years has been presumed for this assessment.

The overall life cycle carbon footprint is somewhere in the region of 100kg. Figure 1 details the different life cycle contributions to this overall figure.

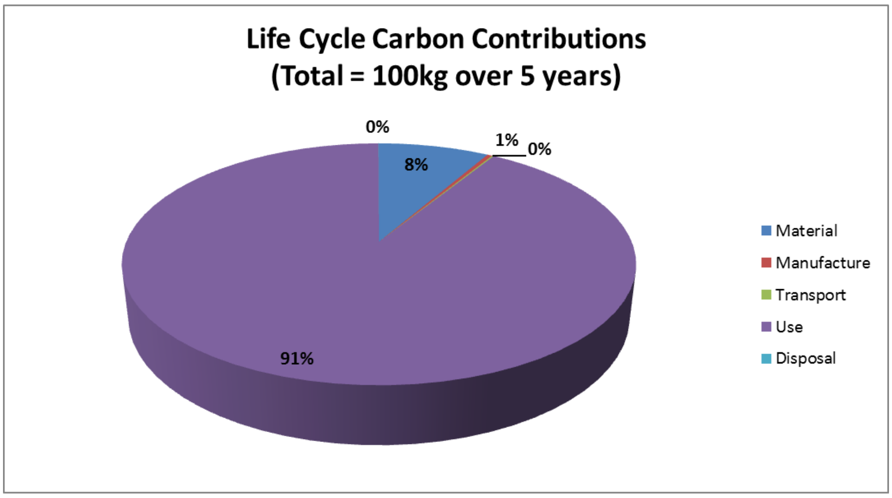


Figure 1 - Overall Life Cycle carbon impact of the Digital Video Baby Monitor 1000

As can be seen the vast majority of the impact of the product comes from the use of energy during its use.

3.2 Total material intensity

To deliver its function over its 5 year life the product uses a total of 0.680kg of materials in terms of the physical material embodied in the final product. It does not account for any materials and wastage apparent in the extraction/refining/processing stages. This includes packaging and batteries but does not include any repairs or accessories that are added during the product's life.

In respect of circular economy goals a number of issues can be highlighted.

3.2.1 Total recycled content

The total recycled content of the product is currently very low. Only the metals content will contain recyclate as the supply chains of these materials use an amount of recyclate as standard practice. All the polymers used are currently 100% virgin. Therefore it is estimated that only 10% of the current product (by weight) is made from recycled materials. The only recycled material used is the recycled content cardboard in the packaging.

3.2.2 Total easily recyclable

The design of the product and the manufacturing operations used to make it have an effect on how easy it is to recycle at the end-of-life and recovery materials for re-use. This product contains a number of different materials and components, some of which are permanently bonded together. This will compromise the ability to recover materials for recycling and may mean that the product ends up being 'downcylced'. In downcycling a material is processed into a material of lower quality. Typical examples include the conversion of: PET drink bottles into fibres for fleece clothing, crushing concrete and brick for use as an aggregate replacement, and reprocessing PP packaging as a wood replacement (decking, park benches). Although it does recover materials, value is much reduced when compared to recycling (where material is reprocessed into a material of similar quality).

Currently is it estimated that the opportunities to recycle, downcycle and landfill the products are as shown in figure 2.

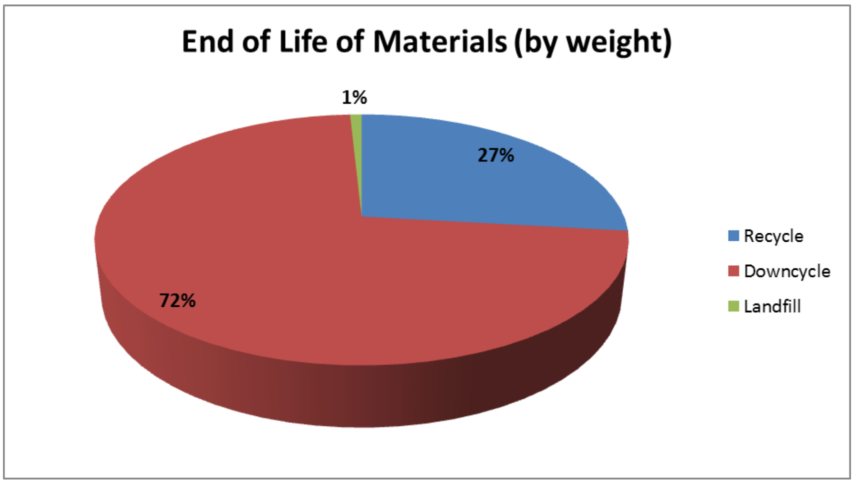


Figure 2 - Estimated end of life routes for materials (by weight)

These figures are a 'best case' scenario, based on the assumption that any clean easily separated non-contaminated plastics will be recycled as will the metals as they can be easily separated even after a product has been shredded. The majority of the materials and components will be downcycled through a shredding process, which is the most likely route for small electrical products like this.

3.2.3 Overall Energy consumption

The product requires energy to function. The receiver part of the product is battery powered and need recharging. The transmitter unit is powered from the mains.

The power supplies are 6v at 800 mA and therefore will draw 4.8w at full power. Full power is assumed to be used when the transmitter is turned on and when the receiver is charging. The trickle change / standby power use is unknown but expected to be in the region of 0.5w. If we presume that the use of the unit will be split as follows (based on 8760 hours in a year and a 5 year life):

Full power use 20% main unit / 0% slave unit

Full power charge 10% main unit / 10% slave unit

Standby / trickle charge 70% main unit / 90% slave unit

The overall energy use will be as shown in Table 1.

	Percentage use		**Number of hours**		**Watts per hour**		**Total Watts**	
	Trans	*Rec*	*Trans*	*Rec*	*Trans*	*Rec*	*Trans*	*Rec*
Full power use	**50%**	**20%**	21,900	8,760	4.8	0	105,120	0
Full power charge	**0%**	**20%**	0	8,760	4.8	4.8	0	42,048
Standby / Trickle	**50%**	**80%**	21,900	35,040	0.5	0.5	10,950	17,520

Table 1 - In use energy consumption over phone's lifecycle (5 years)

Total in-use energy consumption over 5 years is approximately 175 kWh. This is the energy consumed at the mains. The energy required to supply this is much higher due to losses and inefficiencies in the electricity generation and transmission system. These are taken into account in the data show earlier in Figure 1.

If this energy is supplied by the UK grid the associated carbon impacts[2] would be approximately 103.22 kg CO_2e. *NB the CES model uses a more simplified approach to energy use and therefore produces slightly different figures.*

3.2.4 Conflict minerals

Conflict minerals are minerals mined in conditions of armed conflict and human rights abuses, notably in the eastern provinces of the Democratic Republic of the Congo. The profits from the sale of these minerals finance continued fighting in wars, and control of lucrative mines becomes a focus of the fighting as well. The most commonly mined minerals are cassiterite, wolframite, coltan, and gold, which are extracted from the Eastern Congo, and passed through a variety of intermediaries before being purchased by multinational electronics companies.

- Coltan is the metal ore from which the element tantalum is extracted. Tantalum is used primarily for the production of capacitors, particularly for applications requiring high performance, a small compact format and high reliability, ranging widely from hearing aids and pacemakers, to airbags, GPS, ignition systems and anti-lock braking systems in automobiles, through to laptop computers, mobile phones, video game consoles, video cameras and digital cameras.
- Cassiterite is the chief ore needed to produce tin, essential for the production of tin cans and solder on the circuit boards of electronic equipment. Tin is also commonly a component of biocides, fungicides and as tetrabutyl tin/tetraoctyl tin, an intermediate in polyvinyl chloride (PVC) and high performance paint manufacturing.
- Wolframite is an important source of the element tungsten. Minimal amounts are used in electronic devices, including the vibration mechanism of mobile phones.
- Gold is used in jewellery, electronics, and dental products. It is also present in some chemical compounds used in certain semiconductor manufacturing processes.

The baby monitor will contain tantalum in the capacitors used in the electronics, tin in the solder used for the printed circuit boards and gold as a solderable coating on some of the circuit boards. It is unlikely that product contains tungsten.

3.3 Bill of materials Assessment

3.3.1 Component 1 – Packaging

The packaging used for this product comprised sole of paper and cardboard. A corrugated cardboard outer box contains die cut corrugated cardboard inserts. Separate components are wrapped in tissue paper to protect their surface finishes.

[2] UK Grid electricity CO_2e is 0.58982 kg per kWh (Source DEFRA GHG Conversion Factors 2012)

Figure 3 – Digital Video Baby Monitor 1000

- Material – Cardboard / Paper
- Recycled content – Estimated at 50%
- Weight – 140g
- Renewable / sustainable – Yes
- Conflict Minerals? - No
- Marked for recycling? - Yes
- Coatings – Varnish and print
- Readily recyclable - Yes
- Removal – No fixings or fastenings used.

3.3.2 Component 2 – Transmitter

The system uses a single transmitter unit that transmits both audio and pictures to the receiver. It comprises of plastic mouldings, printed circuit boards and other components.

Figure 4 – Baby Monitor Transmitter

3.3.2.1 Transmitter Battery Cover

The cover is a relatively simple injection moulded piece. It has a high gloss finish and is not coated. It is marked for recycling, using the Mobius loop and the letters <ABS>. It is easily removed from the transmitter but might not be easily recycled. A foam pad is glued to the inside of the cover to help keep the batteries in place. The bonding of this foam to the ABS means that recyclability is compromised.

Figure 5 - Handset Battery cover

- Material – ABS
- Recycled content – 0%
- Weight – 15.5g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - YES
- Coatings – NONE
- Readily recyclable – Possibly – contamination from foam.
- Removal – clips off

3.3.2.2 Transmitter Casing

The transmitter consists of 2 parts; a front casing and a rear casing. These are held together with 2 screws and moulded in clips.

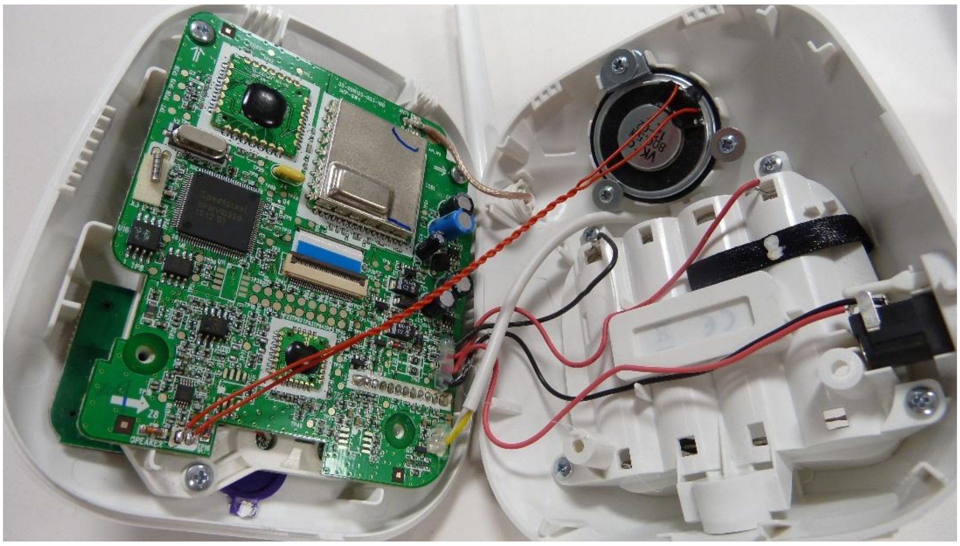


Figure 6 – Transmitter Casings

The rear part of the transmitter casing is injection moulded in ABS. It contains a speaker unit as well as a separate moulded battery compartment (discussed later) with steel battery contacts. It has a gloss finish on the outside and is not coated. It is marked for recycling, using the Mobius loop and the letters <ABS>. A speaker is held into the moulding using 3 screws. It also utilises a removable rubber 'gasket' as well as a 'grill' made from some form of synthetic fabric material. Although the gasket is easily removed the use of the fabric grill (which seems to be bonded in place) could contaminate the ABS and make it difficult to recycle due to 'contamination' of polymer.

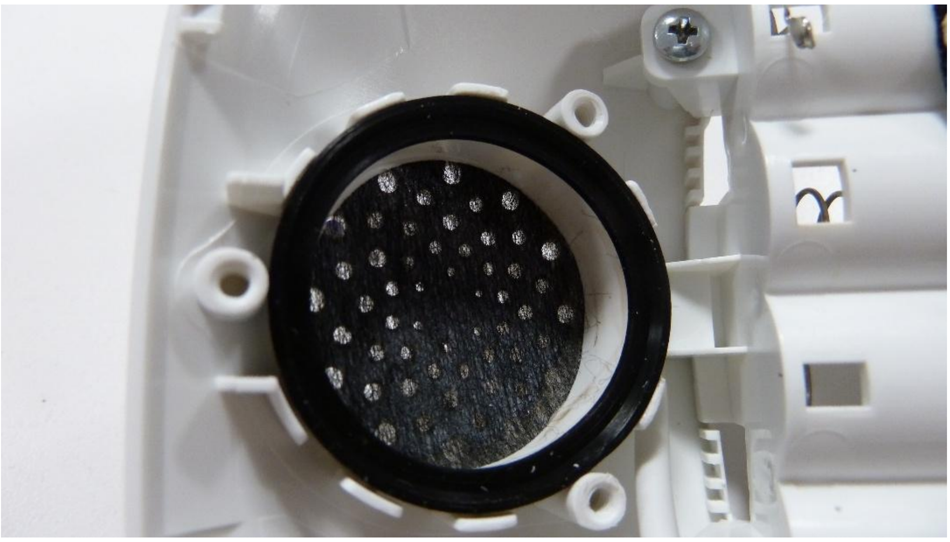


Figure 7 – Speaker 'gasket' and 'grille' in rear casing

The rear casing also contains the antenna, which is moulded from the same gloss white ABS and has a simple wire running inside the moulding.

Figure 8 – Transmitter rear casing with components removed

Rear casing

- Material – ABS / speaker unit /rubber
- Recycled content – 0%
- Weight – 39.5
- Renewable / sustainable – NO
- Conflict Minerals? - No
- Marked for recycling? - YES
- Coatings – none
- Readily recyclable - NO
- Removal – removal of 2 screws to separate the 2 halves of the casing. Then clips apart. Removal of 4 further screws needed to separate the battery holder.

The front part of the transmitter casing is again injection moulded in ABS. This moulding contains more components and sub-assemblies than the rear part as it contains the circuit board, camera unit and buttons. It has the same gloss finish and is printed in some areas with a logo and text. Unlike the rear casing this component does not seem to be marked for recycling.

Figure 9 – Transmitter front casing moulding with components removed

Front Casing

- Material – ABS
- Recycled content – 0%
- Weight – 27.6g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – Small areas of print
- Readily recyclable - NO
- Removal – removal of 2 screws to separate the 2 halves of the casing. Then clips apart. Further 6 screws removed to separate the circuit board contained within the casing.

3.3.2.3 Battery Holder

The rear casing of the transmitter has a battery compartment which is a separate moulding attached with 4 screws. The moulding contains a number of steel springs and battery terminals that simply clip in. It also contains a brass insert which is used to attach the wall bracket (if needed). The moulding does not seem to be marked for recycling.

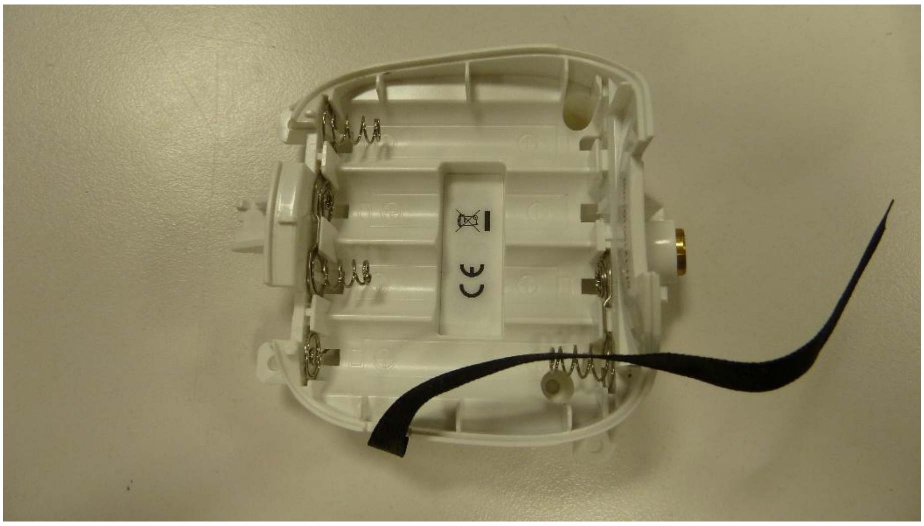


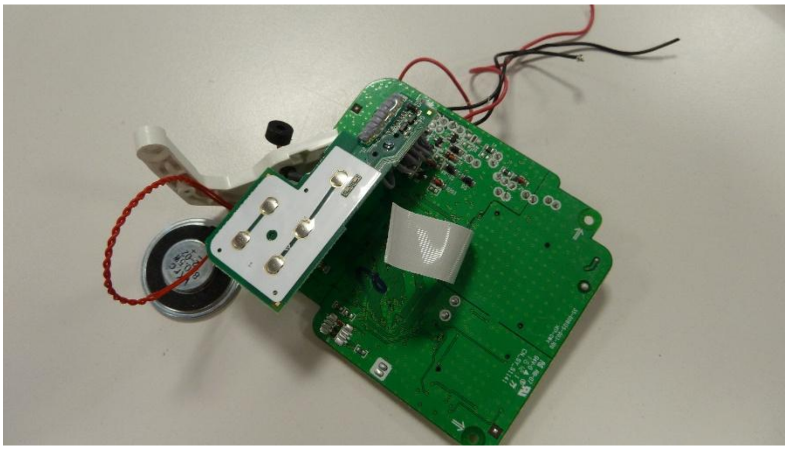
Figure 10 – Transmitter battery holder

- Material – ABS/Steel
- Recycled content – 0% for ABS, steel will contain some recycled content (unknown level)
- Weight – 25g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – None
- Readily recyclable - Yes

- Removal – removal of 4 screws to separate it from the rear casing on the transmitter.

3.3.2.4 Transmitter circuit board assembly

The circuit board assembly used in the transmitter consists of a number of components. The main PCB, a smaller PCB will contacts for buttons, speaker and wires. It removed as whole casings of the transmitter by removing a total of 6 screws from the front casing and 3 screws (for the speaker) in the rear casing. The 'trailing' wires are soldered on to the board.



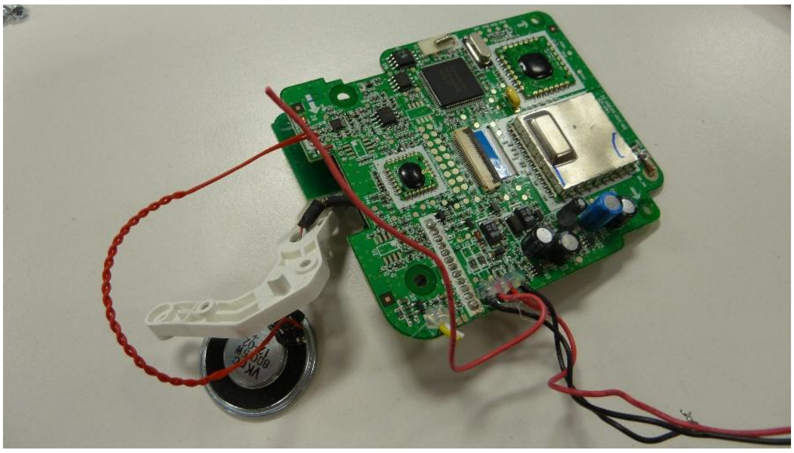


Figure 11 - Circuit board assembly components

- Material – PCB/other
- Recycled content – 0%
- Weight – ??
- Renewable / sustainable – NO
- Conflict Minerals? – Potentially
- Marked for recycling? - NO
- Coatings – conformal coating on PCB
- Readily recyclable – PCB should be able to go for precious metal recovery.
- Removal – PCB assembly uses 6 screws to hold it into the front casing. The speaker (which is attached with a wire) uses 3 screws to attach to the rear casing.

3.3.2.5 Transmitter Camera (casings)

The transmitter unit of the baby monitor contains a camera unit. This is made from ABS / PC mouldings clouded purple and a camera / PCB unit. The main casings are separated by removing 3 screws. The rear of the camera unit has a separate 'stand' component which is screwed into place. This is done as it is not possible to mould the shape in one piece. The front casing contains a silver 'surround' for the camera lens and is also printed with text. The rear of the casing is made from PC rather than ABS (for extra strength).

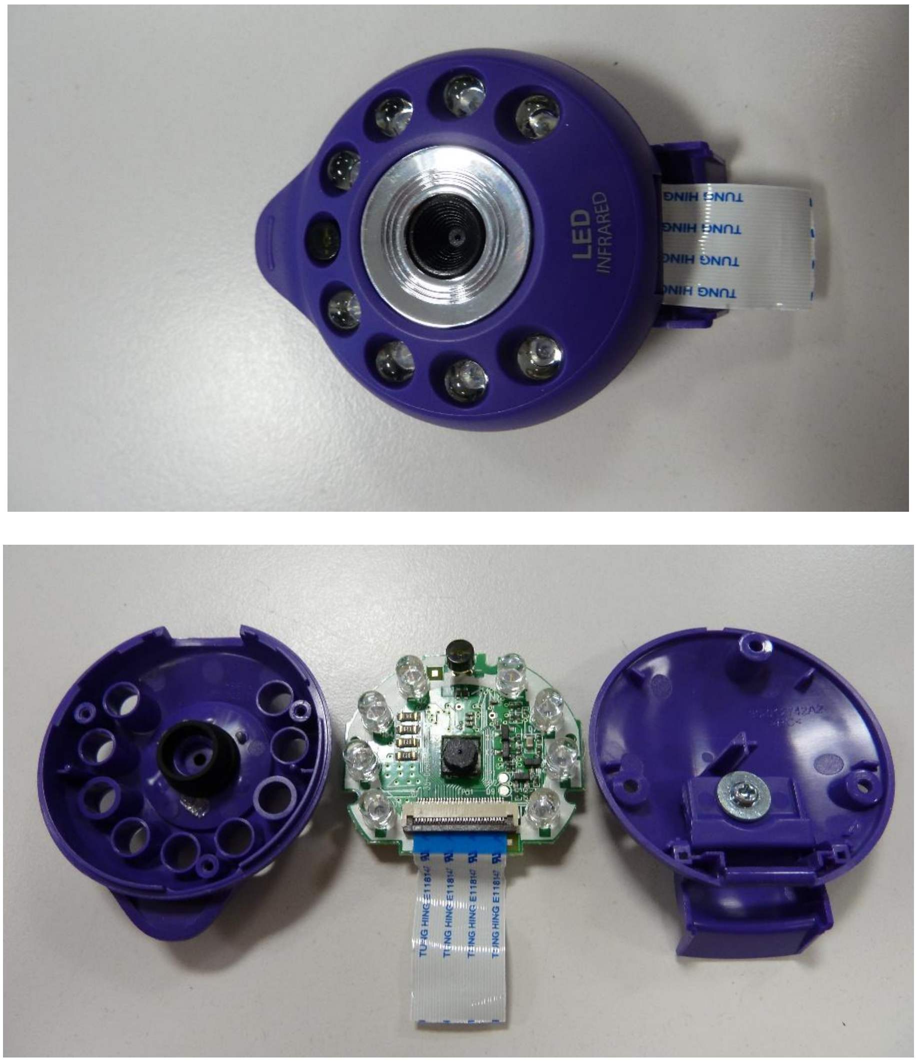


Figure 12 - Transmitter Camera Unit and components

- Material – ABS/PC – Rear case is made from PC front is made from ABS
- Recycled content – 0%
- Weight – 4.7/5.9 Total = 10.6g
- Renewable / sustainable – NO
- Conflict Minerals? – NO
- Marked for recycling? - YES
- Coatings – None (some print)
- Readily recyclable – Yes, if separated from PCB contained inside.

- Removal – Casings are separated by the removal of 3 screws.

3.3.2.6 Transmitter Camera PCB

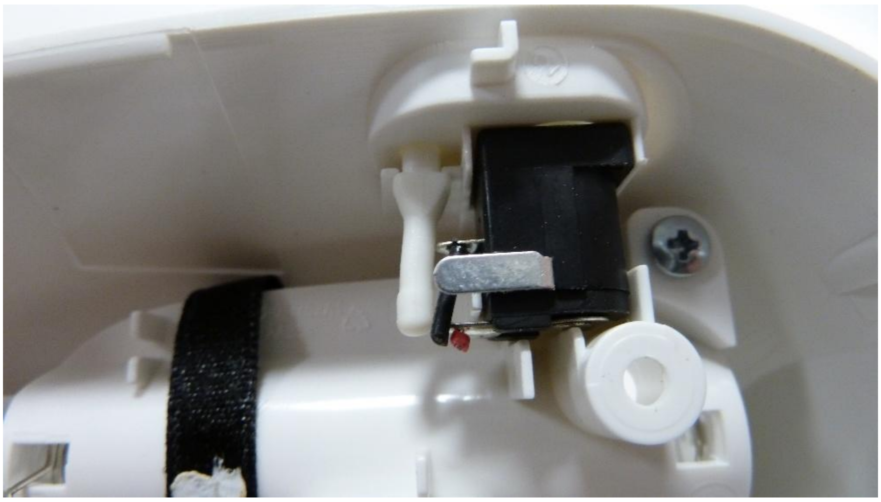
The PCB in the camera unit consists of a standard PCB unit with a number of LEDs attached as well as the small camera. It is a standard type of PCB for this application and looks as though it has a conformal coating applied. It is connected to the main circuit board in the transmitter unit with a ribbon cable.

Figure 13 - Camera Unit PCB

- Material – PCB/LED/Cable
- Recycled content – 0%
- Weight – 5.6g
- Renewable / sustainable – NO
- Conflict Minerals? – Possible
- Marked for recycling? -No
- Coatings – Conformal coating on PCB
- Readily recyclable – PCB should be able to go for precious metal recovery.
- Removal – Once casing are separated the PCB simply lifts out

3.3.2.7 Power Supply Socket

The transmitter unit is both mains and/or battery powered. A power supply socket is clipped into the rear casing. It looks to be made from nylon and is a standard component as used in this type of application across many different product types. It contains metal contacts. There is no material marking on the component but it is likely that it is made from nylon.



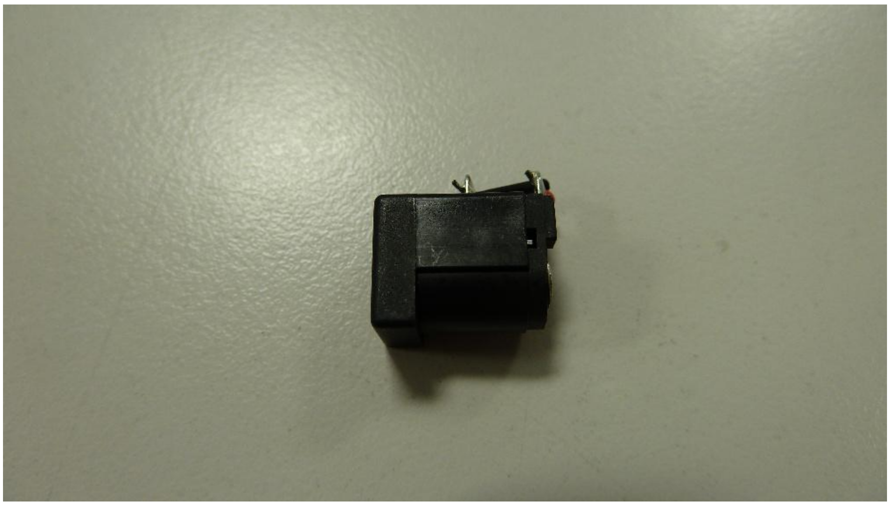


Figure 14 - Transmitter Power Supply Socket

- Material – Nylon/Steel
- Recycled content – 0%
- Weight – 1.6g
- Renewable / sustainable – NO
- Conflict Minerals? – NO
- Marked for recycling? -NO
- Coatings – NONE
- Readily recyclable – possible if separated from main casing (this is unlikely to happen)
- Removal – Once casing are separated the connector simply clips out.

3.3.2.8 Transmitter Buttons

There are 5 buttons on the front of the transmitter unit to allow the user to control a number of functions. They consist of various components made form silicone and ABS. The back on the pad is made from flexible silicone and the ABS buttons are bonded (as separate pieces) to this. Due to the use of differing materials that are permanently bonded together this component could not be recycled back into its constituent materials.

Figure 15 - Transmitter Buttons

- Material – Silicone / ABS
- Recycled content – 0%
- Weight – 5.3
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – Printed buttons
- Readily recyclable - NO
- Removal – simply sits into the transmitter front casing, so very easily removed once the casings are separated.

3.3.2.9 Transmitter screws

There are a considerable number of screws used in total for the transmitter part of the product. Overall there are 22 screws, 3 washers and a metal clip used. This is a considerable amount of fixings for a product of this type and size.

Figure 16 - Screws used in transmitter unit

- Material – Steel
- Recycled content – Unknown but steel will contain an amount of recyclate.
- Weight – 9.6g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – Passivation coating?
- Readily recyclable - YES
- Removal – Nee to be removed from various parts of the product with an appropriate screwdriver.

3.3.2.10 Transmitter wall bracket

The product comes with a bract to allow the transmitter to be attached to the wall if needed. The bracket is moulded from ABS and contains a brass screw which threads into the brass insert in the bottom of the transmitter (contained in the battery case moulding).

Figure 17 - Transmitter wall bracket

- Material – ABS
- Recycled content – 0%
- Weight – 26.2g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – NONE
- Readily recyclable – YES – however brass insert may cause some issues
- Removal – Separate piece.

3.3.2.11 Transmitter Power Supply

The transmitter uses a power supply unit to allow the products to work form the mains. The unit also charges internal batteries which will then allow the unit to be used if a power socket is not available.

The units are standrad items as used across a wide range of similar products.

- Material – ABS/Copper/PVC
- Recycled content – 0%
- Weight – 90g
- Renewable / sustainable – NO
- Conflict Minerals? - Possible
- Marked for recycling? - NO
- Coatings – NONE
- Readily recyclable – Will probably be shredded and 'downcycled'. Copper will be recovered.
- Removal – Separate piece.

3.3.3 Component 3 – Receiver

The systems receiver outputs the audio and video stream from the transmitter. It comprises of plastic mouldings, printed circuit boards and LCD screen and other components. It can powered by batteries or the mains (using a plug in power supply).

The main components of the casing are a front casing (which contains a bonded in screen), a rear casing, a battery cover and a 'frame' that separates the two halves.

Figure 18 – Receiver Unit

Figure 19 – Receiver components

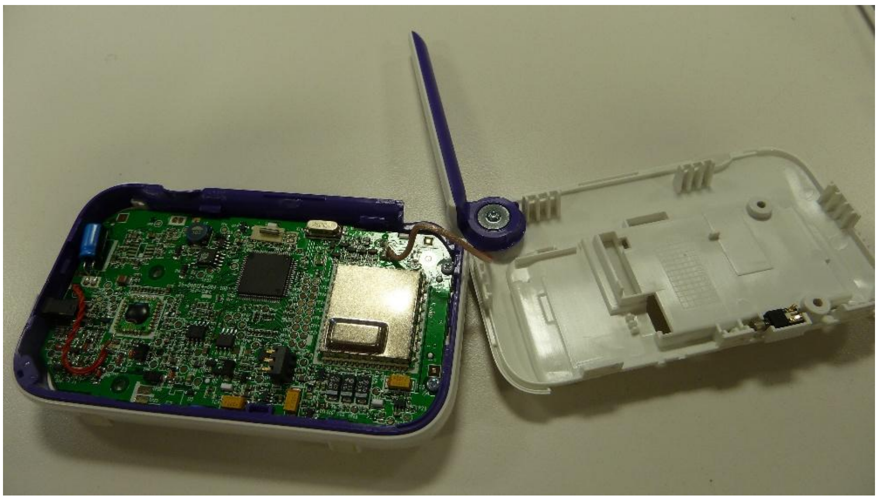
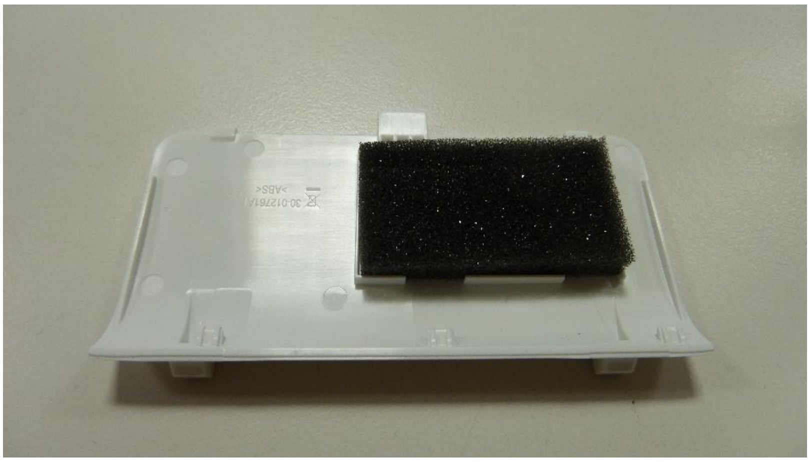


Figure 20 – Receiver components

3.3.3.1 *Receiver battery cover*

As with the cover used on the transmitter the receiver's battery cover is a relatively simple injection moulded piece. It has a high gloss finish and is not coated. It is marked for recycling, using the letters <ABS>. It is easily removed from the phone but might not be easily recycled. A foam pad is glued to the inside of the cover to help keep the batteries in place. The bonding of this foam to the ABS means that recyclability is compromised. There is also a sticker on the outside giving user advice on power management. This might also compromise recyclability.



- Material – ABS
- Recycled content – 0%
- Weight – 10.8g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - YES
- Coatings – NONE – although a sticker is applied.
- Readily recyclable – Possibly – contamination from foam.
- Removal – clips off

3.3.3.2 Receiver Casings

The receiver unit consists of 4 main parts:

1. Front casing
2. Screen (bonded into the front casing)
3. A 'frame'
4. Rear casing

The main casings and 'frame' are injection moulded from moulded from ABS. The screen is made from acrylic and is bonded into the front casing using adhesive. All the components have a high gloss finish. The casings are held together with 2 screws and once these are removed they clip apart. The circuit board held in the upper casing is held in with 2 screws and moulded clips.

Both halves of the casing are marked for recycling.

Figure 21 – Receiver front casing and screen

Figure 22 - Receiver front casing and screen separated

Figure 23 – Receiver casing 'frame'

Figure 24 - Phone cradle moulding and contacts

Rear Casing

- Material – ABS
- Recycled content – 0%
- Weight – 20.5g
- Renewable / sustainable – NO
- Conflict Minerals? - NO

- Marked for recycling? – YES
- Coatings – None
- Readily recyclable – Yes
- Removal – remove 2 screws and clipped apart from front.

Front casing

- Material – ABS
- Recycled content – 0%
- Weight – 12.9g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – YES
- Coatings – None (some print)
- Readily recyclable – NO – bonded acrylic screen contaminates this piece for recycling
- Removal – remove 2 screws and separated from lower part. Logo 'button' needs to be prized off as bonded.

Outer Casing Surround

- Material – ABS? – material not marked
- Recycled content – 0%
- Weight – 17.2
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – NO
- Coatings – NONE
- Readily recyclable – Yes (if material is 'clean' ABS)
- Removal – remove 2 screws and separated front and rear casings, 'frame' then simply clips out of front casing.

Screen

- Material – Acrylic
- Recycled content – 0%
- Weight – 11.8g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – NO
- Coatings – NONE
- Readily recyclable – NO – bonded to ABS casing with double-sided tape so not easily removable
- Removal – Has to be 'prized' apart from the casing

3.3.3.3 *Receiver Antenna*

The receiver contains an antenna. Like the transmitter this is a plastic moulding which contain a wire running up the inside if it. The plastic moulding is 2 colours (white and purple). The antenna attaches to the main casing with a single screw but can only be removed once the main casings are split open. There is also a spring used to help keep the antenna in place when raised.

Figure 25 - Receiver unit antenna

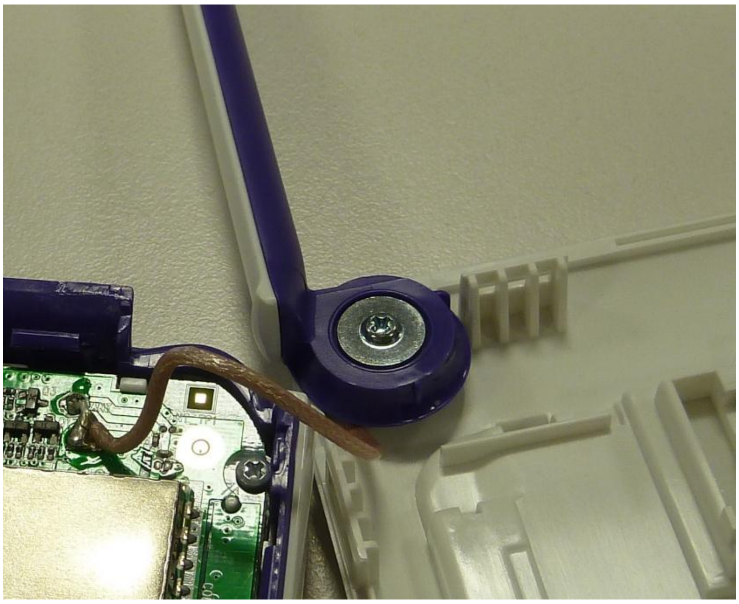


Figure 26 - Detail of receiver unit antenna fixing screw

Antenna

- Material – ABS/steel
- Recycled content – 0%
- Weight – 7g/0.5g Total 7.5g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – NONE
- Readily recyclable – Possibly – internal copper wire might cause problems.

- Removal – once main casings are split – remove one screw.

3.3.3.4 Receiver Circuit Boards

The circuit boards are contained within the front casing of the receiver unit. There are double sided boards with a range of components as well as a large LCD display unit. The speaker used to transmit audio is attached to the PCB with soldered wires. The board is held into the casing with s crews and clips.

Figure 27 - Receiver PCB in situ

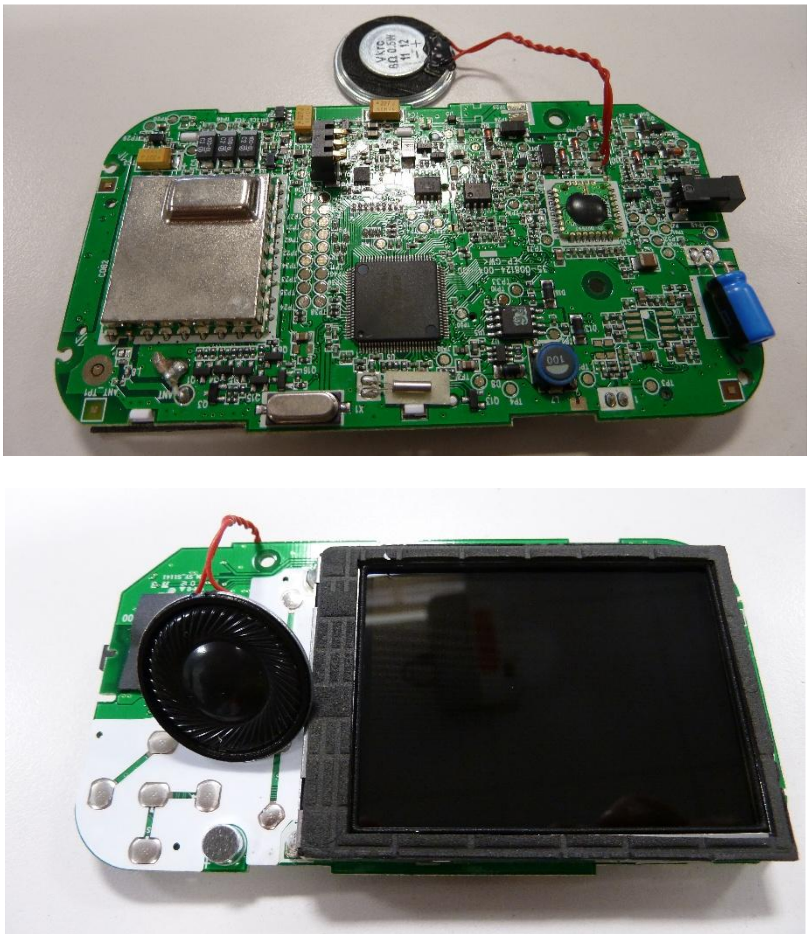


Figure 28 – Receiver circuit board and LCD assembly

PCB

- Material – Double side PCB
- Recycled content – 0%
- Weight – 70.2g
- Renewable / sustainable – NO
- Conflict Minerals? - Possibly
- Marked for recycling? - NO
- Coatings – conformal coating on PCB
- Readily recyclable – Yes (precious metal recovery)
- Removal – once main casing is split remove 2 screws

3.3.3.5 Receiver buttons

The receiver has a set of control buttons located on the front casing. The unit consists of various components made form silicone and polymer. The back on the buttons is a pad is made from flexible silicone and the polymer buttons are 'caps' bonded (as separate pieces) to this. There is no information as to the types of polymer used in the button caps as they are not marked for recycling.

Figure 29 – Receiver keypad

- Material – Silicone / Unknown polymer
- Recycled content – 0%
- Weight – 11g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – Unknown, some print on the underside of the buttons

- Readily recyclable - NO
- Removal – simply sits into the front casing, no fixings used.

3.3.3.6 Battery

A rechargeable battery is used in the receiver unit. It is a lithium polymer type of the kind used in mobile phones and other small electronic devices.

- Material – Li-Polymer Battery
- Recycled content – 0%
- Weight – 20g
- Renewable / sustainable – NO
- Conflict Minerals? - Possibly
- Marked for recycling? - YES
- Coatings – None
- Readily recyclable - Yes
- Removal – lifts out after removal of battery cover.

3.3.3.7 Screws and clips

The receiver unit only uses 5 screws in total. All other fastening are clips. The speaker is held into the front casing with a clip and a rubber gasket that means no bonding is necessary and make thing easier to separate for recycling.

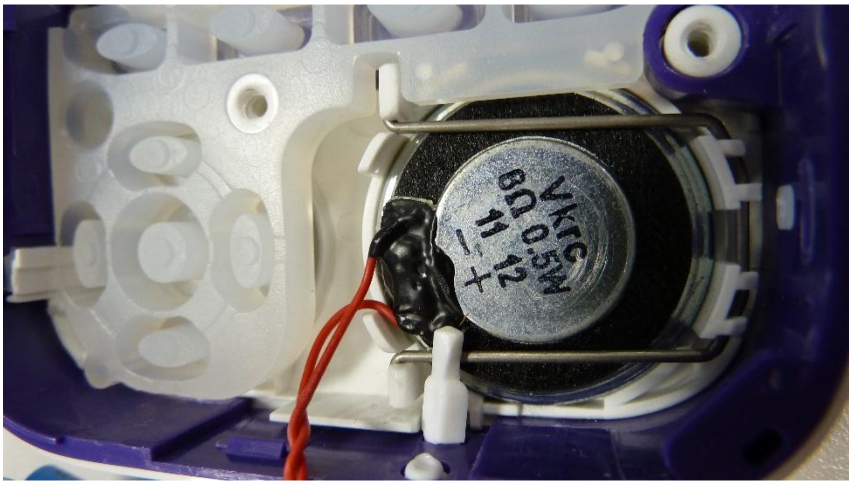


Figure 30 - Speaker clip used in front casing

Screws

- Material – Steel
- Recycled content – unknown but typically includes recycled content
- Weight – 1.7g
- Renewable / sustainable – NO
- Conflict Minerals? - NO

- Marked for recycling? – NO
- Coatings – Passivate / anti-corrosion coating?
- Readily recyclable – Yes
- Removal – removal from item using appropriate screwdriver

3.4 Proposed Design Changes

To propose appropriate design changes that will help make a tangible different in the overall life cycle impacts of the Baby Monitor these changes need to be considered in respect of the goals of a 'circular economy' Two reports[3], published in 2013 by the Ellen Macarthur Foundation explain these principles in detail.

The reports suggest that manufacturers should 'specify the purpose and performance of the end-products, more than those of the input materials'. It goes on to suggest that designers should specify 'pure materials in their production process since they are easier to sort at end of life'. The report also highlights that besides material selection, other areas important for economically successful circular design are standardised components, designed-to-last products, design for easy end-of-life sorting, separation or reuse of products and materials, and design-for-manufacturing criteria that take into account possible useful applications of by-products and wastes.

The principles relevant to this particular product can be summarised as follows:

- Improve the easy of reuse and recovery of materials
- Match the durability requirements of the product to the durability of the design
- Shift to renewable energy sources
- Build in modularity
- Think in systems rather than specific physical products

These will apply to general design themes observed in this product and can be addresses in the following ways:

3.4.1 Improving materials recovery and recycling

The baby monitor uses a number of components which are manufactured from different materials which are not compatible for recycling. This means that the recovery of the materials at end of life becomes very difficult is not impossible.

Practices observed in this product included, bonding foam to plastic components, bonding electronic components to plastic casings and bonding different types of plastics together

In order to address this, new designs should:

1. Ensure materials are clearly marked to aid recycling
2. Attempt to reduce the mix of incompatible materials to a minimum
3. If there are incompatible materials they should be east to separate and bonding them together should be avoided at all costs

[3] Towards the Circular Economy Reports 1 and 2. Ellen Macarthur Foundation 2013

4. Carefully consider the use of any coatings and how they might affect the recyclability of the materials to which they are applied.
5. Try to group similar materials together to allow easier recovery and minimal separation operations.
6. Can new technologies be used to reduce the complexity of current components? E.g. a touch screen as part of the current LCD panel rather than a spate complex keypad.
7. Consider designing components in a way that allows their re-use (if appropriate and viable in the particular product system).

3.4.2 Durability of design

When considering how durable the product needs to be, designers should consider a number of different factors such as:

1. What are the real use patterns of the product
2. How long should it last (consumer expectations)
3. What is its useful technological life – will it become obsolete due to changes in technology
4. Is it appropriate to update and repair the product (costs, expected life etc?)
5. I the product a system in its own right or is it part of another system that might change over time

If these issues are considered the products should be 'appropriate' in terms of durability and expected life. It I possible to 'overdesign' products and make them more robust and more material intensive than they actually need to be.

3.4.3 Renewable Energy Sources

The product only uses a small amount of energy in terms of the power requirement to run the system. However the power is required constantly. There are a number of options in terms of renewable energy such as solar for this particular product but the following issues need to be considered:

1. How reliable is the supply of renewable energy?
2. Does it need to be stored?
3. Can it supply the required level of power / energy
4. Does it mean that the product will have to be placed in a specific position (e.g. near a window).

3.4.4 Modularity

Designing in modularity can bring be to product in respect of the circular economy. Modularity can help extend a product's life, reduce repair costs and allow for easy upgrading. The effectiveness and appropriateness of this approach will depend on a number of factors:

1. What is the expected life of the product – is modularity a sensible approach for short life products?
2. What advantages does modularity offer?
3. Consider how this will affect the way spare parts and upgrades are sold.

The ability to replace either a receiver OR a transmitter (should one fail) would be a move towards are more circular approach. Currently additional cameras can be purchased as replacements but if the receiver fails than it cannot be replaced as a separate unit.

Many products are sold as ‘standalone’ systems. Modern technology and advances in computing, communications technology and home networking mean that in many cases the functions traditionally supplied by a range of standalone products can now be supplied by an integrated system.

For example the use of Wi-Fi enabled cameras attached to apps on phones or to laptops allows the same function as a dedicated baby monitor but uses less materials to deliver the service as it integrates into existing pieces of technology.

The integration of products into new emerging IT and communication systems will mean that the form of many products as we currently know them will change dramatically over the coming years. This could considerably reduce overall resource use for the delivery of a range of services.

See the main summary report for more detailed design proposals.

Appendix 2b

Circular Economy Assessment Product Design Assessment

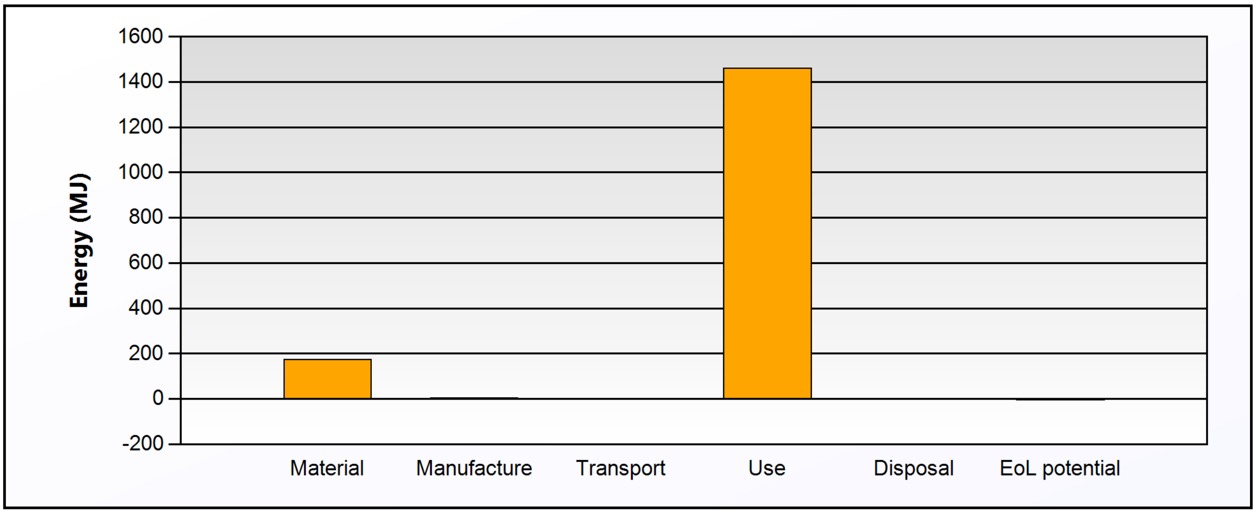
Part 2 – LCA Details

Product: **Digital Video Baby Monitor 1000**

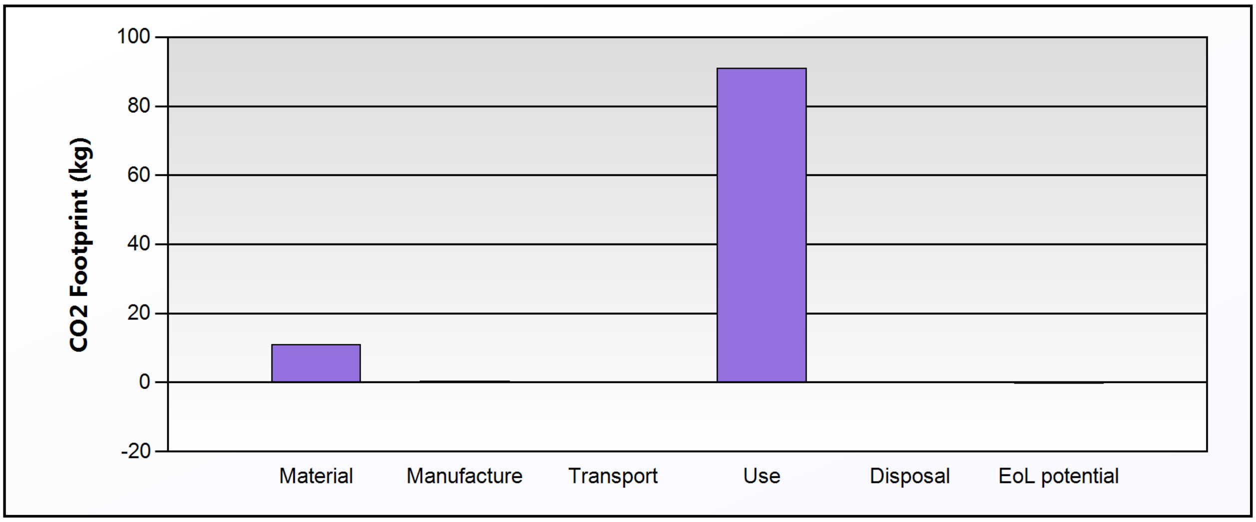
Eco Audit Report

Product Name	BT Digital Video Baby Monitor 1000
Product Life (years)	5

Energy and CO2 Footprint Summary:



Energy Details...



CO2 Details...

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	175	10.7	11	10.7
Manufacture	5.68	0.3	0.428	0.4
Transport	1.94	0.1	0.138	0.1
Use	1.46e+03	88.9	91.2	88.7
Disposal	0.371	0.0	0.026	0.0
Total (for first life)	**1.65e+03**	**100**	**103**	**100**
End of life potential	-6.56		-0.2	

Eco Audit Report

Energy Analysis

Energy and CO2 Summary

	Energy (MJ)/year
Equivalent annual environmental burden (averaged over 5 year product life):	329

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	Energy (MJ)	%
Packaging	Cardboard	50.0%	0.14	1	2.9	56	32.0
Transmitter - Front casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.028	1	0.028	2.6	1.5
Transmitter - Raer casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.04	1	0.04	3.8	2.1
Transmitter - battery holder	ABS (medium-impact, injection molding)	Virgin (0%)	0.025	1	0.025	2.4	1.4
Transmitter - battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.016	1	0.016	1.5	0.8
Transmitter - camera front	ABS (medium-impact, injection molding)	Virgin (0%)	0.0057	1	0.0057	0.54	0.3
Transmitter - camera rear	PC (high viscosity, molding and extrusion)	Virgin (0%)	0.0049	1	0.0049	0.53	0.3
Transmitter - camera PCB	Printed circuit board assembly	Virgin (0%)	0.0056	1	0.0056	0.73	0.4
Transmitter - power supply socket	PA (type 6, molding and extrusion)	Virgin (0%)	0.0016	1	0.0016	0.19	0.1
Transmitter buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.0053	1	0.0053	0.5	0.3
Transmitter - screws	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0096	1	0.0096	0.25	0.1
Transmitter - wall bracket	ABS (medium-impact, injection molding)	Virgin (0%)	0.026	1	0.026	2.5	1.4
Transmitter - power supply	Power supply unit	Virgin (0%)	0.09	1	0.09	41	23.3
Receiver - battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.011	1	0.011	1	0.6
Receiver - rear casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.021	1	0.021	1.9	1.1
Receiver - front casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.013	1	0.013	1.2	0.7
Receiver - outer casing surrond	ABS (medium-impact, injection molding)	Virgin (0%)	0.017	1	0.017	1.6	0.9
Receiver - screen	PMMA (cast sheet)	Virgin (0%)	0.012	1	0.012	1.3	0.8
Receiver - PCB/LCD unit	Printed circuit board assembly	Virgin (0%)	0.07	1	0.07	9.1	5.2
Receiver - switch	Printed circuit board assembly	Virgin (0%)	0.001	1	0.001	0.13	0.1
Receiver - antenna	ABS (medium-impact, injection molding)	Virgin (0%)	0.007	1	0.007	0.66	0.4
Receiver - antenna spring	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0005	1	0.0005	0.013	0.0
Receiver - buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.011	1	0.011	1	0.6
Reveiver - battery	Li-Ion AA cell battery	Virgin (0%)	0.02	1	0.02	4	2.3
Receiver - speaker gasket	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0002	1	0.0002	0.019	0.0
Receiver - screws	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0017	1	0.0017	0.045	0.0
Transmitter - power supply	Power supply unit	Virgin (0%)	0.09	1	0.09	41	23.3
Total				**27**	**3.4**	**1.8e+02**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	Energy (MJ)	%
Packaging	Cutting and trimming	95	2.7 kg	0.81	14.3
Transmitter - Front casing	Polymer molding	-	0.028 kg	0.57	10.0
Transmitter - Raer casing	Polymer molding	-	0.04 kg	0.82	14.4
Transmitter - battery holder	Polymer molding	-	0.025 kg	0.52	9.1
Transmitter - battery cover	Polymer molding	-	0.016 kg	0.32	5.6
Transmitter - camera front	Polymer molding	-	0.0057 kg	0.12	2.1
Transmitter - camera rear	Polymer molding	-	0.0049 kg	0.096	1.7
Transmitter - power supply socket	Polymer molding	-	0.0016 kg	0.035	0.6
Transmitter buttons	Polymer molding	-	0.0053 kg	0.11	1.9
Transmitter - screws	Rough rolling, forging	-	0.0096 kg	0.026	0.5
Transmitter - wall bracket	Polymer molding	-	0.026 kg	0.54	9.5
Receiver - battery cover	Polymer molding	-	0.011 kg	0.22	3.9
Receiver - rear casing	Polymer molding	-	0.021 kg	0.42	7.5
Receiver - front casing	Polymer molding	-	0.013 kg	0.27	4.7
Receiver - outer casing surrond	Polymer molding	-	0.017 kg	0.36	6.3
Receiver - screen	Polymer extrusion	-	0.012 kg	0.071	1.3
Receiver - antenna	Polymer molding	-	0.007 kg	0.14	2.5
Receiver - antenna spring	Rough rolling, forging	-	0.0005 kg	0.0014	0.0
Receiver - buttons	Polymer molding	-	0.011 kg	0.23	4.0
Receiver - speaker gasket	Polymer molding	-	0.0002 kg	0.0035	0.1
Receiver - screws	Rough rolling, forging	-	0.0017 kg	0.0046	0.1
Total				**5.7**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage

Total product mass = 0.67 kg

Stage name	Transport type	Distance (km)	Energy (MJ)	%
Transport form China	Sea freight	1.8e+04	1.9	100.0
Total		**1.8e+04**	**1.9**	**100**

Breakdown by components

Component	Component mass (kg)	Energy (MJ)	%
Packaging	0.14	0.41	21.2
Transmitter - Front casing	0.028	0.079	4.1
Transmitter - Raer casing	0.04	0.11	5.9
Transmitter - battery holder	0.025	0.072	3.7
Transmitter - battery cover	0.016	0.045	2.3
Transmitter - camera front	0.0057	0.016	0.8
Transmitter - camera rear	0.0049	0.014	0.7
Transmitter - camera PCB	0.0056	0.016	0.8
Transmitter - power supply socket	0.0016	0.0046	0.2
Transmitter buttons	0.0053	0.015	0.8
Transmitter - screws	0.0096	0.028	1.4
Transmitter - wall bracket	0.026	0.075	3.9
Transmitter - power supply	0.09	0.26	13.3
Receiver - battery cover	0.011	0.031	1.6
Receiver - rear casing	0.021	0.059	3.0
Receiver - front casing	0.013	0.037	1.9
Receiver - outer casing surrond	0.017	0.05	2.6
Receiver - screen	0.012	0.034	1.8
Receiver - PCB/LCD unit	0.07	0.2	10.4
Receiver - switch	0.001	0.0029	0.1
Receiver - antenna	0.007	0.02	1.0
Receiver - antenna spring	0.0005	0.0014	0.1
Receiver - buttons	0.011	0.032	1.6
Reveiver - battery	0.02	0.058	3.0
Receiver - speaker gasket	0.0002	0.00058	0.0
Receiver - screws	0.0017	0.0049	0.3
Transmitter - power supply	0.09	0.26	13.3
Total	**0.67**	**1.9**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	4
Usage (hours per day)	24
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	Energy (MJ)	%
Static	1.5e+03	100.0
Mobile	0	
Total	**1.5e+03**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	Energy (MJ)	%
Packaging	Recycle	100.0	0.1	26.9
Transmitter - Front casing	Downcycle	100.0	0.014	3.7
Transmitter - Raer casing	Downcycle	100.0	0.02	5.3
Transmitter - battery holder	Downcycle	100.0	0.013	3.4
Transmitter - battery cover	Downcycle	100.0	0.0078	2.1
Transmitter - camera front	Downcycle	100.0	0.0029	0.8
Transmitter - camera rear	Downcycle	100.0	0.0025	0.7
Transmitter - camera PCB	Landfill	100.0	0.0011	0.3
Transmitter - power supply socket	Downcycle	100.0	0.0008	0.2
Transmitter buttons	Downcycle	100.0	0.0027	0.7
Transmitter - screws	Recycle	100.0	0.0067	1.8
Transmitter - wall bracket	Recycle	100.0	0.018	4.9
Transmitter - power supply	Downcycle	100.0	0.045	12.1
Receiver - battery cover	Downcycle	100.0	0.0054	1.5
Receiver - rear casing	Downcycle	100.0	0.01	2.8
Receiver - front casing	Downcycle	100.0	0.0065	1.7
Receiver - outer casing surrond	Downcycle	100.0	0.0086	2.3
Receiver - screen	Downcycle	100.0	0.0059	1.6
Receiver - PCB/LCD unit	Downcycle	100.0	0.035	9.5
Receiver - switch	Downcycle	100.0	0.0005	0.1
Receiver - antenna	Downcycle	100.0	0.0035	0.9
Receiver - antenna spring	Recycle	100.0	0.00035	0.1
Receiver - buttons	Downcycle	100.0	0.0055	1.5
Reveiver - battery	Downcycle	100.0	0.01	2.7
Receiver - speaker gasket	Downcycle	100.0	0.0001	0.0
Receiver - screws	Recycle	100.0	0.0012	0.3
Transmitter - power supply	Downcycle	100.0	0.045	12.1
Total			**0.37**	**100**

EoL potential:

Component	End of life option	% recovered	Energy (MJ)	%
Packaging	Recycle	100.0	-1.9	29.5
Transmitter - Front casing	Downcycle	100.0	-0.35	5.3
Transmitter - Raer casing	Downcycle	100.0	-0.5	7.6
Transmitter - battery holder	Downcycle	100.0	-0.31	4.8
Transmitter - battery cover	Downcycle	100.0	-0.19	3.0
Transmitter - camera front	Downcycle	100.0	-0.071	1.1
Transmitter - camera rear	Downcycle	100.0	-0.07	1.1
Transmitter - camera PCB	Landfill	100.0	0	0.0
Transmitter - power supply socket	Downcycle	100.0	-0.026	0.4
Transmitter buttons	Downcycle	100.0	-0.066	1.0
Transmitter - screws	Recycle	100.0	-0.18	2.8
Transmitter - wall bracket	Recycle	100.0	-1.6	25.1
Transmitter - power supply	Downcycle	100.0	0	0.0
Receiver - battery cover	Downcycle	100.0	-0.14	2.1
Receiver - rear casing	Downcycle	100.0	-0.26	3.9
Receiver - front casing	Downcycle	100.0	-0.16	2.5
Receiver - outer casing surrond	Downcycle	100.0	-0.22	3.3
Receiver - screen	Downcycle	100.0	-0.17	2.7
Receiver - PCB/LCD unit	Downcycle	100.0	0	0.0
Receiver - switch	Downcycle	100.0	0	0.0
Receiver - antenna	Downcycle	100.0	-0.088	1.3
Receiver - antenna spring	Recycle	100.0	-0.0095	0.1
Receiver - buttons	Downcycle	100.0	-0.14	2.1
Reveiver - battery	Downcycle	100.0	0	0.0
Receiver - speaker gasket	Downcycle	100.0	0	0.0
Receiver - screws	Recycle	100.0	-0.032	0.5
Transmitter - power supply	Downcycle	100.0	0	0.0
Total			**-6.6**	**100**

Notes:

Energy and CO2 Summary

Eco Audit Report

CO2 Footprint Analysis

Energy and CO2 Summary

	CO2 (kg)/year
Equivalent annual environmental burden (averaged over 5 year product life):	20.5

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	CO2 footprint (kg)	%
Packaging	Cardboard	50.0%	0.14	1	2.9	2.8	25.6
Transmitter - Front casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.028	1	0.028	0.11	1.0
Transmitter - Raer casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.04	1	0.04	0.15	1.4
Transmitter - battery holder	ABS (medium-impact, injection molding)	Virgin (0%)	0.025	1	0.025	0.096	0.9
Transmitter - battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.016	1	0.016	0.059	0.5
Transmitter - camera front	ABS (medium-impact, injection molding)	Virgin (0%)	0.0057	1	0.0057	0.022	0.2
Transmitter - camera rear	PC (high viscosity, molding and extrusion)	Virgin (0%)	0.0049	1	0.0049	0.03	0.3
Transmitter - camera PCB	Printed circuit board assembly	Virgin (0%)	0.0056	1	0.0056	0.054	0.5
Transmitter - power supply socket	PA (type 6, molding and extrusion)	Virgin (0%)	0.0016	1	0.0016	0.013	0.1
Transmitter buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.0053	1	0.0053	0.02	0.2
Transmitter - screws	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0096	1	0.0096	0.017	0.2
Transmitter - wall bracket	ABS (medium-impact, injection molding)	Virgin (0%)	0.026	1	0.026	0.1	0.9
Transmitter - power supply	Power supply unit	Virgin (0%)	0.09	1	0.09	3.1	27.9
Receiver - battery cover	ABS (medium-impact, injection molding)	Virgin (0%)	0.011	1	0.011	0.041	0.4
Receiver - rear casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.021	1	0.021	0.079	0.7
Receiver - front casing	ABS (medium-impact, injection molding)	Virgin (0%)	0.013	1	0.013	0.049	0.4
Receiver - outer casing surrond	ABS (medium-impact, injection molding)	Virgin (0%)	0.017	1	0.017	0.066	0.6
Receiver - screen	PMMA (cast sheet)	Virgin (0%)	0.012	1	0.012	0.08	0.7
Receiver - PCB/LCD unit	Printed circuit board assembly	Virgin (0%)	0.07	1	0.07	0.68	6.2
Receiver - switch	Printed circuit board assembly	Virgin (0%)	0.001	1	0.001	0.0097	0.1
Receiver - antenna	ABS (medium-impact, injection molding)	Virgin (0%)	0.007	1	0.007	0.027	0.2
Receiver - antenna spring	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0005	1	0.0005	0.0009	0.0
Receiver - buttons	ABS (medium-impact, injection molding)	Virgin (0%)	0.011	1	0.011	0.042	0.4
Reveiver - battery	Li-Ion AA cell battery	Virgin (0%)	0.02	1	0.02	0.3	2.7
Receiver - speaker gasket	Ethylene propylene (diene) (EPDM/EPM, unreinforced)	Virgin (0%)	0.0002	1	0.0002	0.0009	0.0
Receiver - screws	Carbon steel, AISI 1010, annealed	Virgin (0%)	0.0017	1	0.0017	0.0031	0.0
Transmitter - power supply	Power supply unit	Virgin (0%)	0.09	1	0.09	3.1	27.9
Total				**27**	**3.4**	**11**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	CO2 footprint (kg)	%
Packaging	Cutting and trimming	95	2.7 kg	0.062	14.6
Transmitter - Front casing	Polymer molding	-	0.028 kg	0.043	10.0
Transmitter - Raer casing	Polymer molding	-	0.04 kg	0.061	14.3
Transmitter - battery holder	Polymer molding	-	0.025 kg	0.039	9.1
Transmitter - battery cover	Polymer molding	-	0.016 kg	0.024	5.6
Transmitter - camera front	Polymer molding	-	0.0057 kg	0.0088	2.1
Transmitter - camera rear	Polymer molding	-	0.0049 kg	0.0072	1.7
Transmitter - power supply socket	Polymer molding	-	0.0016 kg	0.0026	0.6
Transmitter buttons	Polymer molding	-	0.0053 kg	0.0082	1.9
Transmitter - screws	Rough rolling, forging	-	0.0096 kg	0.0019	0.5
Transmitter - wall bracket	Polymer molding	-	0.026 kg	0.041	9.5
Receiver - battery cover	Polymer molding	-	0.011 kg	0.017	3.9
Receiver - rear casing	Polymer molding	-	0.021 kg	0.032	7.4
Receiver - front casing	Polymer molding	-	0.013 kg	0.02	4.7
Receiver - outer casing surround	Polymer molding	-	0.017 kg	0.027	6.2
Receiver - screen	Polymer extrusion	-	0.012 kg	0.0053	1.2
Receiver - antenna	Polymer molding	-	0.007 kg	0.011	2.5
Receiver - antenna spring	Rough rolling, forging	-	0.0005 kg	0.0001	0.0
Receiver - buttons	Polymer molding	-	0.011 kg	0.017	4.0
Receiver - speaker gasket	Polymer molding	-	0.0002 kg	0.00028	0.1
Receiver - screws	Rough rolling, forging	-	0.0017 kg	0.00034	0.1
Total				**0.43**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage

Total product mass = 0.67 kg

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
Transport form China	Sea freight	1.8e+04	0.14	100.0
Total		**1.8e+04**	**0.14**	**100**

Breakdown by components

Component	Component mass (kg)	CO2 footprint (kg)	%
Packaging	0.14	0.029	21.2
Transmitter - Front casing	0.028	0.0056	4.1
Transmitter - Raer casing	0.04	0.0081	5.9
Transmitter - battery holder	0.025	0.0051	3.7
Transmitter - battery cover	0.016	0.0032	2.3
Transmitter - camera front	0.0057	0.0012	0.8
Transmitter - camera rear	0.0049	0.001	0.7
Transmitter - camera PCB	0.0056	0.0011	0.8
Transmitter - power supply socket	0.0016	0.00033	0.2
Transmitter buttons	0.0053	0.0011	0.8
Transmitter - screws	0.0096	0.002	1.4
Transmitter - wall bracket	0.026	0.0054	3.9
Transmitter - power supply	0.09	0.018	13.3
Receiver - battery cover	0.011	0.0022	1.6
Receiver - rear casing	0.021	0.0042	3.0
Receiver - front casing	0.013	0.0026	1.9
Receiver - outer casing surrond	0.017	0.0035	2.6
Receiver - screen	0.012	0.0024	1.8
Receiver - PCB/LCD unit	0.07	0.014	10.4
Receiver - switch	0.001	0.0002	0.1
Receiver - antenna	0.007	0.0014	1.0
Receiver - antenna spring	0.0005	0.0001	0.1
Receiver - buttons	0.011	0.0022	1.6
Reveiver - battery	0.02	0.0041	3.0
Receiver - speaker gasket	0.0002	4.1e-05	0.0
Receiver - screws	0.0017	0.00035	0.3
Transmitter - power supply	0.09	0.018	13.3
Total	**0.67**	**0.14**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	4
Usage (hours per day)	24
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	91	100.0
Mobile	0	
Total	**91**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	CO2 footprint (kg)	%
Packaging	Recycle	100.0	0.007	26.9
Transmitter - Front casing	Downcycle	100.0	0.00097	3.7
Transmitter - Raer casing	Downcycle	100.0	0.0014	5.3
Transmitter - battery holder	Downcycle	100.0	0.00088	3.4
Transmitter - battery cover	Downcycle	100.0	0.00054	2.1
Transmitter - camera front	Downcycle	100.0	0.0002	0.8
Transmitter - camera rear	Downcycle	100.0	0.00017	0.7
Transmitter - camera PCB	Landfill	100.0	7.8e-05	0.3
Transmitter - power supply socket	Downcycle	100.0	5.6e-05	0.2
Transmitter buttons	Downcycle	100.0	0.00019	0.7
Transmitter - screws	Recycle	100.0	0.00047	1.8
Transmitter - wall bracket	Recycle	100.0	0.0013	4.9
Transmitter - power supply	Downcycle	100.0	0.0031	12.1
Receiver - battery cover	Downcycle	100.0	0.00038	1.5
Receiver - rear casing	Downcycle	100.0	0.00072	2.8
Receiver - front casing	Downcycle	100.0	0.00045	1.7
Receiver - outer casing surrond	Downcycle	100.0	0.0006	2.3
Receiver - screen	Downcycle	100.0	0.00041	1.6
Receiver - PCB/LCD unit	Downcycle	100.0	0.0025	9.5
Receiver - switch	Downcycle	100.0	3.5e-05	0.1
Receiver - antenna	Downcycle	100.0	0.00025	0.9
Receiver - antenna spring	Recycle	100.0	2.5e-05	0.1
Receiver - buttons	Downcycle	100.0	0.00039	1.5
Reveiver - battery	Downcycle	100.0	0.0007	2.7
Receiver - speaker gasket	Downcycle	100.0	7e-06	0.0
Receiver - screws	Recycle	100.0	8.3e-05	0.3
Transmitter - power supply	Downcycle	100.0	0.0031	12.1
Total			**0.026**	**100**

EoL potential:

Component	End of life option	% recovered	CO2 footprint (kg)	%
Packaging	Recycle	100.0	-0.0026	1.3
Transmitter - Front casing	Downcycle	100.0	-0.014	7.0
Transmitter - Raer casing	Downcycle	100.0	-0.02	10.0
Transmitter - battery holder	Downcycle	100.0	-0.013	6.3
Transmitter - battery cover	Downcycle	100.0	-0.0078	3.9
Transmitter - camera front	Downcycle	100.0	-0.0029	1.4
Transmitter - camera rear	Downcycle	100.0	-0.0039	2.0
Transmitter - camera PCB	Landfill	100.0	0	0.0
Transmitter - power supply socket	Downcycle	100.0	-0.0017	0.8
Transmitter buttons	Downcycle	100.0	-0.0027	1.3
Transmitter - screws	Recycle	100.0	-0.012	5.9
Transmitter - wall bracket	Recycle	100.0	-0.066	33.2
Transmitter - power supply	Downcycle	100.0	0	0.0
Receiver - battery cover	Downcycle	100.0	-0.0055	2.7
Receiver - rear casing	Downcycle	100.0	-0.01	5.2
Receiver - front casing	Downcycle	100.0	-0.0065	3.3
Receiver - outer casing surrond	Downcycle	100.0	-0.0087	4.4
Receiver - screen	Downcycle	100.0	-0.011	5.3
Receiver - PCB/LCD unit	Downcycle	100.0	0	0.0
Receiver - switch	Downcycle	100.0	0	0.0
Receiver - antenna	Downcycle	100.0	-0.0035	1.8
Receiver - antenna spring	Recycle	100.0	-0.00062	0.3
Receiver - buttons	Downcycle	100.0	-0.0056	2.8
Reveiver - battery	Downcycle	100.0	0	0.0
Receiver - speaker gasket	Downcycle	100.0	0	0.0
Receiver - screws	Recycle	100.0	-0.0021	1.1
Transmitter - power supply	Downcycle	100.0	0	0.0
Total			**-0.2**	**100**

Notes:

Energy and CO2 Summary

Appendix 3a

Circular Economy Assessment Product Design Assessment

Part 1 – Abridged LCA

Product: **Y-cam Knight S Camera**

Sub-Contents

1 Introduction & Aims

Better Future is the name of a pan-BT programme to deliver on BT's strategic aim to be a responsible and sustainable business leader.

BT Group's Better Future strategy has three dimensions; Building stronger communities through the power of their technology and people, reducing carbon emissions and their impact on the environment through their operations and products, and behaving responsibly towards their customers, people and their suppliers.

One of BT's goals is 'Net Good' where BT's products will achieve three times the carbon saving for their customers than they emit over their lifetime. An enabler of Net Good is implementation of the Circular Economy (CE) principles.

How products are made, what they are made of, where they are made, and what happens at the End of Life (EoL) is crucial to the Net Good strategy.

An abridged Life cycle Assessment (LCA) design review has been undertaken on a Digital Video Baby Monitor 1000. The **Y-Cam** is a product which can offer the same function as the baby monitor (by integrating it into current technologies such as laptops or smartphones) but may be less resource intensive. The aim of this assessment is to review the Y-cam in the same way as the baby monitor and then use this as a benchmark to compare the two alternative ways of providing the same technology.

The goal of this work is to provide evidence-based recommendations to BT on a number of key materials' areas and manufacturing processes, and provide a risk analysis in the form of:

1. **BAU** (do nothing)
2. **Incremental** (BAU+ small changes here and there)
3. **Component** (Mostly BAU, but swap out parts/processes)
4. **Transformational** (Making a big step, adopting total supply chain approach, Circular Economy principles)

The assessment of a non-BT product which could be used to fulfil the same function as a BT product allows a comparison of other alternatives for the delivery of a given function or service.

2 Product Assessment Methodology

There are many ways in which to assess the overall life cycle environmental impacts of a product. The most well-known is Life Cycle Assessment (LCA). LCA is a technique used to assess environmental impacts associated with all the stages of a product's life from-cradle-to-grave (i.e., from raw material extraction through materials processing, manufacture, distribution, use, repair and maintenance, and disposal or recycling. Undertaking a full and scientifically rigorous LCA is very time consuming and expensive. The main stages are:

- Compiling an inventory of relevant energy and material inputs and environmental releases;
- Evaluating the potential impacts associated with identified inputs and releases;

- Interpreting the results to help make a more informed decision.

A full LCA requires the collection of specific data related to the exact materials and manufacturing practices used and the results of such studies are usually complex and for non-experts, difficult to understand.

There is a much more practical method of undertaking assessments known as an abridged LCA. These types of studies us the same principles of full LCA in that they consider the whole life cycle of a product but they use secondary data (from published datasets) and usually consider a limited number of impacts such as Carbon and energy footprints.

The two BT products assessed in this work were done so using an abridged LCA technique through the use of the Eco Audit function of the Cambridge Engineering Selector (CES) software[1]. These assessments require the input of a bill of materials for the product in question and the definition of generic processing routes as well as information relating to energy consumption during use and likely disposal routes at end of life. The assessment also takes into account the impacts of shipping the finished item at end of life.

As well as the use of software to assess the overall carbon and energy impacts of the products in question a design review in respect of CE principles was also undertaken. This involved the physical teardown and examination of the product to identify areas of concern / good practice.

2.1 Physical Teardown and Assessment

Detailed bills of materials containing list of materials, components and weights were not available for the product being assessed. Therefore the product was physically disassembled. This allowed the identification of material types, the measurement of their weights and the assessment of processing routes used. The teardown included the packaging as well as the product itself.

The product was broken down into its constituent parts. Each part was weighed, materials identified and, where possible, the processing routes identified. Where components or materials were joined together they were separated if possible. Where multi-material components were impossible to separate estimates were made in regard if the weights of the different constituent materials.

As well as assessing quantifiable parameters the product were considered in respect of use of recycled content, ease of recyclability and design features that affect the CE principles.

Many of the design features exist as they fulfil a functional and / or aesthetic requirement. When the assessment was undertaken these issues were taken into account and considered when alternative solutions were proposed.

The physical teardown gives and invaluable insight into the design, form and function of a product. The process of disassembly shows how easy materials and components are to separate, highlights

[1] http://www.grantadesign.com/products/ces

issues relating to materials, processes, design and the implications these have on durability, use patterns and end of life options.

2.2 Use of CES Software

The quantitative information gained from the physical teardown stage was used to undertake a whole-life impact assessment using Granta CES Software. This software uses a database of materials properties (which included environmental measures such as Energy and CO_2e) to generate a whole life cycle impact and communicate how each life cycle stage contributes to this.

The bill of materials was entered and estimates of energy consumption during use were also added. The product is manufactured in China so the transport of the products to the UK by sea freight was included in the assessment. Finally, the expected end of life scenario for the product was described in CES. As this product is a small electrical item which come under the requirements of the WEEE Directive it is anticipated that it would be returned or collected for recovery and recycling. In the majority of cases these types of products are shredded and material recover is undertaken where possible. For the assessment an end of life scenario of 'downcycling' was specific for the majority of materials in both products as it is very unlikely that they would go through a closed loop recycling process and the materials be re-used in similar products.

The expected life of the product was set at 5 years. The assumptions made in respect of energy consumption is shown later in this report.

The results were exported into MS Excel to allow manipulation of the figures and presentation in a pie-chart format.

3 Product Assessment Results

3.1 Summary of Lice Cycle Impacts

Using the bill of materials generated form a teardown of the product and certain assumptions about the end-of-life scenarios for the materials and components a simplified life cycle assessment was undertaken using CES Selector software. This is an 'indicative' study that allows the identification of the largest areas of life cycle impact in terms of energy and carbon. It is not a scientifically rigorous study but can be used to identify areas where changes can be made in the product's design to allow overall life cycle impacts to be reduced. A product life of 5 years has been presumed for this assessment.

The overall life cycle carbon footprint is somewhere in the region of 65 kg. Figure 1 details the different life cycle contributions to this overall figure.

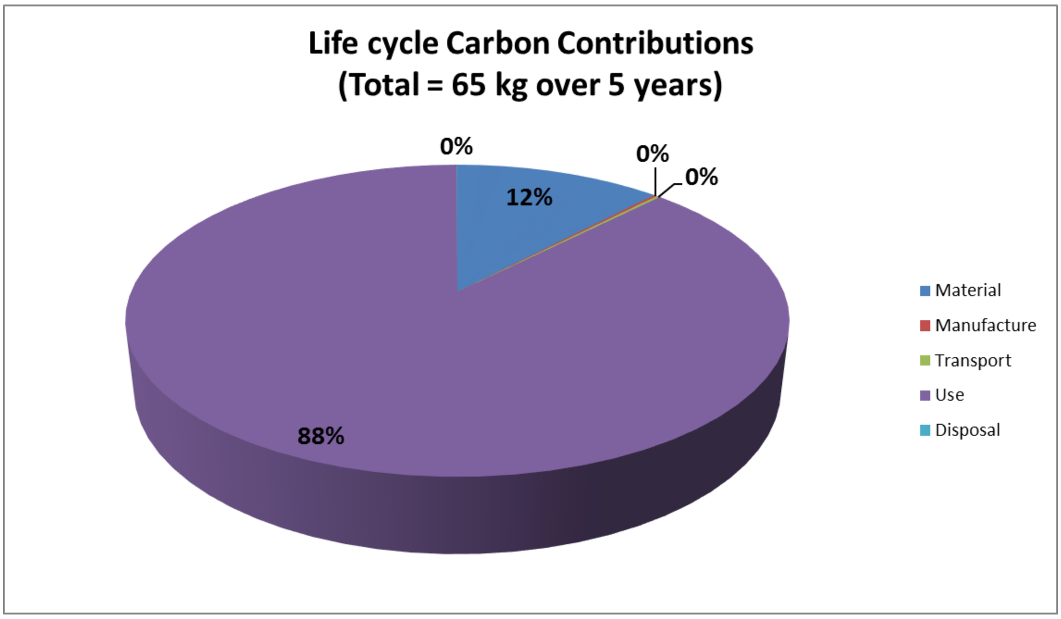


Figure 1 - Overall Life Cycle carbon impact of the Y-cam Knight S

As can be seen the vast majority of the impact of the product comes from the use of energy during its use.

3.2 Total material intensity

To deliver its function over its 5 year life the product uses a total of 0.74kg o of materials in terms of the physical material embodied in the final product. It does not account for any materials and wastage apparent in the extraction/refining/processing stages. This includes packaging and batteries but does not include any repairs or accessories that are added during the product's life. It should be noted that over 170g (23%) of this is from a large steel mounting bracket supplied with the camera.

In respect of circular economy goals a number of issues can be highlighted.

3.2.1 Total recycled content

The total recycled content of the product is currently very low. Only the metals content will contain recyclate as the supply chains of these materials use an amount of recyclate as standard practice. All the polymers used are currently 100% virgin. The cardboard in the packaging materials will contain up to 70% recycled fibres. Therefore it is estimated that approximately 33% of the current product (by weight) is made from recycled materials.

3.2.2 Total easily recyclable

The design of the product and the manufacturing operations used to make it have an effect on how easy it is to recycle at the end-of-life and recovery materials for re-use. This product contains a number of different materials and components, some of which are permanently bonded together. This will compromise the ability to recover materials for recycling and may mean that the product ends up being 'downcylced'. In downcycling a material is processed into a material of lower quality. Typical examples include the conversion of: PET drink bottles into fibres for fleece clothing, crushing concrete and brick for use as an aggregate replacement, and reprocessing PP packaging as a wood replacement (decking, park benches). Although it does recover materials, the value is much reduced when compared to recycling (where material is reprocessed into a material of similar quality).

Currently is it estimated that the opportunities to recycle, downcycle and landfill the products are as shown in figure 2.

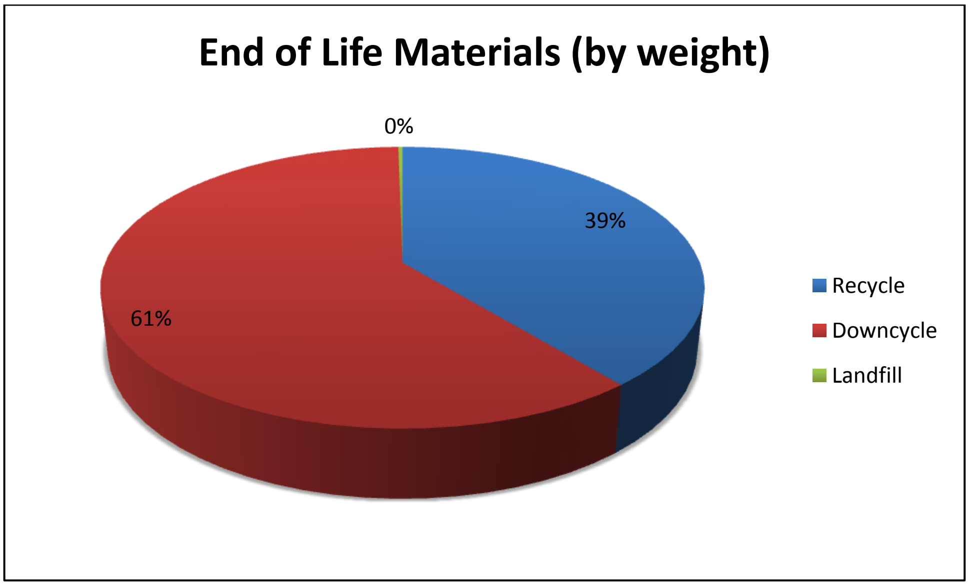


Figure 2 - Estimated end of life routes for materials (by weight)

These figures are a 'best case' scenario, based on the assumption that any clean easily separated non-contaminated plastics will be recycled as will the metals as they can be easily separated even after a product has been shredded. The majority of the materials and components will be downcycled through a shredding process, which is the most likely route for small electrical products like this. The high level of recyclability (by weight) comes from the ease of recycling the camera mount bracket which is made from steel and packaging which is made from cardboard.

3.2.3 Overall Energy consumption

The product requires energy to function. The receiver part of the product is battery powered and need recharging. The transmitter unit is powered from the mains.

It is estimated that the camera will draw 5w at full power. Full power is assumed to be used when the camera is functioning. It has been assumed that the camera will be functioning for 12 hours each day.

Total in-use energy consumption over 5 years is approximately 110 kWh. This is the energy consumed at the mains. The energy required to supply this is much higher due to losses and inefficiencies in the electricity generation and transmission system. These are taken into account in the data show earlier in Figure 1.

If this energy is supplied by the UK grid the associated carbon impacts[2] would be 64.6 kg CO_2e. *NB the CES model uses a more simplified approach to energy use and therefore produces slightly different figures.*

3.2.4 Conflict minerals

Conflict minerals are minerals mined in conditions of armed conflict and human rights abuses, notably in the eastern provinces of the Democratic Republic of the Congo. The profits from the sale of these minerals finance continued fighting in wars, and control of lucrative mines becomes a focus of the fighting as well. The most commonly mined minerals are cassiterite, wolframite, coltan, and gold, which are extracted from the Eastern Congo, and passed through a variety of intermediaries before being purchased by multinational electronics companies.

- Coltan is the metal ore from which the element tantalum is extracted. Tantalum is used primarily for the production of capacitors, particularly for applications requiring high performance, a small compact format and high reliability, ranging widely from hearing aids and pacemakers, to airbags, GPS, ignition systems and anti-lock braking systems in automobiles, through to laptop computers, mobile phones, video game consoles, video cameras and digital cameras.
- Cassiterite is the chief ore needed to produce tin, essential for the production of tin cans and solder on the circuit boards of electronic equipment. Tin is also commonly a component of biocides, fungicides and as tetrabutyl tin/tetraoctyl tin, an intermediate in polyvinyl chloride (PVC) and high performance paint manufacturing.
- Wolframite is an important source of the element tungsten. Minimal amounts are used in electronic devices, including the vibration mechanism of mobile phones.
- Gold is used in jewellery, electronics, and dental products. It is also present in some chemical compounds used in certain semiconductor manufacturing processes.

The Y-cam will contain tantalum in the capacitors used in the electronics, tin in the solder used for the printed circuit boards and gold as a solderable coating on some of the circuit boards. It is unlikely that the phone contains tungsten.

3.3 Bill of materials Assessment

3.3.1 Component 1 – Packaging

The packaging used for this product comprised solely of cardboard. A corrugated cardboard outer box contains a moulded card pulp inner and is covered with a cardboard outer ‘slip’.

[2] UK Grid electricity CO_2e is 0.58982 kg per kWh (Source DEFRA GHG Conversion Factors 2012)

Figure 3 – Y-Cam Packaging

- Material – Cardboard / Paper
- Recycled content – Estimated at 70%
- Weight – 36g/122g/49g/16.5g – Total = 224g
- Renewable / sustainable – Yes
- Conflict Minerals? - No
- Marked for recycling? – Only outer 'slip'
- Coatings – Varnish and print
- Readily recyclable - Yes
- Removal – No fixings or fastenings used.

3.3.2 Component 2 – Camera

The Y-cam system consists of a single wireless camera unit. This can be connected into a local area network and the pictures it transmits can be viewed on other devices connected to that network (such as laptops and smartphones).

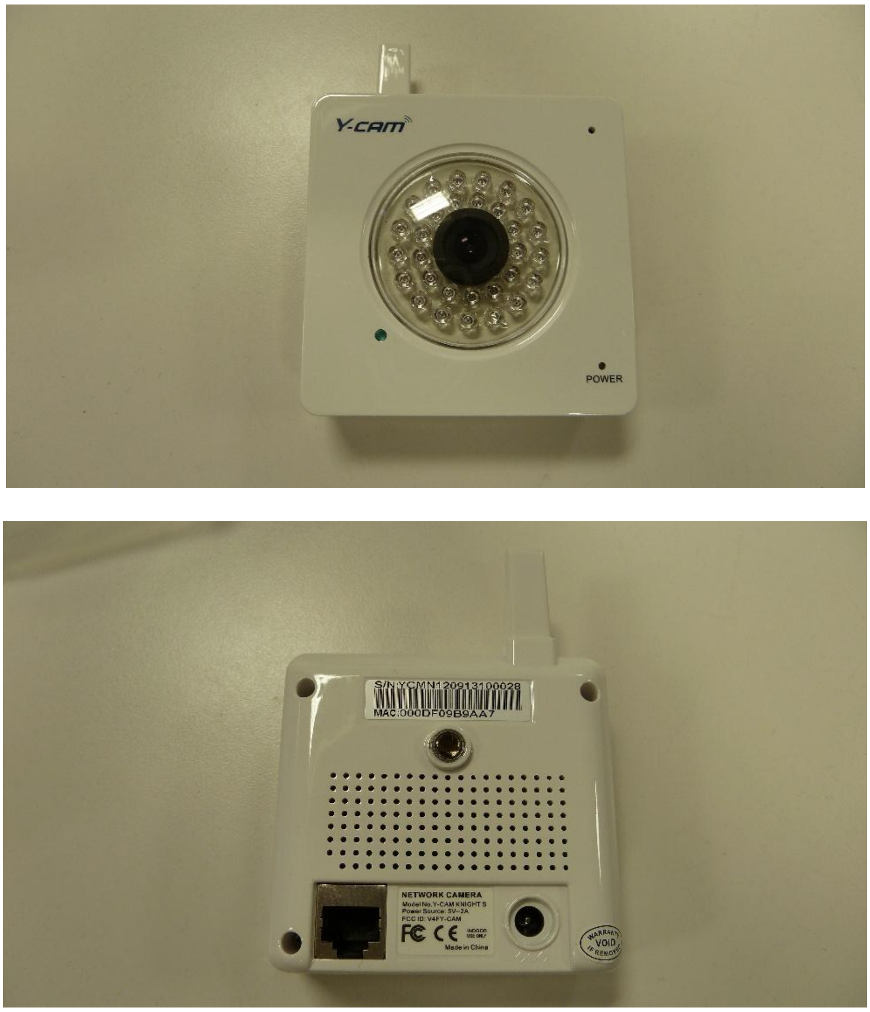


Figure 4 – Y-cam Camera Unit

3.3.2.1 Rear Casing

The cover is a relatively simple injection moulded piece. It has a high gloss finish and is not coated. It is NOT marked for recycling. It is easily removed from the front casing through the removal of 4 screws. Although it is a simple 'single' material component it might not be easily recycled. The piece contains a metal threaded insert for attaching the camera to a bracket. The inclusion of this insert in the moulding that recyclability is compromised.

Figure 5 - Front and rear casings opened

Figure 6 – Rear Casing insert

- Material – ABS
- Recycled content – 0%
- Weight – 36.2g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – NONE
- Readily recyclable – Possibly – contamination from metal insert
- Removal – 4 screws removed to separate from front casing

3.3.2.2 Front Casing Assembly

The front casing is again an injection moulded piece. It is simpler than the rear in itself but has a number of other components attached to it. As with the rear casing it is made from ABS and has a high gloss finish with no coatings. In this case it is a single material apart from a small black housing which displays the light from an LED on the front of the unit. (See Fig. 8). This unit is heat welded in and is black ABS. This dark coloured ABS permanently bonded to a lighter colour will not cause and recycling issues but it will lead to colouration of the white polymer which will make it more difficult to recycle into a light colour.

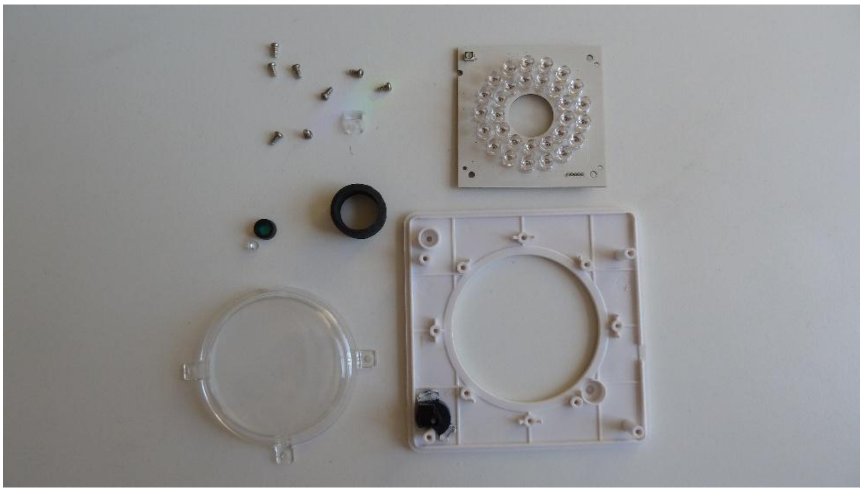


Figure 7 – Front casing assembly components

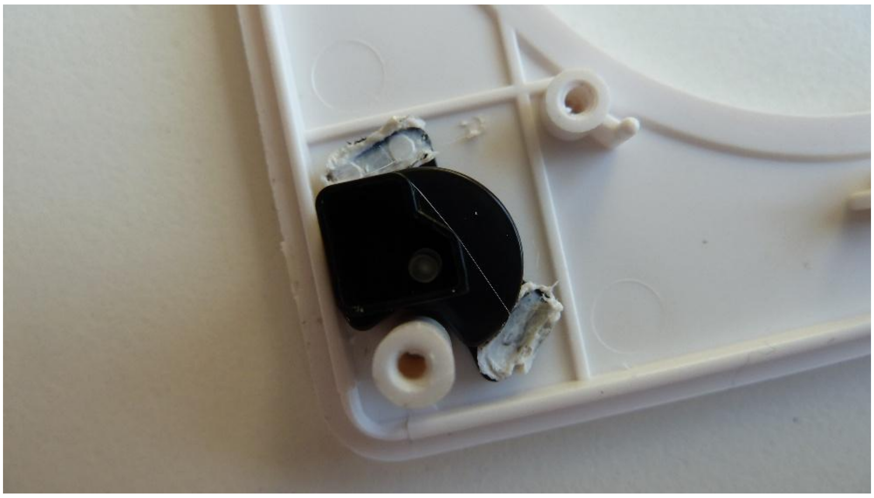


Figure 8 – LED housing 'heat welded' in

The rear casing also contains the antenna, which is moulded from the same gloss white ABS and has a simple wire running inside the moulding.

Rear casing

- Material – ABS
- Recycled content – 0%
- Weight – 16.1
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - YES
- Coatings – none
- Readily recyclable - YES
- Removal – removal of 4 screws to separate from rear casing and a further 8 screws to remove other components attached.

3.3.2.3 Lens Cover

The front casing of the camera has a clear polycarbonate lens cover attached to the inside by 4 screws. This is a single material injection moulded piece. It is unlikely to contain any recycled contact as it has to be optically clear. To remove it from the ABS casing firstly a circuit board must be removed (4 screws) and then a further 4 screws holding in the lens cover itself must be removed.

Figure 9 – Camera Lens Cover

- Material – PC
- Recycled content – 0%
- Weight – 6.7g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – None
- Readily recyclable - Yes
- Removal – removal of 8 screws to separate it from front casing

3.3.2.4 Antenna

The rear casing has a small plastic antenna inserted into a hole in the moulding. The antenna is used to relay the wireless signal to the appropriate receiving device(s). The antenna consist of an injection moulded ABS outer (same colour and surface finish as the main casings) and an internal wire antenna. The plastic outer is removed from the rear casing by removing 2 screws. The internal wire is easily pulled away from the antenna casing once it is removed from the main camera.

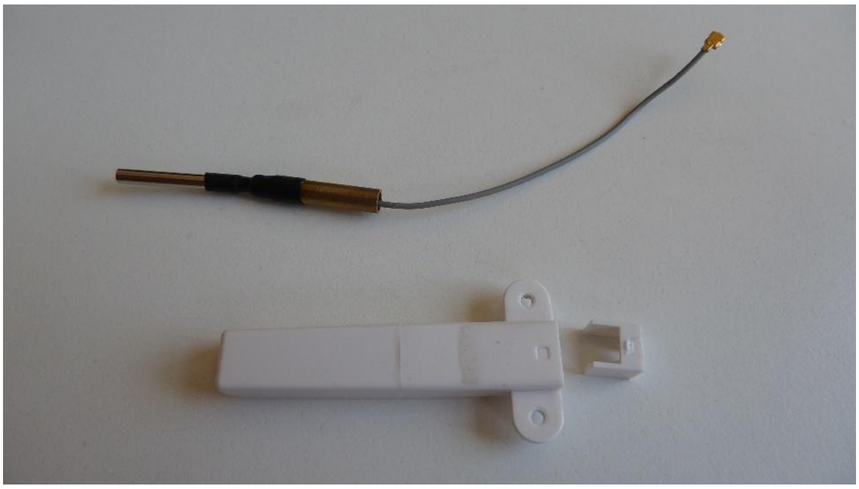


Figure 10 – Y-Cam Antenna

- Material – ABS/Brass/Copper
- Recycled content – 0%
- Weight – 2.4g/2.9g – Total = 5.3g
- Renewable / sustainable – NO
- Conflict Minerals? – NO
- Marked for recycling? - NO
- Coatings – NONE
- Readily recyclable – Metals might be able to be extracted after shredding
- Removal – remove 2 screws from the rear casing, once the camera casings have been opened.

3.3.2.5 PCBs

The camera contains a number of PCB units. There are three main units in all. Two main green PCBs in the main body of the rear casing and a smaller grey PCB with LEDs housed in the front casing of the unit. 2 cables are used to connect the PCBs together.

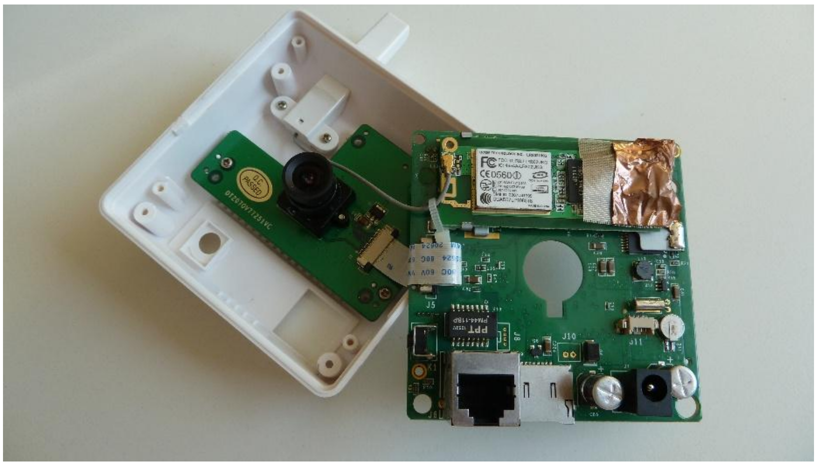


Figure 11 – Main PCB in camera

The cable between the grey LED PCB and the main unit is easily removed as it is a push connector type. The main PCBs are attached together by what seems to be a semi-permanent connection with a ribbon cable.

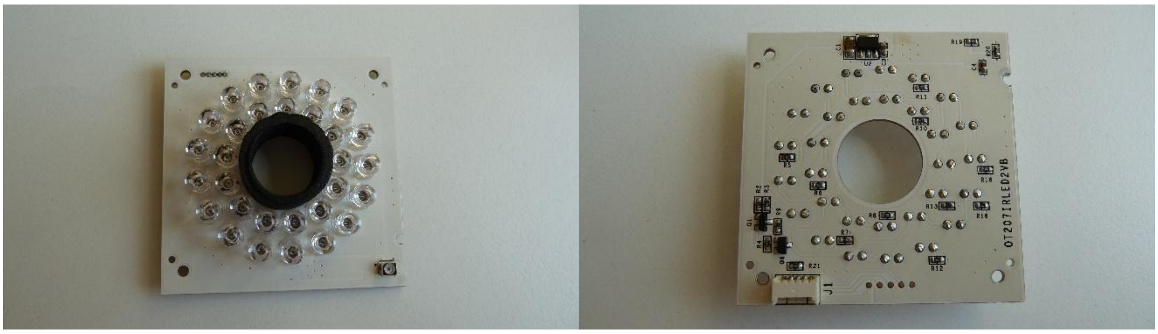


Figure 12 - LED PCB Board (front and rear)

The units are standard PCB types with a mixture of surface mount and through-hole soldering. The rear of the camera unit has some silicone added as a seal of some kind. This could make the camera unit difficult to remove form the PCB especially if it fails and need replacing. However in practice it is very unlikely that this product would be repaired if it failed. It is much more likely to simply be replaced.

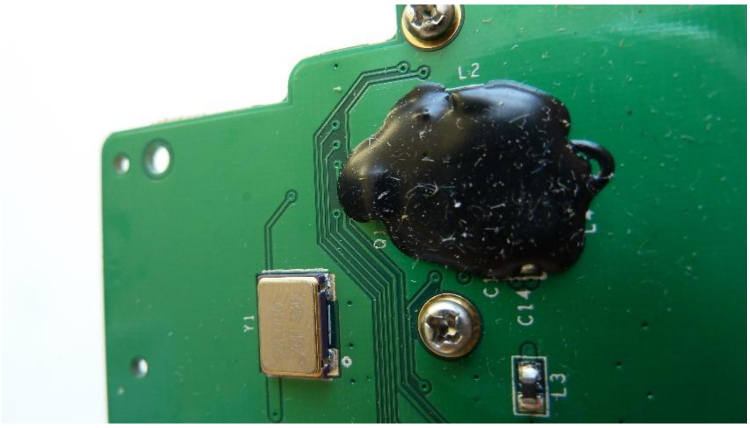


Figure 13 - Camera unit sealed to PCB

- Material – PCB/LED/Cable
- Recycled content – 0%
- Weight – 76g total
- Renewable / sustainable – NO
- Conflict Minerals? – Possible
- Marked for recycling? -NO
- Coatings – PCB does not appear to have a conformal coating
- Readily recyclable – PCB should be able to go for precious metal recovery.
- Removal – Once casing are separated the PCBs are released through the removal of a total of 10 screws.

3.3.3 Component 3 – Wall Bracket

The camera comes with a bracket to allow it to be attached to the wall if needed. The bracket is made front powder coated steel contains a plated steel attachment for the camera which has a plastic (PP) thumbwheel. The bracket is made from various components but apart from the thumbwheel all the components are made from steel. This makes the bracket very easy to recycle.

There are no marking for the material but in the case of steel components this is not necessary. Waste and recycling streams can easily separate out steel using magnets.

The powder coating does not compromise the recyclability of the steel.

Figure 14 - Camera wall bracket

- Material – Steel / PP
- Recycled content – Up to 56% (typical) / 0%
- Weight – 171g / 2.3g – Total = 173.3g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? - NO
- Coatings – Powder coated.
- Readily recyclable – YES
- Removal – Separate piece.

3.3.4 Component 4 – Screws, Power Supply and Cables

The camera unit is held together with a number of screws – 20 in total. This would seem to be an excessive amount for such a small light product. These would be easily separated from a waste stream and recycled as they are all steel.

Figure 15 - Screws used in the Y-Cam

Screws

- Material – Steel
- Recycled content – unknown but typically includes recycled content (up to 56%)
- Weight – 2.7g
- Renewable / sustainable – NO
- Conflict Minerals? - NO
- Marked for recycling? – NO
- Coatings – Passivate / anti-corrosion coating?
- Readily recyclable – Yes
- Removal – removal from item using appropriate screwdriver

The power supply unit supplied with the camera is a typical switched mode power supply. It has a rated output of 2 amps at a voltage of 5V. It is made of ABS mouldings, PVC and copper wiring it weigh 177g.

An Ethernet cable is included in the packaging. It is standard piece of cable made from PVC and copper with standard Ethernet connectors on the ends. Its total weight is 30.2g.

3.4 Proposed Design Changes

To propose appropriate design changes that will help make a tangible different in the overall life cycle impacts of the phone these changes need to be considered in respect of the goals of a 'circular economy' Two reports[3], published in 2013 by the Ellen Macarthur Foundation explain these principles in detail.

The reports suggest that manufacturers should 'specify the purpose and performance of the end-products, more than those of the input materials'. It goes on to suggest that designers should specify 'pure materials in their production process since they are easier to sort at end of life'. The report also highlights that besides material selection, other areas important for economically successful circular design are standardised components, designed-to-last products, design for easy end-of-life

[3] Towards the Circular Economy Reports 1 and 2. Ellen Macarthur Foundation 2013

sorting, separation or reuse of products and materials, and design-for-manufacturing criteria that take into account possible useful applications of by-products and wastes.

The principles relevant to this particular product can be summarised as follows:

- Improve the easy of reuse and recovery of materials
- Match the durability requirements of the product to the durability of the design
- Shift to renewable energy sources
- Build in modularity
- Think in systems rather than specific physical products

These will apply to general design themes observed in this product and can be addresses in the following ways:

3.4.1 Improving materials recovery and recycling

The Y-Cam uses a number of components which are manufactured from different materials which are not compatible for recycling. This means that the recovery of the materials at end of life becomes very difficult is not impossible.

Practices observed in this product included, bonding foam to plastic components, bonding electronic components to plastic casings and bonding different types of plastics together

In order to address this, new designs should:

1. Ensure materials are clearly marked to aid recycling
2. Attempt to reduce the mix of incompatible materials to a minimum
3. If there are incompatible materials they should be east to separate and bonding them together should be avoided at all costs
4. Carefully consider the use of any coatings and how they might affect the recyclability of the materials to which they are applied.
5. Try to group similar materials together to allow easier recovery and minimal separation operations.
6. Can new technologies be used to reduce the complexity of current components? E.g. a touch screen as part of the current LCD panel rather than a spate complex keypad.
7. Consider designing components in a way that allows their re-use (if appropriate and viable in the particular product system).

3.4.2 Durability of design

When considering how durable the product needs to be, designers should consider a number of different factors such as:

1. What are the real use patterns of the product
2. How long should it last (consumer expectations)
3. What is it’s useful technological life – will it become obsolete due to changes in technology
4. Is it appropriate to update and repair the product (costs, expected life etc?)
5. I the product a system in its own right or is it part of another system that might change over time

If these issues are considered the products should be ‘appropriate’ in terms of durability and expected life. It I possible to ‘overdesign’ products and make them more robust and more material intensive than they actually need to be.

3.4.3 Renewable Energy Sources

The product only uses a small amount of energy in terms of the power requirement to run the system. However the power is required constantly. There are a number of options in terms of renewable energy such as solar for this particular product but the following issues need to be considered:

1. How reliable is the supply of renewable energy?
2. Does it need to be stored?
3. Can it supply the required level of power / energy
4. Does it mean that the product will have to be placed in a specific position (e.g. near a window).

3.4.4 Modularity

Designing in modularity can bring be to product in respect of the circular economy. Modularity can help extend a product’s life, reduce repair costs and allow for easy upgrading. The effectiveness and appropriateness of this approach will depend on a number of factors:

1. What is the expected life of the product – is modularity a sensible approach for short life products?
2. What advantages does modularity offer?
3. Consider how this will affect the way spare parts and upgrades are sold.

Many products are sold as ‘standalone’ systems. Modern technology and advances in computing, communications technology and home networking mean that in many cases the functions traditionally supplied by a range of standalone products can now be supplied by an integrated system.

The Y-Cam is an example of a product which can be integrated into existing systems to provide a function using fewer resources than a product which is stand alone.

The integration of products into new emerging IT and communication systems will mean that the form of many products as we currently know them will change dramatically over the coming years. This could considerably reduce overall resource use for the delivery of a range of services.

See the main summary report for more detailed design proposals.

Appendix 3b

Circular Economy Assessment Product Design Assessment

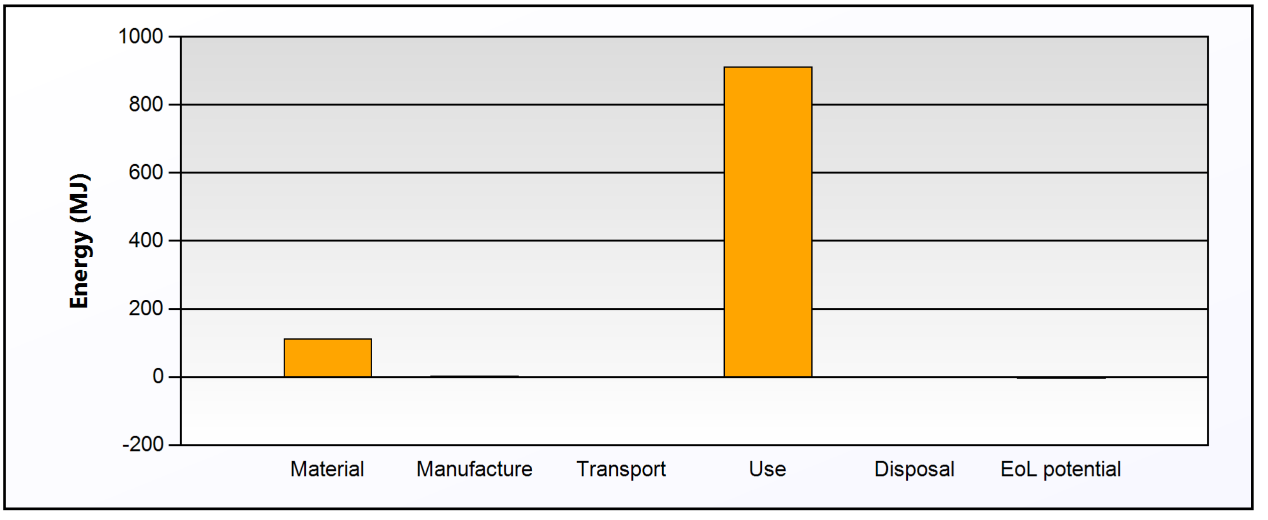
Part 2 – LCA Details

Product: **Y-cam Knight S Camera**

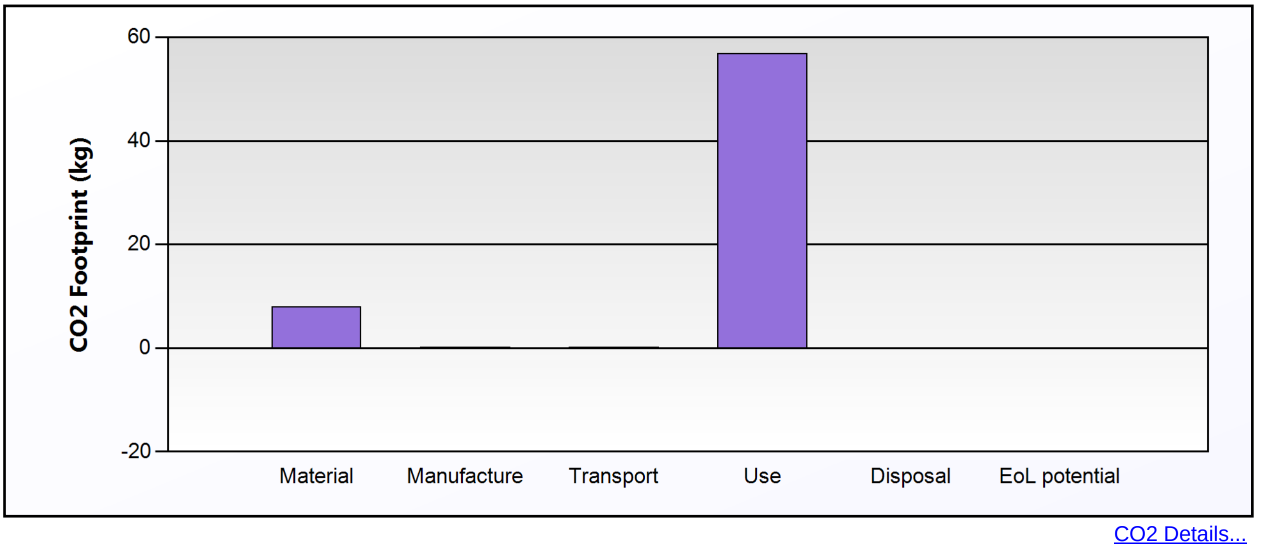
Eco Audit Report

Product Name	Y-Cam Kinght S - Wireless Camera
Product Life (years)	5

Energy and CO2 Footprint Summary:



Energy Details...



CO2 Details...

Phase	Energy (MJ)	Energy (%)	CO2 (kg)	CO2 (%)
Material	113	10.9	8	12.3
Manufacture	2.56	0.2	0.173	0.3
Transport	2.14	0.2	0.152	0.2
Use	912	88.6	56.8	87.2
Disposal	0.45	0.0	0.0315	0.0
Total (for first life)	**1.03e+03**	**100**	**65.2**	**100**
End of life potential	-4.53		-0.159	

Eco Audit Report

Energy Analysis

Energy and CO2 Summary

	Energy (MJ)/year
Equivalent annual environmental burden (averaged over 5 year product life):	206

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	Energy (MJ)	%
Rear casing	ABS (high-impact, injection molding)	Virgin (0%)	0.036	1	0.036	3.4	3.1
Front Casing	ABS (high-impact, injection molding)	Virgin (0%)	0.016	1	0.016	1.5	1.4
Lens cover	PC (copolymer, high-heat)	Virgin (0%)	0.0067	1	0.0067	0.73	0.6
Anntena	ABS (high-impact, injection molding)	Virgin (0%)	0.0029	1	0.0029	0.28	0.2
LEDS	Semiconductor diodes, LEDs	Virgin (0%)	0.0015	1	0.0015	4.5	4.0
PCB for LEDs	Printed circuit board assembly	Virgin (0%)	0.011	1	0.011	1.4	1.3
Main PCBs	Printed circuit board assembly	Virgin (0%)	0.063	1	0.063	8.2	7.3
Anntena wire	Cable	Virgin (0%)	0.0024	1	0.0024	0.22	0.2
Mount bracket thumb wheel	PP (copolymer, low flow)	Virgin (0%)	0.0022	1	0.0022	0.18	0.2
Power Supply	Power supply unit	Virgin (0%)	0.18	1	0.18	80	71.3
Ethernet cable	Cable	Virgin (0%)	0.03	1	0.03	2.7	2.4
Outer sleeve	Cardboard	70.0%	0.036	1	0.036	0.97	0.9
Main box	Cardboard	70.0%	0.12	1	0.12	3.3	2.9
Inner insert	Cardboard	70.0%	0.049	1	0.049	1.3	1.2
Power supply box	Cardboard	70.0%	0.016	1	0.016	0.44	0.4
Bracket	Carbon steel, AISI 1010, annealed	Typical %	0.17	1	0.17	3.1	2.8
Total				**16**	**0.74**	**1.1e+02**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	Energy (MJ)	%
Rear casing	Polymer molding	-	0.036 kg	0.65	25.4
Front Casing	Polymer molding	-	0.016 kg	0.29	11.3
Lens cover	Polymer molding	-	0.0067 kg	0.15	5.7
Anntena	Polymer molding	-	0.0029 kg	0.052	2.0
Mount bracket thumb wheel	Polymer molding	-	0.0022 kg	0.047	1.8
Bracket	Rough rolling, forging	-	0.17 kg	0.46	18.1
Coating on bracket	Powder coating (polymer)	-	0.012 m^2	0.91	35.6
Total				**2.6**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 0.74 kg

Stage name	Transport type	Distance (km)	Energy (MJ)	%
Transport from China	Sea freight	1.8e+04	2.1	100.0
Total		**1.8e+04**	**2.1**	**100**

Breakdown by components

Component	Component mass (kg)	Energy (MJ)	%
Rear casing	0.036	0.1	4.9
Front Casing	0.016	0.046	2.2
Lens cover	0.0067	0.019	0.9
Anntena	0.0029	0.0084	0.4
LEDS	0.0015	0.0043	0.2
PCB for LEDs	0.011	0.032	1.5
Main PCBs	0.063	0.18	8.5
Anntena wire	0.0024	0.0069	0.3
Mount bracket thumb wheel	0.0022	0.0063	0.3
Power Supply	0.18	0.51	23.7
Ethernet cable	0.03	0.087	4.1
Outer sleeve	0.036	0.1	4.8
Main box	0.12	0.35	16.4
Inner insert	0.049	0.14	6.6
Power supply box	0.016	0.047	2.2
Bracket	0.17	0.49	23.0
Total	**0.74**	**2.1**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	5
Usage (hours per day)	12
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	**Energy (MJ)**	**%**
Static	9.1e+02	100.0
Mobile	0	
Total	**9.1e+02**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	Energy (MJ)	%
Rear casing	Downcycle	100.0	0.018	4.0
Front Casing	Downcycle	100.0	0.0081	1.8
Lens cover	Downcycle	100.0	0.0034	0.7
Anntena	Downcycle	100.0	0.0015	0.3
LEDS	Landfill	100.0	0.0003	0.1
PCB for LEDs	Downcycle	100.0	0.0055	1.2
Main PCBs	Downcycle	100.0	0.032	7.0
Anntena wire	Downcycle	100.0	0.0012	0.3
Mount bracket thumb wheel	Downcycle	100.0	0.0011	0.2
Power Supply	Downcycle	100.0	0.088	19.6
Ethernet cable	Downcycle	100.0	0.015	3.4
Outer sleeve	Recycle	100.0	0.025	5.6
Main box	Recycle	100.0	0.085	19.0
Inner insert	Recycle	100.0	0.035	7.7
Power supply box	Recycle	100.0	0.011	2.5
Bracket	Recycle	100.0	0.12	26.6
Total			**0.45**	**100**

EoL potential:

Component	End of life option	% recovered	Energy (MJ)	%
Rear casing	Downcycle	100.0	-0.45	10.0
Front Casing	Downcycle	100.0	-0.2	4.5
Lens cover	Downcycle	100.0	-0.096	2.1
Anntena	Downcycle	100.0	-0.036	0.8
LEDS	Landfill	100.0	0	0.0
PCB for LEDs	Downcycle	100.0	0	0.0
Main PCBs	Downcycle	100.0	0	0.0
Anntena wire	Downcycle	100.0	0	0.0
Mount bracket thumb wheel	Downcycle	100.0	-0.023	0.5
Power Supply	Downcycle	100.0	0	0.0
Ethernet cable	Downcycle	100.0	0	0.0
Outer sleeve	Recycle	100.0	-0.29	6.4
Main box	Recycle	100.0	-0.99	22.0
Inner insert	Recycle	100.0	-0.4	8.9
Power supply box	Recycle	100.0	-0.13	2.9
Bracket	Recycle	100.0	-1.9	41.9
Total			**-4.5**	**100**

Notes:

Energy and CO2 Summary

Eco Audit Report

CO2 Footprint Analysis

Energy and CO2 Summary

	CO2 (kg)/year
Equivalent annual environmental burden (averaged over 5 year product life):	13

Detailed breakdown of individual life phases

Material:

Energy and CO2 Summary

Component	Material	Recycled content* (%)	Part mass (kg)	Qty.	Total mass processed** (kg)	CO2 footprint (kg)	%
Rear casing	ABS (high-impact, injection molding)	Virgin (0%)	0.036	1	0.036	0.14	1.7
Front Casing	ABS (high-impact, injection molding)	Virgin (0%)	0.016	1	0.016	0.062	0.8
Lens cover	PC (copolymer, high-heat)	Virgin (0%)	0.0067	1	0.0067	0.04	0.5
Anntena	ABS (high-impact, injection molding)	Virgin (0%)	0.0029	1	0.0029	0.011	0.1
LEDS	Semiconductor diodes, LEDs	Virgin (0%)	0.0015	1	0.0015	0.34	4.2
PCB for LEDs	Printed circuit board assembly	Virgin (0%)	0.011	1	0.011	0.11	1.3
Main PCBs	Printed circuit board assembly	Virgin (0%)	0.063	1	0.063	0.61	7.7
Anntena wire	Cable	Virgin (0%)	0.0024	1	0.0024	0.016	0.2
Mount bracket thumb wheel	PP (copolymer, low flow)	Virgin (0%)	0.0022	1	0.0022	0.0068	0.1
Power Supply	Power supply unit	Virgin (0%)	0.18	1	0.18	6	75.3
Ethernet cable	Cable	Virgin (0%)	0.03	1	0.03	0.21	2.6
Outer sleeve	Cardboard	70.0%	0.036	1	0.036	0.035	0.4
Main box	Cardboard	70.0%	0.12	1	0.12	0.12	1.5
Inner insert	Cardboard	70.0%	0.049	1	0.049	0.049	0.6
Power supply box	Cardboard	70.0%	0.016	1	0.016	0.016	0.2
Bracket	Carbon steel, AISI 1010, annealed	Typical %	0.17	1	0.17	0.22	2.8
Total				**16**	**0.74**	**8**	**100**

*Typical: Includes 'recycle fraction in current supply'

**Where applicable, includes material mass removed by secondary processes

Manufacture:

Energy and CO2 Summary

Component	Process	% Removed	Amount processed	CO2 footprint (kg)	%
Rear casing	Polymer molding	-	0.036 kg	0.049	28.3
Front Casing	Polymer molding	-	0.016 kg	0.022	12.6
Lens cover	Polymer molding	-	0.0067 kg	0.011	6.3
Anntena	Polymer molding	-	0.0029 kg	0.0039	2.3
Mount bracket thumb wheel	Polymer molding	-	0.0022 kg	0.0035	2.0
Bracket	Rough rolling, forging	-	0.17 kg	0.035	20.1
Coating on bracket	Powder coating (polymer)	-	0.012 m^2	0.049	28.5
Total				**0.17**	**100**

Transport:

Energy and CO2 Summary

Breakdown by transport stage Total product mass = 0.74 kg

Stage name	Transport type	Distance (km)	CO2 footprint (kg)	%
Transport from China	Sea freight	1.8e+04	0.15	100.0
Total		**1.8e+04**	**0.15**	**100**

Breakdown by components

Component	Component mass (kg)	CO2 footprint (kg)	%
Rear casing	0.036	0.0074	4.9
Front Casing	0.016	0.0033	2.2
Lens cover	0.0067	0.0014	0.9
Anntena	0.0029	0.00059	0.4
LEDS	0.0015	0.00031	0.2
PCB for LEDs	0.011	0.0022	1.5
Main PCBs	0.063	0.013	8.5
Anntena wire	0.0024	0.00049	0.3
Mount bracket thumb wheel	0.0022	0.00045	0.3
Power Supply	0.18	0.036	23.7
Ethernet cable	0.03	0.0062	4.1
Outer sleeve	0.036	0.0073	4.8
Main box	0.12	0.025	16.4
Inner insert	0.049	0.01	6.6
Power supply box	0.016	0.0034	2.2
Bracket	0.17	0.035	23.0
Total	**0.74**	**0.15**	**100**

Use:

Energy and CO2 Summary

Static mode

Energy input and output type	Electric to em radiation (LED)
Use location	United Kingdom
Power rating (W)	5
Usage (hours per day)	12
Usage (days per year)	3.7e+02
Product life (years)	5

Relative contribution of static and mobile modes

Mode	CO2 footprint (kg)	%
Static	57	100.0
Mobile	0	
Total	**57**	**100**

Disposal:

Energy and CO2 Summary

Component	End of life option	% recovered	CO2 footprint (kg)	%
Rear casing	Downcycle	100.0	0.0013	4.0
Front Casing	Downcycle	100.0	0.00056	1.8
Lens cover	Downcycle	100.0	0.00023	0.7
Anntena	Downcycle	100.0	0.0001	0.3
LEDS	Landfill	100.0	2.1e-05	0.1
PCB for LEDs	Downcycle	100.0	0.00039	1.2
Main PCBs	Downcycle	100.0	0.0022	7.0
Anntena wire	Downcycle	100.0	8.4e-05	0.3
Mount bracket thumb wheel	Downcycle	100.0	7.7e-05	0.2
Power Supply	Downcycle	100.0	0.0062	19.6
Ethernet cable	Downcycle	100.0	0.0011	3.4
Outer sleeve	Recycle	100.0	0.0018	5.6
Main box	Recycle	100.0	0.006	19.0
Inner insert	Recycle	100.0	0.0024	7.7
Power supply box	Recycle	100.0	0.0008	2.5
Bracket	Recycle	100.0	0.0084	26.6
Total			**0.032**	**100**

EoL potential:

Component	End of life option	% recovered	CO2 footprint (kg)	%
Rear casing	Downcycle	100.0	-0.018	11.5
Front Casing	Downcycle	100.0	-0.0081	5.1
Lens cover	Downcycle	100.0	-0.0053	3.4
Anntena	Downcycle	100.0	-0.0015	0.9
LEDS	Landfill	100.0	0	0.0
PCB for LEDs	Downcycle	100.0	0	0.0
Main PCBs	Downcycle	100.0	0	0.0
Anntena wire	Downcycle	100.0	0	0.0
Mount bracket thumb wheel	Downcycle	100.0	-0.00091	0.6
Power Supply	Downcycle	100.0	0	0.0
Ethernet cable	Downcycle	100.0	0	0.0
Outer sleeve	Recycle	100.0	-0.00039	0.2
Main box	Recycle	100.0	-0.0013	0.8
Inner insert	Recycle	100.0	-0.00054	0.3
Power supply box	Recycle	100.0	-0.00018	0.1
Bracket	Recycle	100.0	-0.12	77.0
Total			**-0.16**	**100**

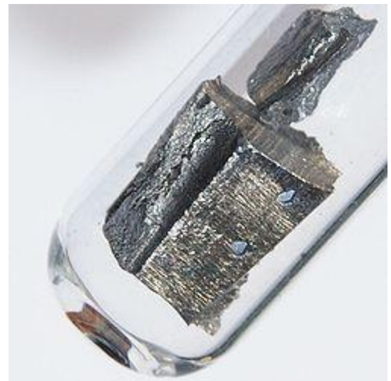
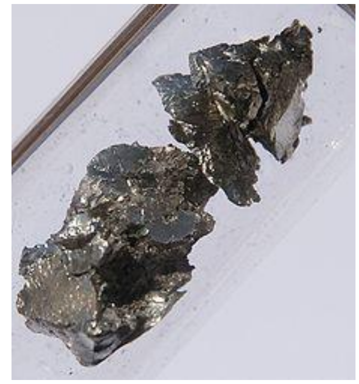
Notes:

Energy and CO2 Summary

Appendix 4

Rare Earth Materials and Materials at Risk



RARE EARTH ELEMENTS 101

April 2012





IAMGOLD® CORPORATION

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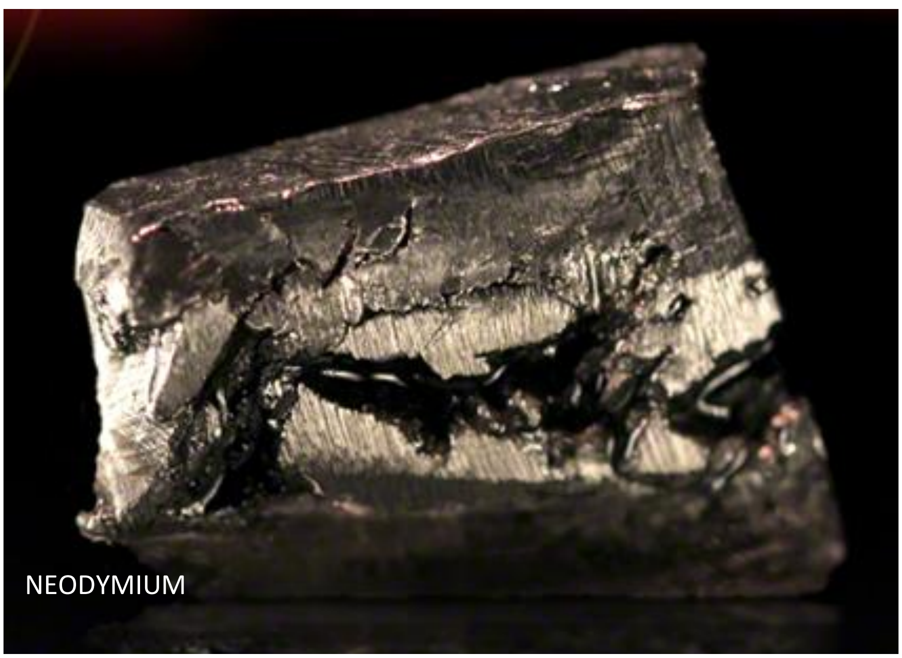
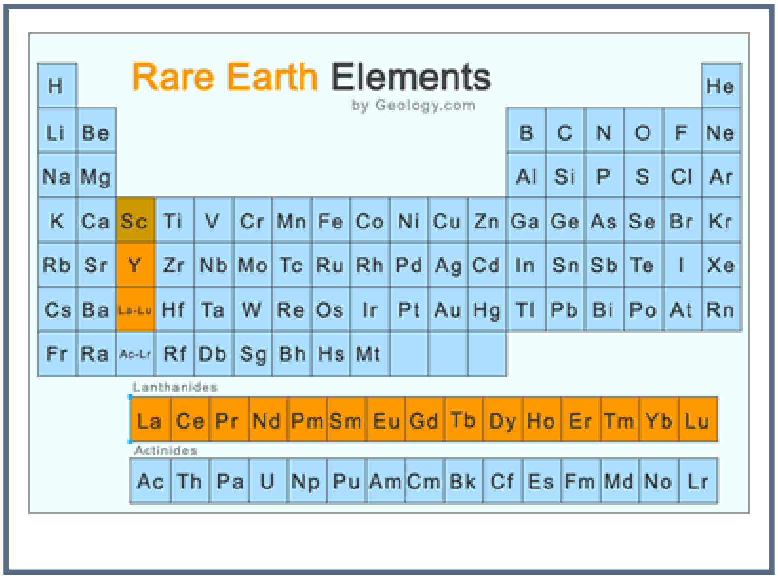


Rare Earth Elements (REE) Explained

The rare earth elements (REE) are a group of 17 chemical (metallic) elements which appear in the periodic table. The group consists of the 15 lanthanide elements along with Yttrium and Scandium. They share many similar properties, which is why they occur together in geological deposits. The 17 REEs are found in all REE deposits but their distribution and concentrations vary. They are referred to as 'rare' because it is not common to find them in commercially viable concentrations. REEs generally fall into one of two categories – light rare earths (LREE) and heavy rare earths (HREE), with varying levels of uses and demand. REE mineral deposits are usually rich in either LREE or HREE, but rarely contain both in significant quantities. In general, they are vital to some of the world's fastest growing markets: clean energy and high technology.



Rare Earths Expected to be in Short Supply in the next 15 years *

Neodymium, Europium, Terbium, Dysprosium, Yttrium

Light Rare Earths

- Lanthanum (La)
- Cerium (Ce)
- Praseodymium (Pr)
- Neodymium (Nd)
- Samarium (Sm)

Lanthanum and Cerium: Accounted for 66.8% of global demand in 2010

Heavy Rare Earths

(Less common and more valuable)

- Europium (Eu)
- Gadolinium (Gd)
- Terbium (Tb)
- Dysprosium (Dy)
- Holmium (Ho)
- Erbium (Er)
- Thulium (Tm)
- Ytterbium (Yb)
- Lutetium (Lu)
- Yttrium (Y)

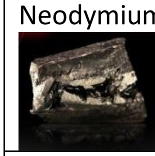
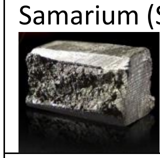
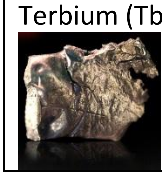
Notes:

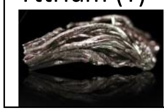
- Yttrium is lighter than the light rare earths, but included in the heavy rare earth group because of its chemical and physical associations with heavy rare earths in natural deposits.

**Ernst & Young - Technology Minerals – The rare earths race is on! - April 2011*

Unique Properties

Silvery-white or gray in colour, these metals have a high lustre and tarnish readily when exposed to air. REEs are found in most everyday applications because of their unique chemical and physical properties. New applications have arisen consistently over the past 50 years CIBC, including important environmental innovations such as catalytic converters and the development of permanent magnets which have enabled greater efficiency, miniaturization, durability and speed in electric and electronic components. Substitutes exist, but rarely work as effectively. The properties of each REE along with the percentage share of estimated global production in 2015 are summarized in the following table.

REE	Catalytic	Magnetic	Electrical	Chemical	Optical	% Share of Estimated World Supply in 2015*
Lanthanum (La) 	X		X	X	X	27%
Cerium (Ce) 	X		X	X	X	40%
Praseodymium (Pr) 		X	X	X	X	5%
Neodymium (Nd) 	X	X	X		X	16%
Samarium (Sm) 		X				2%
Europium (Eu) 					X	.4%
Gadolinium (Gd) 		X			X	2%
Terbium (Tb) 		X			X	.2%

REE	Catalytic	Magnetic	Electrical	Chemical	Optical	% Share of Estimated World Supply in 2015*
Dysprosium (Dy) 		X			X	.9%
Erbium (Er) 					X	.4%
Yttrium (Y) 					X	5%

This list excludes Holmium, Thulium, Ytterbium, Lutetium and Scandium as they represent a very small portion of total supply
**Source: IMCOA - Based on Estimated Supply in 2015 of ~225,000 tons.*

Rare Earth Applications

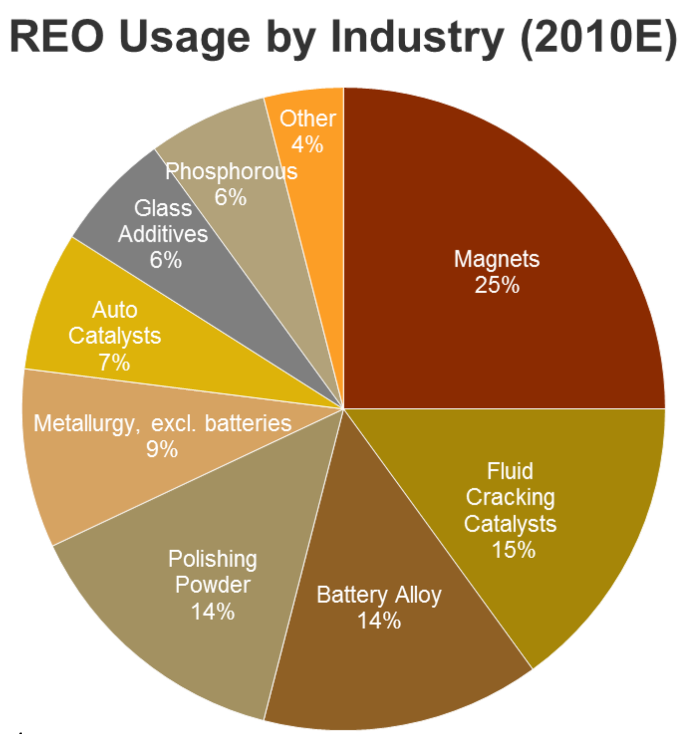
Often referred to as the `seeds of technology` by the Japanese, REEs are a major constituent of many advanced materials, especially in the high tech and green energy sectors where robust performance, durability and low carbon emissions are so important.

Application by Individual REE

Lanthanum	Used to make rechargeable lanthanum nickel metal hydride batteries – the type used in electric and hybrid vehicles, laptop computers, cameras; fibre optics to increase transmission rates, high-end camera lenses, telescopes, binoculars – as lanthanum improves visual clarity; infrared absorbing glass for night vision goggles, used to reduce the level of phosphates in patients with kidney disease.
Cerium	Used to polish glass, metal and gemstones, computer chips, transistors and other electronic components; automotive catalytic converters to reduce pollution, added in glass making process to decolourize it, gives compact fluorescent bulbs the green part of the light spectrum.
Praseodymium	Used in combination with neodymium, its primary use is to make high power magnets. Used to make welder and glass blower goggles as praseodymium oxide protects against yellow flare and UV light; plastic, vibrant yellow ceramics.
Neodymium	An elemental twin of praseodymium, the principal use of Neodymium is in the manufacture of the strongest magnets in the world. These magnets are so strong that one the size of a coin cannot be removed from a refrigerator by hand. Other important applications include laser range finders and guidance systems.
Samarium	Primary use is in the production of permanent magnets but also in X-ray lasers, precision guided weapons and white-noise production in stealth technology.
Europium	Primarily used in phosphors used in pilot display screens, televisions (reddish-orange), and energy efficient fluorescent lights (reddish-orange and blue).

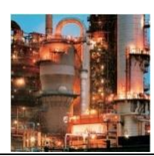
Gadolinium	Used to enhance the clarity of MRI scans by injecting Gadolinium contrast agents into the patient. Used in nuclear reactor control rods to control the fission process.
Terbium	Primarily used in phosphors, particularly in fluorescent bulbs and tubes (yellow-green), high intensity green emitter used in projection televisions and X-ray intensifying screens (yellow-green, violet, and blue).
Dysprosium	Most commonly used in the manufacture of neodymium-iron-boron high strength permanent magnets. Dysprosium-165 is injected into joints to treat rheumatoid arthritis. Dysprosium is used in radiation badges to detect and monitor radiation exposure.
Erbium	Used in glass coloring, as an amplifier in fiber optics, and in lasers for medical and dental use.
Yttrium	Yttrium phosphors are used in energy efficient fluorescent lamps and bulbs. Yttria stabilized zirconium oxide is used in high temperature applications, such as thermal barrier coating to protect aerospace high temperature surfaces. Can increase the strength of metallic alloys.

Applications in High Growth Markets



Source: CIBC World Markets

The fastest growing markets for REEs are permanent magnets, rechargeable batteries, phosphors and polishing agents, with neodymium, praseodymium, dysprosium, yttrium, and terbium having the greatest exposure to these segments.

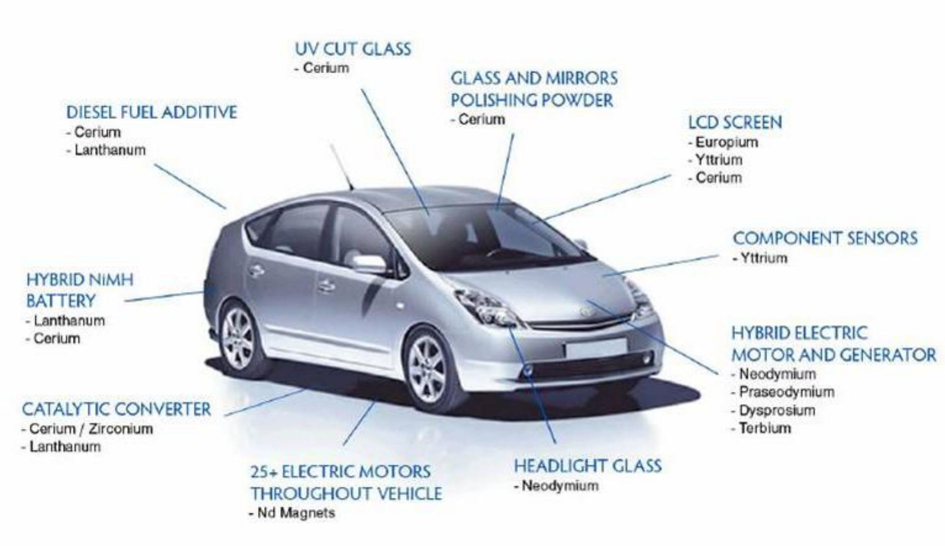
Application	Estimated Compound Annual Growth Rate 2010-2015*
Permanent Magnets The largest end user of REEs is the permanent magnet industry. This segment represents about 25% of total demand and is expected to grow to 30% by 2015. They are in high demand due to their strength, heat resistance and ability to maintain their magnetism over very long periods of time. Magnets made from rare earth elements, such as neodymium, praseodymium, and dysprosium are the strongest known permanent magnets. Their higher performance and smaller size enables many miniature applications, such as personal electronic devices (smart phones, ear buds, iPod music players). A miniature magnet made with neodymium causes the cell phone to vibrate when a call is received. Capacity utilization is one of the biggest challenges in the wind energy sector. Replacing gear driven turbines with powerful direct-drive permanent magnet generators can increase efficiency by 25%. Some of the largest turbines require two tons of rare earth magnets, which contain about 30% REE.	**16%** 
Rechargeable Batteries Rechargeable batteries (NiMH) made from lanthanum, cerium, neodymium and praseodymium (combined with nickel, cobalt, manganese and/or aluminum) are used in car batteries in hybrid electric vehicles, electronic devices and power tools.	**18%** 
Auto Catalysts Lanthanum and Cerium are used in the manufacture of catalytic converters which convert the pollutants in engine exhaust to non-toxic compounds.	**8%** 
Fluid Cracking Catalysts Fluid cracking catalysts, which contain lanthanum and cerium, are used in the refining of crude oil. They are essential to the process of transforming heavy molecules into more useful forms such as gasoline, jet fuel and diesel.	**6%** 

Polishing Powders Cerium Oxide polishing powder is one of the best polishing materials. It is used for polishing glass, lenses, CRTs, jewels, silicon chips, TV screens and monitors.	**15%** 
Glass Additives Cerium reduces transmission of UV light and Lanthanum increases the glass reflective index for digital camera lenses.	**4%** 
Phosphors Europium, terbium and yttrium are REEs used extensively in the electronics industry to manufacture LCDs and colour TVs. Used as phosphors they enable colour changes as electrical currents are transmitted through them. Terbium and Europium are used in energy efficient lighting applications. Light emitting diodes (LEDs) are 80% more efficient than incandescent lighting and 40% more efficient than compact fluorescent bulbs.	**30%** 

** CIBC World Markets*

REEs Play a Key Role in the Green Energy Sector

Electric and hybrid cars can contain 20-25 pounds of rare earths, which is double that found in a standard gasoline vehicle. The battery itself is made from several pounds of rare earth compounds. REEs are also used in regenerative braking systems and electric traction motors. The motors consist of powerful magnets made from neodymium and dysprosium.



REEs on the Critical List

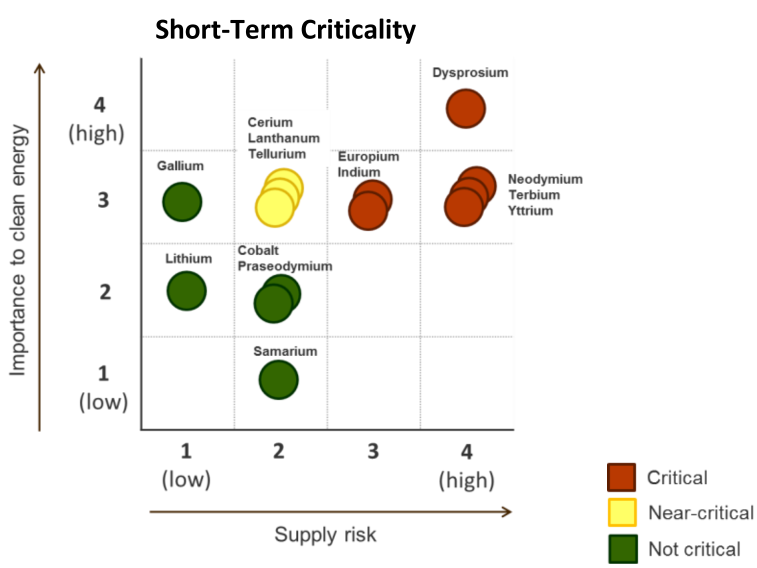
Demand is driven in large part by two of the fastest growing sectors: energy and high-tech. The criticality of each element depends on the end application demand pattern.

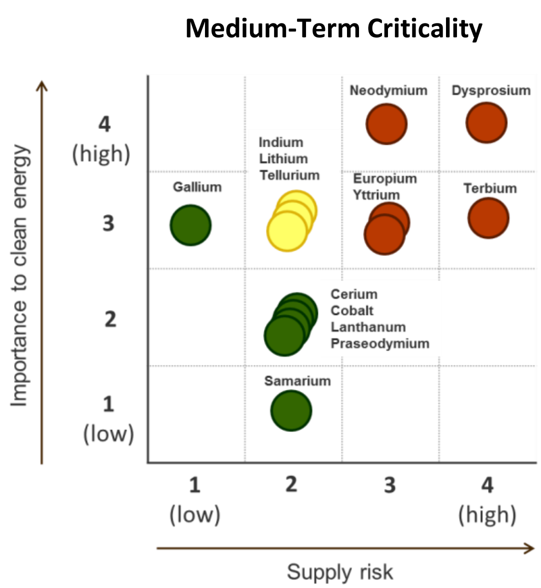
Supply and demand calculations are complicated because each REE has different applications and is produced in varying quantities. This means that certain rare earths will be in short supply and others will be in surplus, depending on the supply and demand fundamentals of the end markets. The fastest growing market segments are permanent magnets, rechargeable batteries, and phosphors, particularly given their application in the fast growing green energy and high tech segments. In 2010, The U.S. Department of Energy classified the five REEs critical to these markets to be in short supply. Four of these are the HREEs. China's Ministry of Commerce has indicated that China's HREEs could be depleted in the next 15-20 years.

REE on the Critical List		Applications	Estimated Compound Annual Growth Rate 2010-2015
Light	Neodymium	Permanent magnets, auto catalysts, petroleum refining, lasers	16%
Heavy	Dysprosium	Permanent magnets, hybrid engines	16%
	Europium	Phosphors, fuel cells, neutron absorbers	27%
	Terbium	Phosphors, permanent magnets	30%
	Yttrium	Red phosphor, fluorescent lamps, ceramics, metal alloys	30%

Source: IMCOA and CIBC World Markets and Dundee Capital Markets

These minerals, with the exception of Yttrium are expected to be in short supply over the next 10 years. The magnitude and duration of these shortages will mainly depend on the success of REE exploration projects. Various governments and industrial users worldwide have begun to develop strategies to safeguard their REE supplies in order to overcome future supply problems. Some industrial users have established joint ventures with mining companies. Market mechanisms should ensure serious shortages are averted in the long term. This supply gap has led to increasing attention from governments, exploration companies and end users.



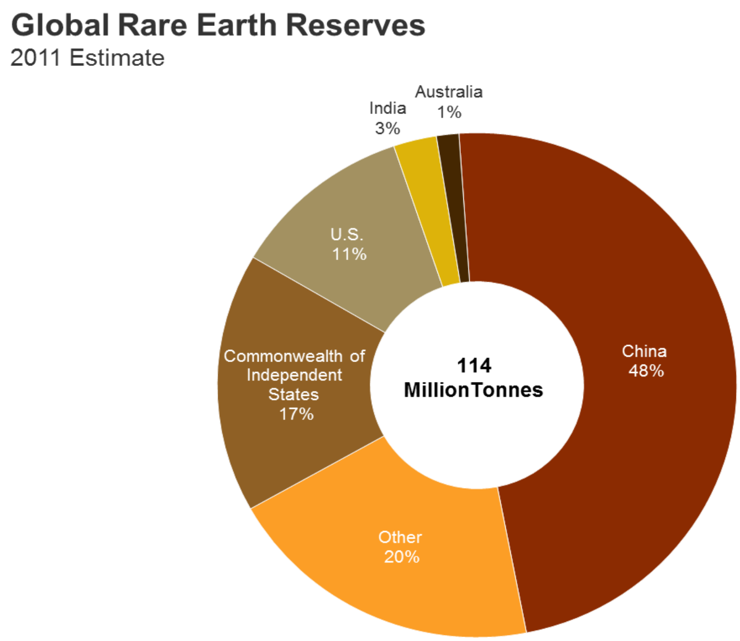


Source: U.S. Department of Energy, Critical Materials strategy, Dec. 2010

Supply and Demand Fundamentals

Large and Growing Market
Demand for rare earth elements is growing at 9-15% a year *(CIBC World Markets)*, and according to a report by *Ernst & Young - Technology Minerals – The Race is On – April 2011,* the market for REEs is currently valued at *$2-3 billion* and is expected to double to $4-6 billion by 2015.

China Accounts for 48% of the World's Reserves
Global rare earth reserves were estimated at 114 million metric tons in 2011, with China accounting for 48%. Only a small proportion of REE deposits are of sufficient size, type and concentration to be exploited economically using existing technology.



Note: IMCOA – "Reserve figures encompass a wide range of mineral qualities and do not necessarily comply with the internationally recognized codes for the definition of reserves."

China Accounts for 94% of Global Production
In 2010, global REE production was about 125,000 metric tonnes; up 54% from 80,000 tonnes in 2000. China is by far the dominant producer of rare earth elements, accounting for 94% of global production. Significant amounts of REE are produced in only a few other countries, such as Brazil, India and Malaysia.

More than 70% of light rare earth elements are supplied from one mine in China: the 56 million tonne Bayan Obo deposit in Inner Mongolia, which commenced production in 1957 and is the largest deposit in the world. In 2010, it produced 55,000 tons of REOs, representing 46% of Chinese production and 42% globally. Before the Bayan Obo deposit came on stream, the largest producer was Molycorp's Mountain Pass deposit in California. However, China started selling rare earths at such low prices in the early 1990's that the Mountain Pass mines and others in the world were unable to compete. Mining at Mountain Pass ceased in 2002 but was recently re-commissioned and is expected to return to full production in 2012.

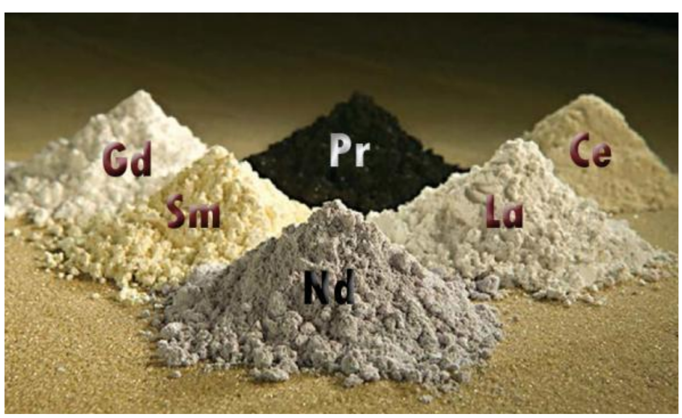
China is the World's Largest Consumer
China is also the world's leading consumer of rare earth elements, accounting for about 60% of global consumption.

China Takes Measures to Protect its Supply
It is believed that the resource grade of China's Bayan Obo deposit may be dwindling – resulting in a reduced forecast over next five years. Therefore, China has taken multiple measures to protect its supply, and some feel that China could go from being a net exporter to a net importer. In 2010, China began to restrict exports so as to ensure an abundant supply for its downstream technology sector. Export quotas in 2010 were down 40% from 2009. When a single country controls almost all of the production and then reduces exports, the entire supply is threatened and prices quickly rise. The panic buying that was triggered by the reduction in export quotas resulted in rare earth prices surging to record high levels in early 2010. The significant price increases in 2010 led to a drop in demand, which in turn restored pricing stability. At the end of December 2011, the Chinese Ministry of Commerce announced that "in order to protect international demand and maintain the basic stability of rare-earth supplies, the total export quotas for 2012 will be basically the same." China also took steps to nationalize the industry, bringing 11 REE mines under State control, and to crack down on illegal and environmentally questionable mining practices.

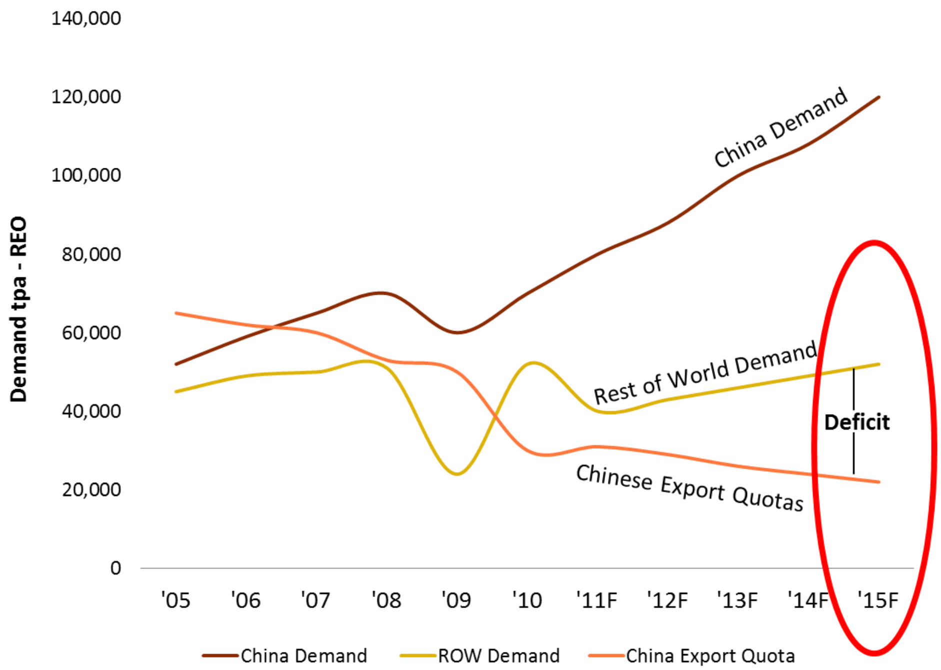
China's Actions Prompt a Rare Earth Race
The steps taken by China have raised concerns that the world is reliant on a single source for rare earths. Currently, the world is nearly 100% dependant on Chinese exports of a commodity that is essential to certain high-tech, renewable-energy, and defense-related technologies. Thus the race is on for the rest of the world to develop rare earth deposits.

The U.S. considers REEs as a strategic material and in April 2011 legislation known as Rare Earths Supply Chain Technology and Resources Transformation Act HR 1388 (RESTART) was introduced to avert a rare earth crisis by re-establishing a domestic rare earth industry. Subsequently, California based Molycorp signed a Joint Venture with Daido Steel and Mitsubishi to manufacture high power magnets. It is expected that this first non-Chinese Joint Venture should pave the way for other western producers to establish rare earth joint ventures outside of China – leading to a tripling in demand for neodymium over the next three years. (*Source: Rare Earth Market - December 2011)*.

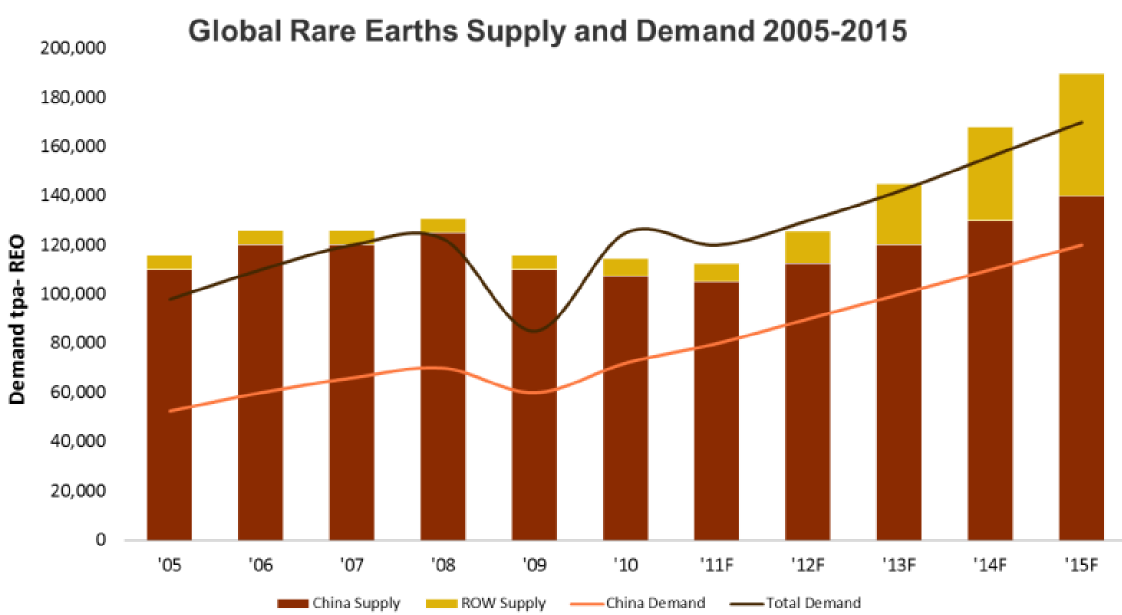
As a result of China's actions, two separate markets have been created – the China market and the rest of the world market (ROW).



Gap between Supply from China and Rest of World Demand is Growing
The following chart illustrates the widening gap between the supply from China and the demand from the rest of the world:



Rest of World Production Expected to Fill the Growing Gap
While China accounted for 94% of production in 2011, this is expected to fall to 70% by 2015 as new projects in the rest of the world come on stream.



Source: D. Kingsworth IMCOA 2011

Speed to Market Critical

It is expected that the supply shortfall will continue for the next few years. There are insufficient REEs available to meet growing demand. Given the very attractive supply/demand fundamentals, bringing deposits into production as fast as possible is critical.

While there are known deposits in countries outside of China that are potentially economic to mine, it can take 10 years to bring a deposit into production. High grade deposits close to infrastructure and in mining friendly jurisdictions are hard to come by. According to *Technology Metals Research*, it's estimated that there are 165 companies with 251 projects in 24 countries. Most of these companies are small.

Major REE production projects expected to come on stream in the near future are listed below:

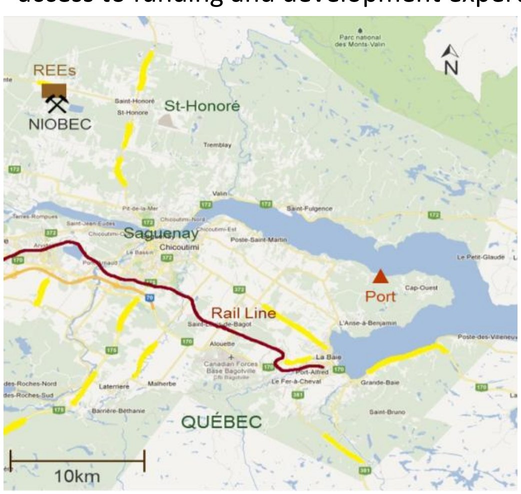
Company	Project	Expected Production(mt)	Targeting Production in:
Lynas (Australia)	Mount Weld	22,000	2011*
Molycorp (California)	Mountain Pass	40,000	2011*
Arafura (Australia)	Nolans Bore	20,000	2013
Greenland Minerals	Kvanefjeld	44,000	2015
Avalon (Canada)	Thor Lake	10,000	2015
Quest Rare Minerals	Strange Lake	12,000	2015

*Molycorp's Mountain Pass and Lynas' Mount Weld mines are expected to reach full production in 2012.

Source: IMCOA

IAMGOLD Advantage

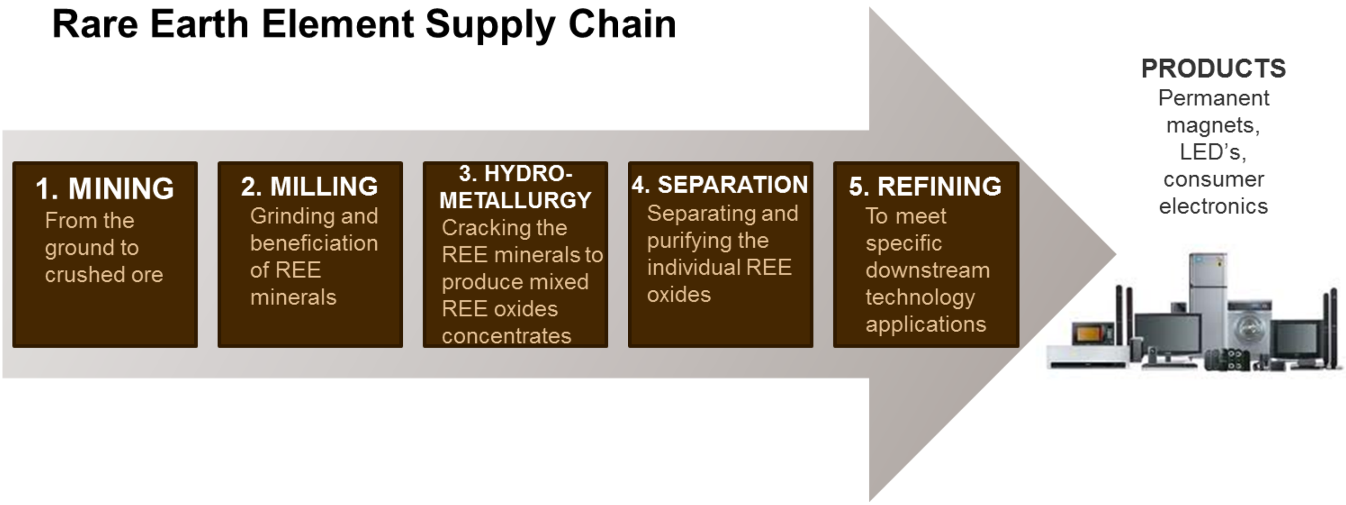
IAMGOLD's rare earth resource is located one kilometre north of its Niobec niobium mine in the mining friendly jurisdiction of Quebec, Canada. The Niobec mine has been operating for more than 35 years and IAMGOLD has established excellent relations with the local community and all levels of government. The region has a long mining history and draws on an experienced and well educated pool of labour in the area. In addition to its close proximity to an existing mine infrastructure and the Saguenay River which, within a short distance of the deposit widens and deepens enough for a deep water ocean port, the Company has access to very competitive power rates of 4.5 cents per kWh. These factors, together with access to funding and development expertise provide a "speed to market" advantage.



The Rare Earths Value Chain – Ground to Market

REEs are principally found in carbonatites, which are igneous rocks comprising more than 50% carbonate minerals. Less important sources are secondary deposits which form when rare earth and heavy minerals are concentrated by the physical weathering of primary mineralization.

Most REE mines produce only REEs although there are a few where REEs are produced as a by-product. Most use large-scale techniques, involving drilling, blasting and hauling. Separation of the ore from the waste is carried out in a variety of ways. The production process is quite involved as one rare earth mineral may contain up to 17 different elements which must be separated from one another. The following diagram summarizes the basic steps of mining and processing REE.



REE Pricing

Prices increased dramatically in 2010 following China's decision to reduce exports. This led to reduced demand which in turn restored pricing stability. As the world races to secure REE supply outside of China, future pricing projections indicate a strong market sustained by growing demand.

($/kg)

REE	2009	Nov. 2011	Jan 25, 2012	2012(E)*
Lanthanum	6	60	62	17
Cerium	4	55	100	29
Praseodymium	16	60	250	150
Neodymium	16	235	295	154
Samarium	5	87	150	32
Dysprosium	107	2,000	2,600	688
Europium	473	4,000	3,850	1,393

**CIBC World Markets*

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British Geological Survey

Risk List 2012

An update to the supply risk index for elements or element groups that are of economic value

The updated risk list provides a quick and simple indication of the relative risk in 2012 to the supply of 41 elements or element groups that we need to maintain our economy and lifestyle. The position of an element on this list is determined by a number of factors that might affect availability. These include the natural abundance of elements in the Earth's crust, the location of current production and reserves, and the political stability of those locations. ***New for 2012 recycling rates and substitutability of the elements has been considered in the analysis.*** Data sources used in the compilation of the list are internationally recognised and publicly available. ***The updated risk list contains fewer elements than the 2011 version. Eleven of the original 52 elements have been excluded from the update because of data availability and quality issues.***

The risk list highlights a group of elements for which global production is concentrated in very few countries. The restricted reserve distribution and the relatively low political stability ratings for some major producing countries combine to significantly increase risk to supply. ***This is compounded by low rates of recycling and limited substitutes for many of these elements.*** Concern over rare earth element supply has received significant attention recently and this element group remains at the top of the list. However, the list highlights other economically important metals with similar high levels of risk to supply disruption including platinum group metals (active components in auto-catalysts), niobium (used in MRI scanners and touch screens) and tungsten (a key hard metal used in almost all cutting tools). ***These elements, particularly the rare earth elements and tungsten, have medium to low recycling rates and a limited number of substitutes.*** The list also shows the current dominance of China in production of many metals and minerals. China is now the leading global producer of 22 of the 41 elements and element groups on the list (Figure 1).

As demand for metals and minerals increases, driven by relentless growth in the emerging economies in Asia and South America, competition for resources is growing. The risk list gives an indication of which elements might be subject to supply disruption, most likely resulting from human factors such as geopolitics ('haves' seeking to influence 'have nots') or resource nationalism (state influence on, or control of, production), along with events such as mine strikes and accidents. Policy-makers, industry and consumers should be concerned about supply security and the need to ensure diversified supply of primary resources. Equally important will be the need to make full use of secondary resources and recycling, and to reduce our intensity of resource use i.e. 'do more with less'.

With the exception of substitutability the list focuses on risks to supply and does not include any assessment of factors that influence demand, such as criticality of an element to a particular technology.

An in-depth discussion of the risk list methodology and limitations can be found below.

British Geological Survey

Risk list 2012—Current supply risk index for chemical elements or element groups which are of economic value

Element or element group	Symbol	Relative supply risk index	Leading producer	Top reserve holder
rare earth elements	REE	9.5	China	China
tungsten	W	9.5	China	China
antimony	Sb	9.0	China	China
bismuth	Bi	9.0	China	China
molybdenum	Mo	8.6	China	China
strontium	Sr	8.6	China	China
mercury	Hg	8.6	China	Mexico
barium	Ba	8.1	China	China
carbon (graphite)	C	8.1	China	China
beryllium	Be	8.1	USA	Unknown
germanium	Ge	8.1	China	Unknown
niobium	Nb	7.6	Brazil	Brazil
platinum group elements	PGE	7.6	South Africa	South Africa
colbalt	Co	7.6	DRC	DRC
thorium	Th	7.6	India	USA
indium	In	7.6	China	Unknown
gallium	Ga	7.6	China	Unknown
arsenic	As	7.6	China	Unknown
magnesium	Mg	7.1	China	Russia
tantalum	Ta	7.1	Brazil	Brazil
selenium	Se	7.1	Japan	Russia
cadmium	Cd	6.7	China	India
lithium	Li	6.7	Australia	Chile
vanadium	V	6.7	South Africa	China
tin	Sn	6.7	China	China
fluorine	F	6.7	China	South Africa
silver	Ag	6.2	Mexico	Peru
chromium	Cr	6.2	South Africa	Kazakhstan
nickel	Ni	6.2	Russia	Australia
rhenium	Re	6.2	Chile	Chile
lead	Pb	6.2	China	Australia
carbon (diamond)	C	6.2	Russia	DRC
manganese	Mn	5.7	China	South Africa
gold	Au	5.7	China	Australia
uranium	U	5.7	Kazakhstan	Australia
zirconium	Zr	5.7	Australia	Australia
iron	Fe	5.2	China	Australia
titanium	Ti	4.8	Canada	China
aluminium	Al	4.8	Australia	Guinea
zinc	Zn	4.8	China	Australia
copper	Cu	4.3	Chile	Chile

Supply risk index runs from 1 (blue—very low risk) to 10 (red—very high risk)

Limitations and methodology are set out in accompanying notes

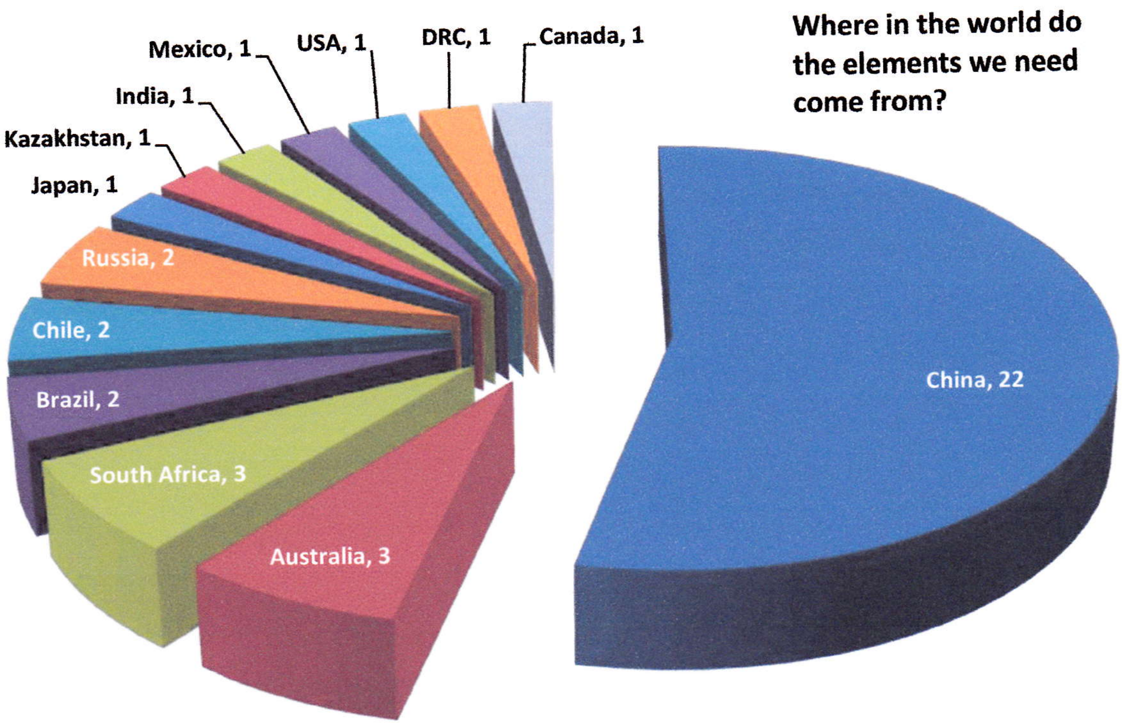

Figure 1. Chart indicates the number of times a country is the leading global producer of an element or element group of economic value. ***Source: BGS World Mineral Statisitics***

Methodology for estimating the relative risk to supply of the chemical elements

The following methodology was used to define the relative risk to supply of the following elements:

Silver (Ag); Aluminium (Al); Arsenic (As); Gold (Au); Barium (Ba); Beryllium (Be); Bismuth (Bi); Diamond; Graphite; Cadmium (Cd); Cobalt (Co); Chromium (Cr); Copper (Cu); Fluorine (F); Iron (Fe); Gallium (Ga); Germanium (Ge); Mercury (Hg); Indium (In); Lithium (Li); Magnesium (Mg); Manganese (Mn); Molybdenum (Mo); Niobium (Nb); Nickel (Ni); Lead (Pb); Platinum Group Elements (PGE - Ruthenium (Ru), Palladium (Pd), Osmium (Os), Iridium (Ir) and Platinum (Pt)) ; Rhenium (Re); Rare Earth Elements (REE - Lanthanum (La), Cerium (Ce), Praseodymium (Pr), Neodymium (Nd), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Holmium (Ho), Erbium (Er), Thulium (Tm), Ytterbium (Yb) and Lutetium (Lu)); Antimony (Sb); Selenium (Se); Tin (Sn); Strontium (Sr); Tantalum (Ta); Thorium (Th); Titanium (Ti); Uranium (U); Vanadium (V); Tungsten (W); Zinc (Zn); and Zirconium (Zr).

Elements not included are those for which insufficient data exist.

An Excel spreadsheet was used to rank the above elements in terms of the relative risk to supply. The ranking system was based on seven criteria scored between 1 and 3.

- Scarcity
- Production concentration
- Reserve distribution
- Recycling Rate
- Substitutability
- Governance (top producing nation)
- Governance (top reserve-hosting nation)

A score of 1 indicates that a particular criterion has a low contribution to supply risk, while a score of 3 indicates a high risk. The scores for each criterion were summed to give an overall risk to supply, the larger the score the greater the potential risk to supply. Each criterion was given equal weight. The elements were ranked according to their score and a gradational colour scale applied such that increased risk is indicated by hotter colours.

Scarcity

Crustal abundances (Table 1) provide an indication of the scarcity of a given element on a global scale. For example, gold would be classified as high-risk due to its low crustal abundance of 0.0013 ppm, while iron would classified as low-risk with a crustal abundance of about 52,157 ppm.

The scores were allocated as follows:

1 (low) = >100 ppm
2 (medium) = >1 to 100 ppm
3 (high) = <1 ppm

Element	Abundance (ppm)	Element	Abundance (ppm)
Ag	0.055	Mn	774
Al	84,149	Mo	0.8
As	2.5	Na	22,774
Au	0.0013	Nb	8
B	11	Nd	20
Ba	456	Ni	26.6
Be	1.9	Os	0.000041
Bi	0.18	P	567
Br	0.88	Pb	11
Cd	0.08	Pd	0.0015
Ce	43	Pr	4.9
Co	26.6	Pt	0.0015
Cr	135	Re	0.000188
Cu	27	Ru	0.00057
Dy	3.6	S	404
Er	2.1	Sb	0.2
Eu	1.1	Se	0.13
F	553	Sm	3.9
Fe	52,157	Sn	1.7
Ga	16	Sr	320
Gd	3.7	Ta	0.7
Ge	1.3	Tb	0.6
Hg	0.03	Th	5.6
Ho	0.77	Ti	4136
I	0.71	Tm	0.28
In	0.052	U	1.3
Ir	0.000037	V	138
K	15,025	W	1
La	20	Yb	1.9
Li	16	Zn	72
Lu	0.3	Zr	132
Mg	28,104		

Table 1 - Average total crustal abundance of the elements included in this study. Data from Rudnick and Gao (2003).

Production concentration

Where the production of a given commodity is concentrated in a few countries this can increase the risk to supply. For example, about 84 per cent of the world's tungsten is currently sourced from China. The BGS' World Mineral Production data (2006-2010) were used to identify the top three producing countries and the percentage of world supply for which the leading country is responsible.

The percentage production for the top three countries was scored as follows:

1 (low) = <33.3 %
2 (medium) = >33.3 to 66.6 %
3 (high) = >66.6 %

Reserve distribution

Mineral deposits are unequally distributed across borders and concentration of reserves in a few countries poses an increased risk to short-term supply. For example, about 97 per cent of the world's reserves of niobium are found in Brazil. We have used mineral reserve distribution data from the USGS to provide an indication of the potential for short-term supply disruption. *Mineral Reserves* are effectively 'working inventories' that are continually revised and updated in light of numerous factors pertaining to mining, metallurgy, economics, marketing, law, and the environment (USGS, 2010). USGS' Commodity Summaries (2012) reserves data were used to identify the three countries contributing the largest share to global reserves and the percentage of the world reserves held by the top country.

The percentage of the global reserves held by the top three countries was scored as follows:

1 (low) = <33.3 %
2 (medium) = >33.3 to 66.6 %
3 (high) = >66.6 %

Where USGS data are unavailable an arbitrary score of 2 was allocated. For example, beryllium, arsenic, germanium, indium, and gallium are allocated a score of 2 since reserve information is unavailable. USGS reserve data are also unavailable for uranium. However, reserve data for 2009, available from the World Nuclear Authority (WNA), are used in this study.

Recycling rate (recyclability)

The recycling rate of a given commodity may either contribute to, or reduce risk to supply. A higher recycling rate might, for example, lead to a reduction in demand for primary resources. Currently, about 50 per cent of the world's iron is recycled, whilst the recycling rate of beryllium is approximately less than one per cent. The United Nations Environment Programme (UNEP) report on 'Recycling Rates of Metals' (2011) was used to identify the recycling rates of 42 commodities.

The recycling rate was scored as follows:

1 (high) = >30 %
2 (medium) = >10 to 30 %
3 (low) = <10 %

Where data are unavailable an arbitrary score of 2 was allocated. For example, fluorspar, diamond, graphite, uranium, and thorium are allocated a score of 2 since recycling rate information is unavailable.

Substitutability

The substitutability (the potential for one commodity to take the place of another in a given application) of a given commodity may either contribute to, or reduce risk to supply. The availability of suitable substitutes for a given commodity may, for example, lead to a reduction in demand for primary resources. Currently substitutes for the rare earth elements are very limited. However, several substitutes exist for copper, such as silver, aluminium, fibre optics, steel, and even plastics for some applications. The University of Augsburg report on 'Materials Critical to the Energy Industry' (2011)[1] and the EU Raw Materials Initiative report 'Defining Critical Raw Materials' (2008)[2] were used to identify the substitutability of 31 commodities.

1 = Low[1] *or* <0.3[2]
2 = Medium[1] *or* 0.3 to 0.7[2]
3 = High[1] *or* >0.7[2]

Where data are unavailable an arbitrary score of 2 was allocated. For example, arsenic, gold, bismuth, diamond, mercury, lead, selenium, tin, strontium, and zirconium are allocated a score of 2 since substitutability information is unavailable.

Governance indicators

The political stability of a producing country, or country in which large reserves are held, may impact upon the supply of mineral commodities e.g. supplies may be interrupted by war, government intervention, famine or other forms of unrest. A political stability score was derived from World Bank governance indicators (2011), for both the leading producing country, and for the country with the largest reserves. The World Bank website provides percentile rank information for 213 countries on six different criteria: voice and accountability; political stability; government effectiveness; regulatory equality; rule of law; and control of corruption. Only political stability was considered as part of this study.

Countries with a political stability percentile of <33.3 per cent were scored 3, those with a percentile between >33.3 and 66.6 per cent were scored 2 and those with a percentile of >66.6 per cent were scored 1.

For each commodity an individual political stability score for both the leading global producer and for the chief reserve holder were scored as follows:

1 (high) = >66.6 %
2 (medium) = >33.3 to 66.6 %
3 (low) = <33.3 %

For example, China (with a WB percentile rank of 24.1) is the leading producing country for rare earth elements, and also has the largest share of global reserves, earning it a score of 3 in both cases, while Brazil (with a WB percentile rank of 48.1) is the leading producing country of niobium, and also has the largest share of global reserves, giving it a score of 2 in both cases.

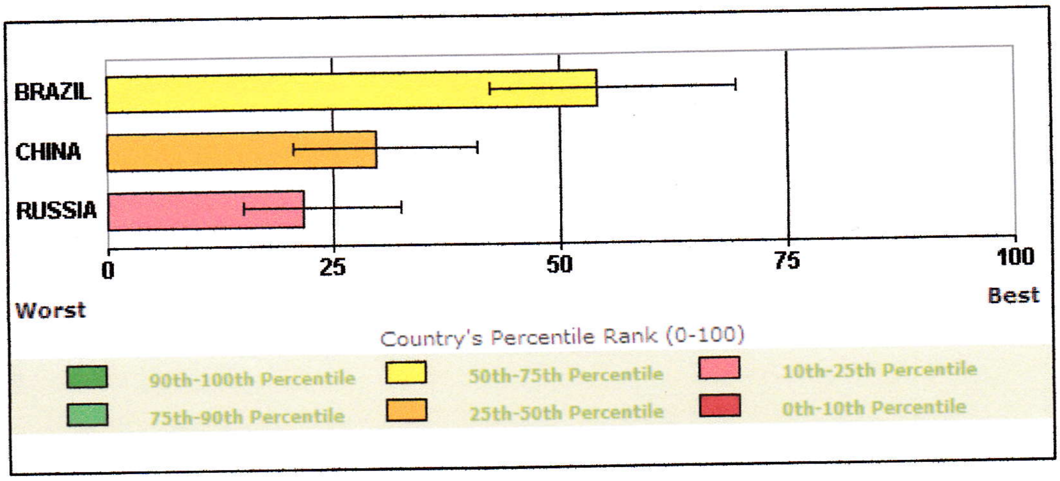

Figure 2 - Political stability indicators for Brazil, China and Russia. Data from the World Bank after Kaufmann *et al.* (2011).

Supply risk

An integrated supply risk was calculated by combining the scores for each of the seven criteria. This is illustrated for two elements, rare earth elements and copper, in Table 2.

Category	Rare Earth Element Score		Copper Score	
	Value	**Score**	**Value**	**Score**
Recycling rate (%)	<10	3	>30	1
Substitutability	H	3	L	1
Crustal abundance (ppm)	0.3	3	27	2
Reserve distribution (%)	50	2	28	1
Production concentration (%)	97	3	34	2
Political stability (top reserve holder)	24.1	3	67.5	1
Political stability (top producing country)	24.1	3	67.5	1
Total		**20**		**9**
Supply Risk Index (Total/2.1)		**9.5**		**4.3**

Table 2 - The calculation of a supply risk index.

Aggregate scores were divided by 2.1 to produce a simple supply risk index from 1 (very low risk) to 10 (very high risk). For example, copper has an initial aggregate score of 9. This is divided by 2.1 to give a score of 4.3. This shows that copper has a lower relative risk to supply compared to REE with a score of 9.5. Below is the final ranked output list with gradational colour scale such that increased risk is indicated by hotter colours (Table 3).

Element or Element Groups	Relative Supply Risk Index	Top Producer	Top Reserve Holder
REE	9.5	China	China
W	9.5	China	China
Sb	9.0	China	China
Bi	9.0	China	China
Mo	8.6	China	China
Sr	8.6	China	China
Hg	8.6	China	Mexico
Ba	8.1	China	China
C (graphite)	8.1	China	China
Be	8.1	USA	Unknown
Ge	8.1	China	Unknown
Nb	7.6	Brazil	Brazil
PGE	7.6	South Africa	South Africa
Co	7.6	DRC	DRC
Th	7.6	India	USA
In	7.6	China	Unknown
Ga	7.6	China	Unknown
As	7.6	China	Unknown
Mg	7.1	China	Russia
Ta	7.1	Brazil	Brazil
Se	7.1	Japan	Russia
Cd	6.7	China	India
Li	6.7	Australia	Chile
V	6.7	South Africa	China
Sn	6.7	China	China
F	6.7	China	South Africa
Ag	6.2	Mexico	Peru
Cr	6.2	South Africa	Kazakhstan
Ni	6.2	Russia	Australia
Re	6.2	Chile	Chile
Pb	6.2	China	Australia
C (diamond)	6.2	Russia	DRC
Mn	5.7	China	South Africa
Au	5.7	China	Australia
U	5.7	Kazakhstan	Australia
Zr	5.7	Australia	Australia
Fe	5.2	China	Australia
Titanium (Rutile, Ilmenite, and Leucoxene)	4.8	Canada	China
Al	4.8	Australia	Guinea
Zn	4.8	China	Australia
Cu	4.3	Chile	Chile

Table 3 - The relative supply risk index. Risk is scaled between 1 (blue) and 10 (red), hotter colours indicate a greater risk to supply.

Limitations to the methodology

Previous studies of this nature have included information pertaining to the environment, supply and demand, TMR (total material requirements), and climate change. This study omits many of these factors. For instance, we have not taken into account the potential impact of supply disruptions e.g. mercury is little used therefore the impact would be less than for an interruption to the supply of platinum group elements.

IMPORTANTLY - this represents a 'snapshot' in time and does not take in to account future issues and supply-demand scenarios. The minerals market is not static, new reserves are continually added in response to drivers such as demand and advances in technology. In the future recycling is likely to contribute an increasing share to the global market and substitutability may also increase as new technologies are delivered.

Crustal abundance values do not take into account crustal dispersion, nor do they account for the tendency of an element to become economically concentrated.

Where more than one mineral source exists for a given element e.g. titanium occurring in rutile, leucoxene and ilmenite, all sources have been combined to give a total.

Where appropriate, groups of elements have been combined and dealt with as a single commodity e.g. platinum group elements and rare earth elements. For these grouped elements a worst case scenario has been taken in terms of the crustal abundance e.g. lutetium at 0.3 ppm has been used to calculate the crustal abundance risk for rare earth elements rather than cerium at 43 ppm. Likewise, iridium 0.000037 ppm has been used to calculate the crustal abundance risk for platinum group elements rather than palladium at 0.0015 ppm.

Certain commodities have been used as a proxy for a given element; this approach may mean that not all sources of an element have been included in the production and reserve calculations (Table 4).

Element	Proxy
Fluorine	Fluorspar - CaF_2
Carbon	Coal, diamonds, and graphite
Barium	Barytes - $BaSO_4$
Beryllium	Beryl - $Be_3Al_2(SiO_3)_6$
Titanium	Rutile and Ilmenite - TiO_2 and $FeTiO_3$
Magnesium	Magnesite - $MgCO_3$
REE	Rare Earth Oxides (REO)

Table 4 - Proxy data used in the calculation of production and reserve concentrations for selected elements.

Where primary production data for a given commodity is limited other sources of data have been included (Table 5).

Element	Data Source
Indium	BGS estimates
Gallium	USGS production 'capacity'
Germanium	U.S. imports
Thorium	Monazite concentrate production
Selenium	Selenium metal production

Table 5 - Data sources used where production data for a given commodity are limited or non-existent.

Mineral resources[3] have been omitted from this study as there are no reliable comprehensive data on distribution or volumes.

Elements that have little or no commercial use have been omitted from this study e.g. polonium, astatine, and radium. Likewise, synthetic or 'manufactured' elements have also been omitted e.g. elements of atomic number 95 to 114, and hydrogen. Elements naturally occurring in a gaseous state are also not included e.g. the Noble gases, oxygen and nitrogen because the criteria used are unsuitable for assessing the supply risk of these elements. Production and reserve information for some of the minor metals e.g. scandium, yttrium, caesium, tellurium, thulium, and rubidium is unavailable because they are commonly produced as by-products or co-products of other metals. For example, yttrium is often associated with rare earth element-bearing minerals; scandium is found in trace amounts in minerals such as beryl, garnet and wolframite; caesium is often a by-product of lithium extraction; and tellurium, along with selenium, is a common by-product of nickel and copper ore extraction.

Definitions

1. *Reserves* - a 'mineral reserve' is the part of the resource which has been fully geologically evaluated and is commercially and legally mineable. Reserves may be regarded as 'working inventories', which are continually revised in the light of various 'modifying factors' related to mining, metallurgy, economics, marketing, law, the environment, communities, government, etc, etc (USGS, 2010).

2. *Resources* - a 'mineral resource' is a natural concentration of minerals or a body of rock that is, or may become, of potential economic interest as a basis for the extraction of a mineral commodity. A resource has physical and/or chemical properties that make it suitable for specific uses and it is present in sufficient quantity to be of intrinsic economic interest. It encompasses 'mineral reserve' and 'reserve base' plus other identified resources which could be exploited in the future if required according to the economic situation (USGS, 2010).

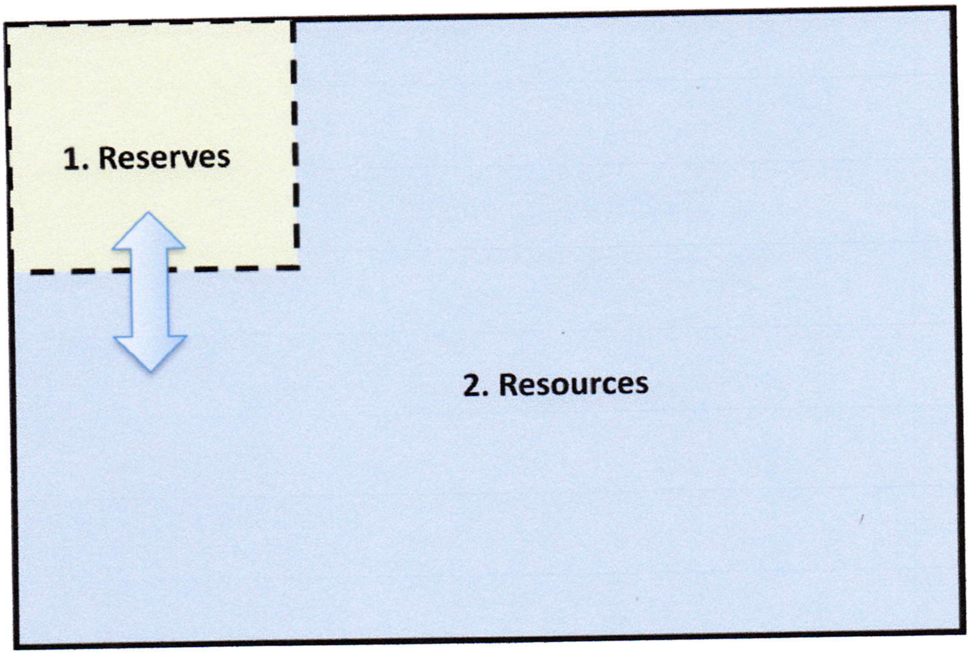

Figure 3 - Graphical representation of the relationship between reserves and resources.

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Appendix 5

Tairilac (by Formasa) Virgin ABS Data Sheets

FCFC TAIRILAC ABS RESINS

TECHNICAL INFORMATIONS

GENERAL PURPOSE GRADE

TAIRILAC	AG1000	AG10A1
TAIRILAC	AG12A0	AG12A1
TAIRILAC	AG15A0	AG15A1
TAIRILAC	AG15E0	AG15E1

FORMOSA CHEMICALS & FIBRE CORPORATION
PLASTICS DIVISION

CONTENTS

This technical data gives the characteristics of FCFC ABS General Purpose Grades and their injection moldability.

1. Characteristics of FCFC ABS general purpose grades

The following four grades are available as FCFC ABS general purpose grades, and their characteristics are:

(1) Superior impact resistance and Flexural modulus.
(2) Stability of physical properties over a wide range of temperatures.
(3) Excellent chemical resistance.
(4) Superior processability.
(5) Superior dimensional stability and finish.

Table 1. Features of FCFC ABS general purpose grades

Grades	Features
AG1000	Highest impact resistance
AG12A0	High impact resistance
AG15A0	Medium impact resistance
AG15E0	Medium impact resistance

Compared with A0 grades, Series of A1 grades which FCFC newly developed, especially suitable for those injection molding products requested for higher gloss.

2. Typical properties

Table 2. Typical properties of FCFC ABS general purpose grades

Properties	ASTM Test Method	Condition	Unit	AG1000	AG12A0	AG15A0	AG15E0
Tensile strength at yield 1/8" thickness	D638	23℃ 73°F	kg/cm² psi	390 5,540	480 6,820	510 7,240	530 7,530
Flexural strength at yield 1/8"×1"×4" bar	D790	23℃ 73°F	kg/cm² psi	580 8,230	750 10,650	850 12,070	870 12,350
Flexural modulus 1/8"×1"×4" bar	D790	23℃ 73°F	kg/cm² psi	19,500 276,900	25,000 355,000	27,000 383,000	28,000 398,000
Rockwell hardness	D785	23℃ 73°F	R scale	95	106	110	110
Izod impact strength (notched) 1/4"×1/2"×5/2" bar	D256	23℃ 73°F	kg.cm/cm ft.lb/in	40 7.3	30 5.5	20 3.7	14 2.6
		0℃ 32°F	kg.cm/cm ft.lb/in	36 6.6	26 4.8	16 2.9	11 2.0
		-20℃ - 4°F	kg.cm/cm ft.lb/in	33 6.1	22 4.0	10 1.8	7 1.3
		-40℃ -40°F	kg.cm/cm ft.lb/in	30 5.5	18 3.3	—	—
Heat deflection temperature unannealed	D648	18.6kg/cm² 264 psi	℃ °F	86 187	88 190	89 192	88 190
Melt Flow Index	D1238	200℃×5kg	g/10 min	0.4	1.6	1.7	1.9
		220℃×10kg	g/10 min	10	17	19	21
Specific gravity	D792	23℃ 73°F		1.03	1.04	1.05	1.05
Flammability	UL94	1/8"		HB	HB	HB	HB
		1/16"		HB	HB	HB	HB

Table 3. Typical properties of FCFC ABS high gloss general purpose grades

Properties	ASTM Test Method	Condition	Unit	AG10A1	AG12A1	AG15A1	AG15E1
Tensile strength at yield 1/8" thickness	D638	23℃	kg/c㎡	390	450	510	530
		73°F	psi	5,540	6,390	7,240	7,530
Flexural strength at yield 1/8"×1"×4" bar	D790	23℃	kg/c㎡	580	750	850	870
		73°F	psi	8,230	10,650	12,070	12,350
Flexural modulus 1/8"×1"×4" bar	D790	23℃	kg/c㎡	18,000	25,000	27,000	28,000
		73°F	psi	256,000	355,000	383,000	398,000
Rockwell hardnes	D785	23℃ 73°F	R scale	90	105	110	110
Izod impact strength (notched) 1/4"×1/2"×5/2" bar	D256	23℃ 73°F	kg.cm/cm ft.lb/in	35 6.4	30 5.5	20 3.7	14 2.6
		0℃ 32°F	kg.cm/cm ft.lb/in	32 5.8	26 4.8	16 2.9	11 2.0
		-20℃ - 4°F	kg.cm/cm ft.lb/in	29 5.3	22 4.0	10 1.8	7 1.3
		-40℃ -40°F	kg.cm/cm ft.lb/in	26 4.7	18 3.3	—	—
Heat deflection temperature unannealed	D648	18.6kg/c㎡	℃	87	88	89	88
		264 psi	°F	189	190	192	190
Melt Flow Index	D1238	200℃×5kg	g/10 min	0.4	1.6	1.7	1.9
		220℃×10kg	g/10 min	10	17	19	21
Specific gravity	D792	23℃ 73°F		1.03	1.04	1.05	1.05
Flammability	UL94	1/8"		—	—	HB	—
		1/16"		—	—	HB	—

2.1 Mechanical properties

Figures 1, 2, and 3, "Stress-strain curve vs temperature" show that the yield strain of FCFC ABS general purpose grades is about 5% and the strain at the elasticity limit is about 3%.

Figures 4, 5, 6, and 7, indicate that FCFC ABS general purpose grades retain good physical properties even at high temperatures around 60℃.

Figure 8 gives "Tensile creep curev" which indicates that FCFC ABS general purpose grades have excellent creep resistances.

"Impact strength vs temperature" in Figure 9 and 10 demonstrates that these grades maintain high impact strength even at low temperature.

Falling dart impact test is a good measure in judging the practical impact resistance of plastic materials some of the test results are shown in Table 4.

Table 4. Falling dart impact strength of FCFC ABS general purpose grades and some other plastics

Grades	Falling dart impact strength
AG1000	90(kg.cm/mm)
AG12A0	88
AG15A0	77
GPS	5
PMMA	8
SAN	9
PP	60
PE	55
Nylon 6	130
Polycarbonate	150

Dart top: R=3/16"

Figure 11 shows the mumber of flexing before the test specimens break on at the repeated flexural fatigue test perform under a fixed strain.

Repeated stress should be restricted to 150 kg/cm² or less, and strain to 1.5% or less in dynamic use.

2.2 Thermal properties

"Heat deflection temperature vs fiber stress" is shown in Figure 12, as a criterion of the maximum practical temperature of molded products. It will be noticed from this Figure the heat deflection temperature changes less in the FCFC ABS general purpose grades as the loads varied than in crystalline plastics such as polyethylene, polypropylene, nylon, polyacetal.

Unannealed molded products of FCFC ABS general purpose grades should be used at the temperature below 80℃, as deduced from Figure 13 "Thermal shrinkage of molded products". However, if the molded products are annealed, applicable temperature can be extended to 85℃ or 90℃.

2.3 Weathering resistance

Ultra violet rays will produce a very thin, hard and brittle layer on the surface of molded products, resulting in cracking. Thus, the weathering resistance influences the impact strength. Refer to Figures 14 and 15. Molded products can be protected from deterioration by coloring them with carbon black (Figure 16) or by painting or metal plating (Figure 17).

2.4 Chemical resistance

Main chemical resistant properties of FCFC ABS general purpose grades are shown in Table 4.

These grades resist to inorganic acid, alkali, salt and non-polarity oil, but dissolve or swell in esters, ketones, aromatics, or chlorinated hydrocarbon.

In case residual strains remain in molded products, solvent cracks are produced in glacial acetic acid, alcohol and gasoline and in some cases, cracks are produced even in vegetable oils.

Table 4. Chemical resistance

Weight change (%) in 7 days
immersion at room temperature

Chemicals	AG1000	AG12A0	AG15A0	Appearance
Water	0.45	0.46	0.48	Unchanged
10% Ammonium hydroxide	0.96	0.74	0.71	Unchanged
5% Acetic acid	0.46	0.44	0.45	Unchanged
10% Hydrochloric acid	0.38	0.36	0.37	Unchanged
3% Sulfuric acid	0.47	0.45	0.49	Unchanged
10% Sodium hydroxide	0.33	0.36	0.38	Unchanged
95% Ethyl alcohol	1.98	1.62	1.30	AG1000 turned slightly white
n-heptane	2.57	0.04	0.07	AG1000 turned slightly white
Regular gasoline	—	—	4.92	Swelled
Machine oil	0.03	0.03	0.02	Unchanged
Corn oil	0.03	0.02	0.00	Unchanged
Dioctyl phthalate	-0.02	-0.01	0.02	Unchanged

3. Injection molding property

3.1 Flowability

The flowability of ABS resins is slightly less than that of polystyrene and polyolefin. However, since ABS resins are superior in dimensional accuracy and heat stability, and flashes and sink marks are hardly produced at the time of molding, ABS resins can be molded with ordinary injection molding machines.

"Spiral flow vs temperature" is shown in Figure 18 as a criterion of flowability in actual injection molding.

Figure 19 shows the ratio of flow length to thickness of molded products (L/T).

3.2 Pre-drying

FCFC ABS resins have low water absorbancy like any other ABS. However, when they are molded without predrying, silver streaks and uneven gloss occurred in some instances.

Figure 20 shows "Drying and water absorption curve of FCFC ABS general purpose grades".

It is desirable to dry ABS pellets for 2 to 3 hours at 70 to 80℃ in a hot air circulation dryer. ABS pellets should be laid in the thickness of 2 to 3 cm in the dryer.

3.3 Molding conditions and properties

Figures 21 and 22 show the effects of molding temperatures on tensile strength and impact strength.

Figures 23 and 24 show the effects of molding temperatures and residence time in the cylinder on impact strength.

The above data indicate that stock temperatures of FCFC ABS general purpose grades should be kept less than 250℃.

Figure 25 shows the relation between mold shrinkage and mold pressure. Mold shrinkage is subject to many factors such as molding conditions, product shapes and mold structures.

However, in general, FCFC ABS general purpose grades shrink by 0.4-0.7% in the direction of material flow and by 0.3-0.5% at the right angle to this direction.

Figure 26 indicates the relation between gloss and mold temperature.

Figure 27 shows the relation between number of recycling and deterioration. Materials made under normal molding conditions show little deterioration in physical properties, even if recycled.

However, blending ratio of recycled materials to virgin resins should be restricted to 20% or less.

Molding examples for FCFC AG1000

Molding machine		Nikko Ankerwerk V165-1150	Kawaguchi IP-220S
Molded products		Engine cooling fan cover	Safety helmet
Weight	g	560	270
Gate Runner	mm mm	Pinpoint 2φ Trapezoid 6×12×6	Direct 6φ
Molding temp.			
Cylinder H1	℃	170	150
H2	℃	230	205
H3	℃	240	215
H4	℃	250	225
Nozzle	℃	250	180
Injection pressure	kg/cm²	1,300	900
Screw revolution	rpm	31	—
Mold temperature	℃	60	70

Molding examples for FCFC AG12A0

Molding machine		Nissei Plastic Industrial Co., Ltd.	Kawaguchi IP-650-100S
Molded product		Attache case	Chair for school children
Weight	g	300×2	900
Gate Runner	mm mm	Pinpoint 1.2φ×2 points 1.6φ×1 point	Ring 22φ×1
Molding temp.			
Cylinder H1	℃	230	170
H2	℃	245	210
H3	℃	245	225
H4	℃	248	250
Nozzle	℃	245	220
Injection pressure	kg/cm²	1,000	1,000
Screw revolution	rpm	65	60
Mold temperature	℃	70	60

Molding examples for FCFC AG15A0

Molding machine		Kawaguchi IP-220S	Mitsubishi NATCO 225E-20
Molded product		Bobbin for filament	Jar
Weight	g	220×2	900
Gate Runner	mm mm	Side 3×4 10ϕ	Direct 12ϕ
Molding temp. Cylinder H1 H2 H3 H4 Nozzle	 ℃ ℃ ℃ ℃ ℃	 180 210 220 230 220	 180 210 240 245 240
Injection pressure	kg/cm²	1,000	950
Screw revolution	rpm	46	46
Mold temperature	℃	60	60

Figure 1. Stress-Strain curve vs temperature FCFC AG1000

Test specimen: ASTM dumbbell type I

Test speed : 50 mm/min

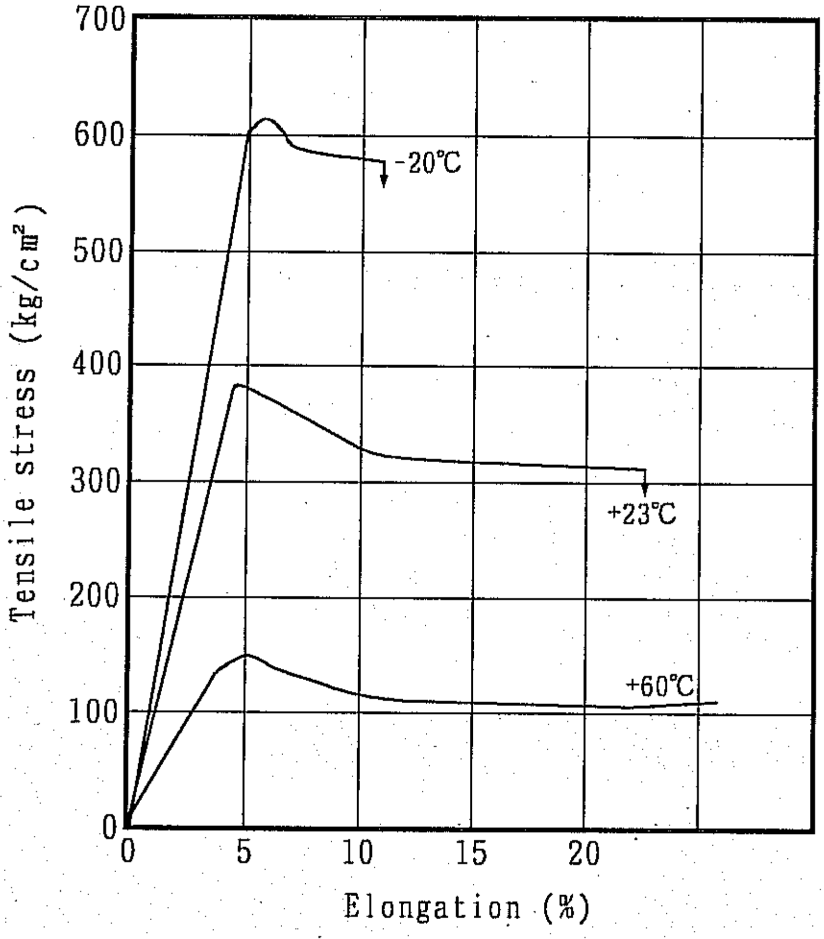


Figure 2. Stress-Strain curve vs temperature FCFC AG12A0
Test specimen: ASTM dumbbell type I
Test speed : 50 mm/min

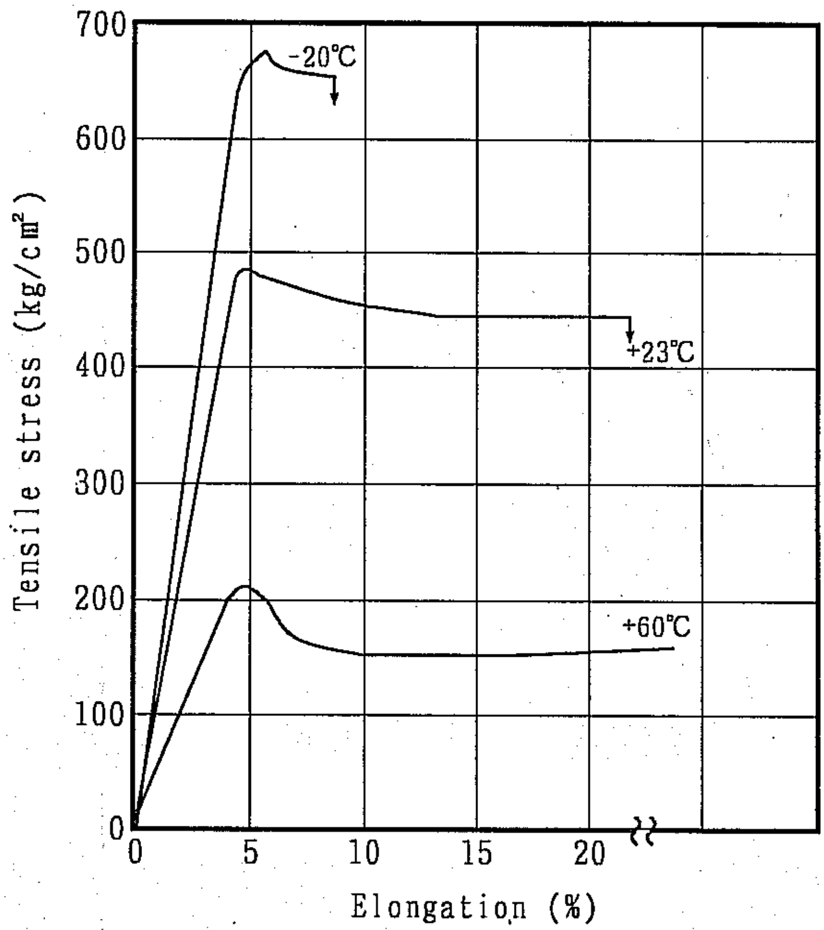


Figure 3. Stress-Strain curve vs temperature FCFC AG15A0
Test specimen: ASTM dumbbell type I
Test speed : 50 mm/min

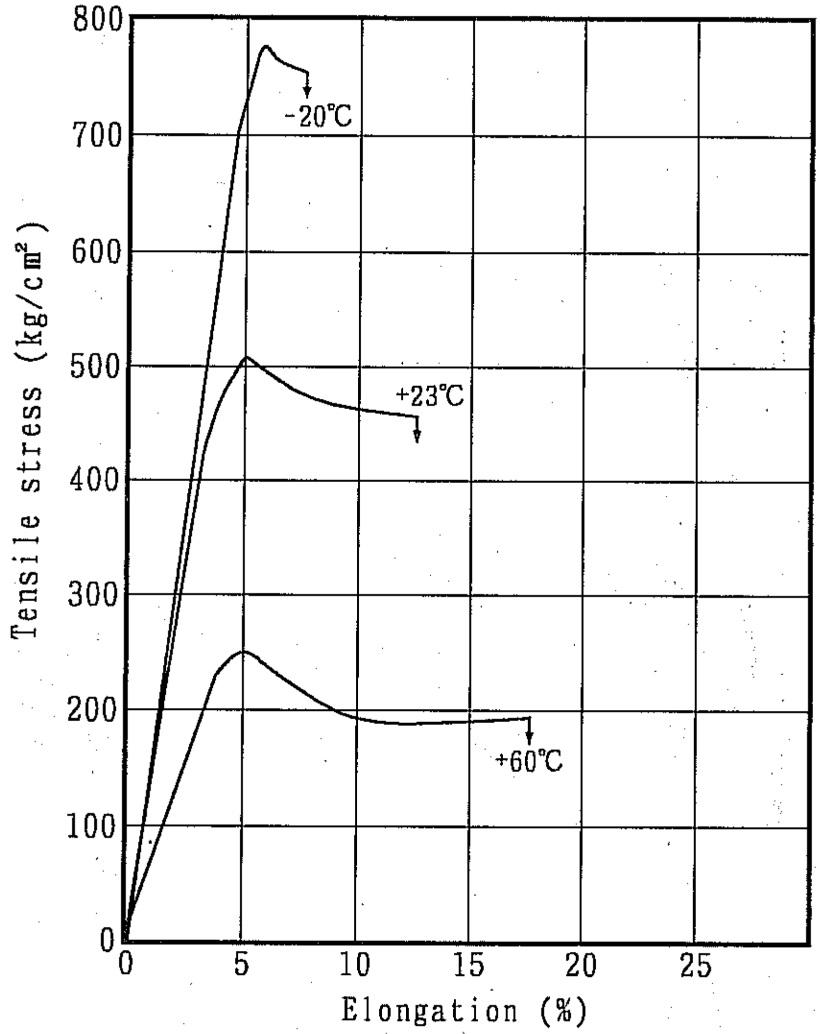


Figure 4. Tensile strength vs temperature ASTM D638
Test specimen: ASTM dumbbell type I
Test speed : 50 mm/min

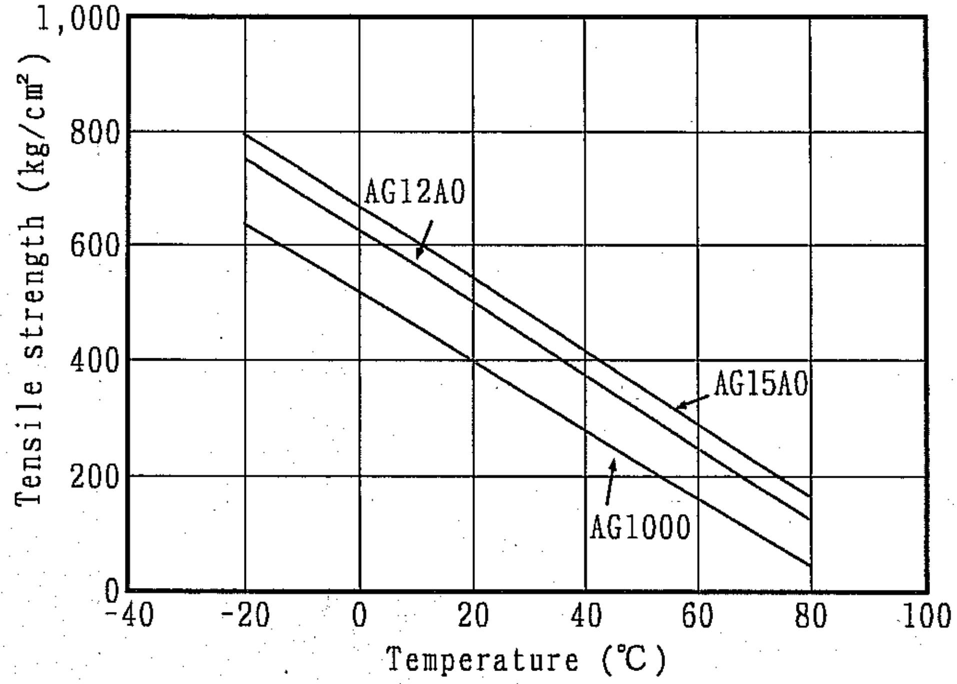


Figure 5. Tensile strength vs test speed ASTM D638
Test specimen: ASTM dumbbell type I

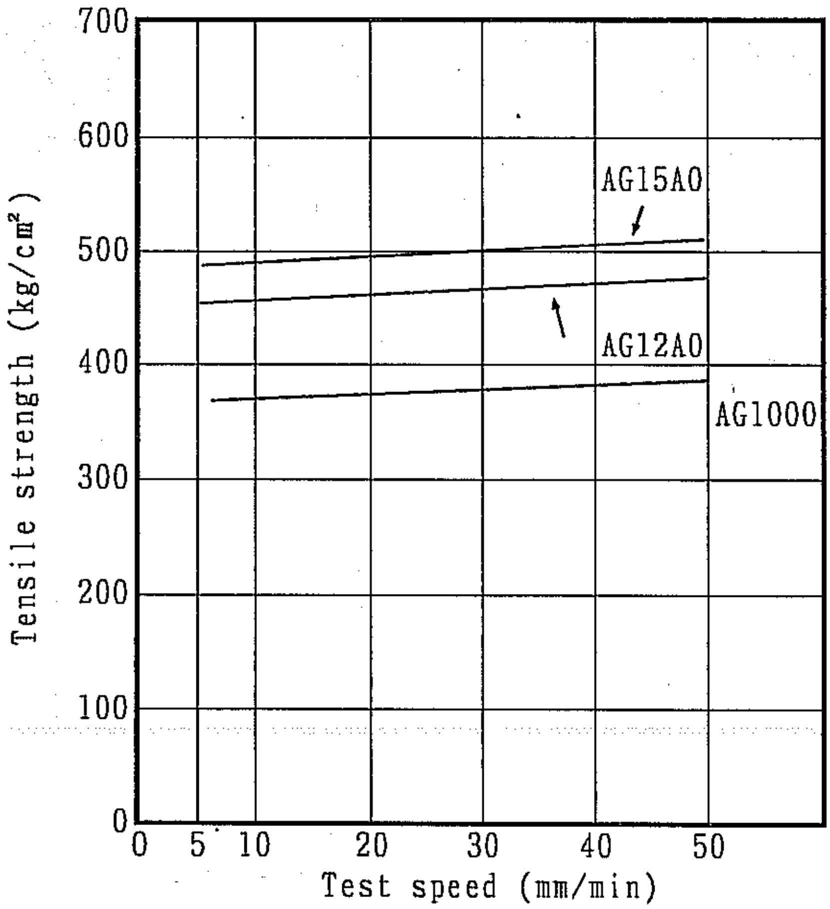


Figure 6. Flexural strength vs temperature ASTM D790

Test speed : 15 mm/min

Test specimen: 3.2×25×80mm

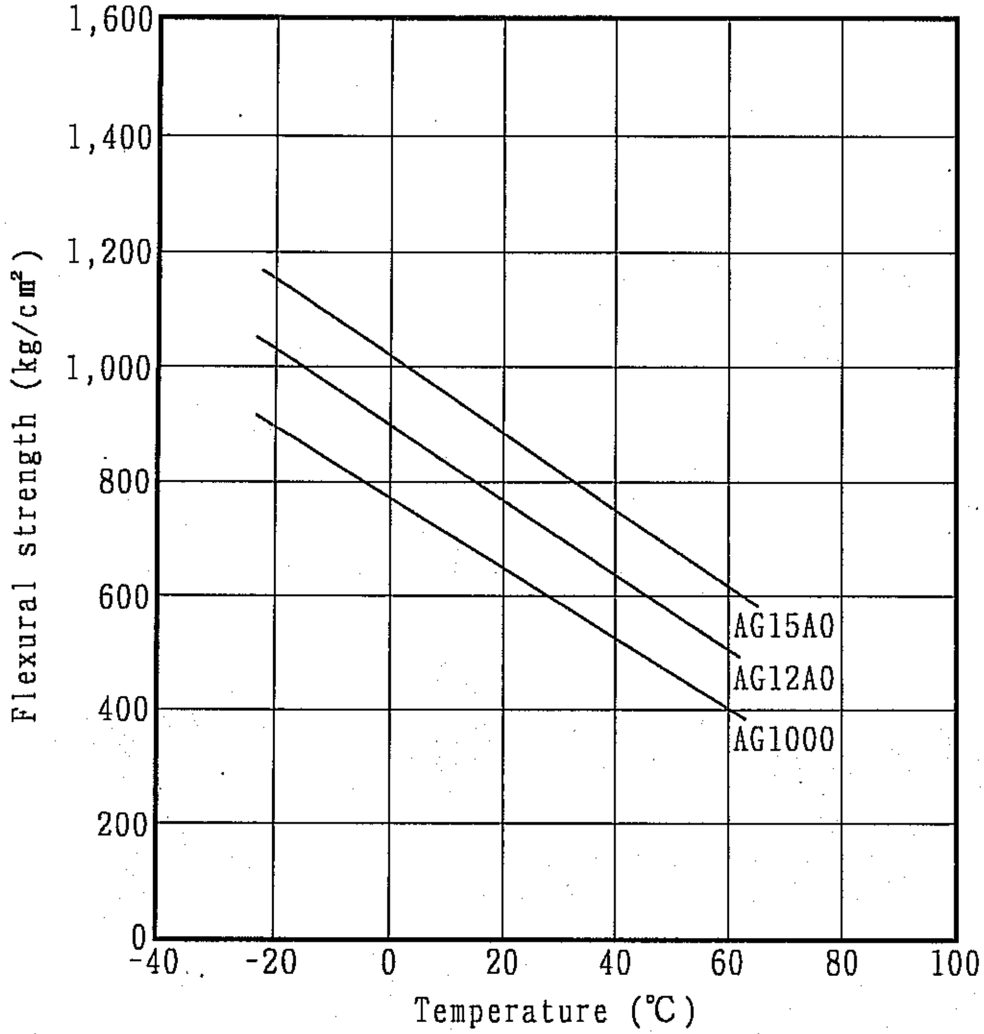


Figure 7. Flexural modulus vs temperature ASTM D790

Test speed : 15 mm/min

Test specimen: 3.2×25×80mm

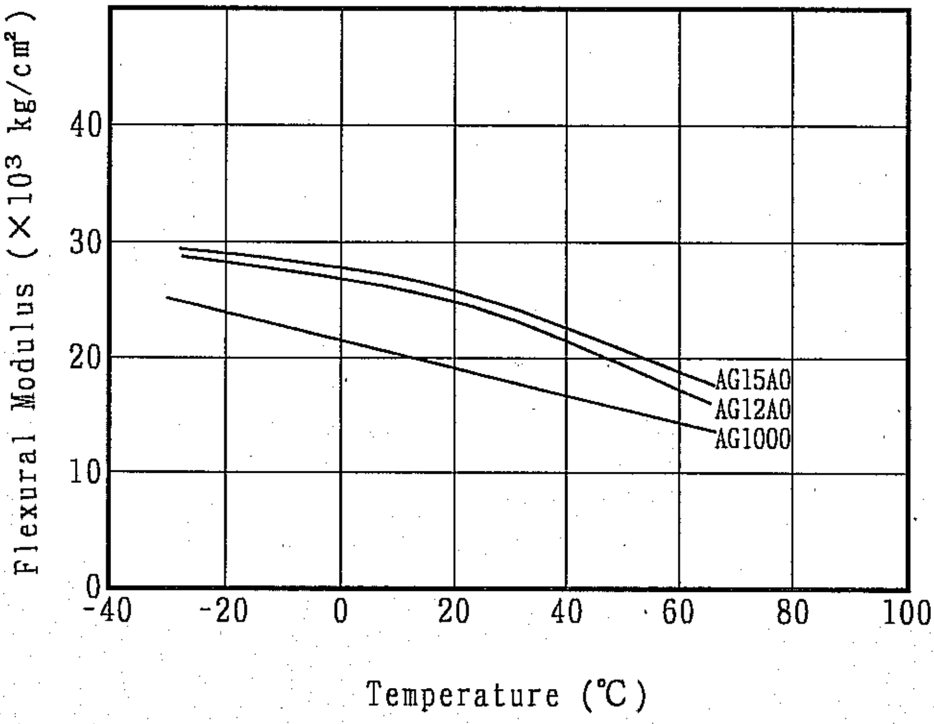


Figure 8. Tensile creep curve

Test temperature: 23℃

Test specimen : ASTM dumbbell type I

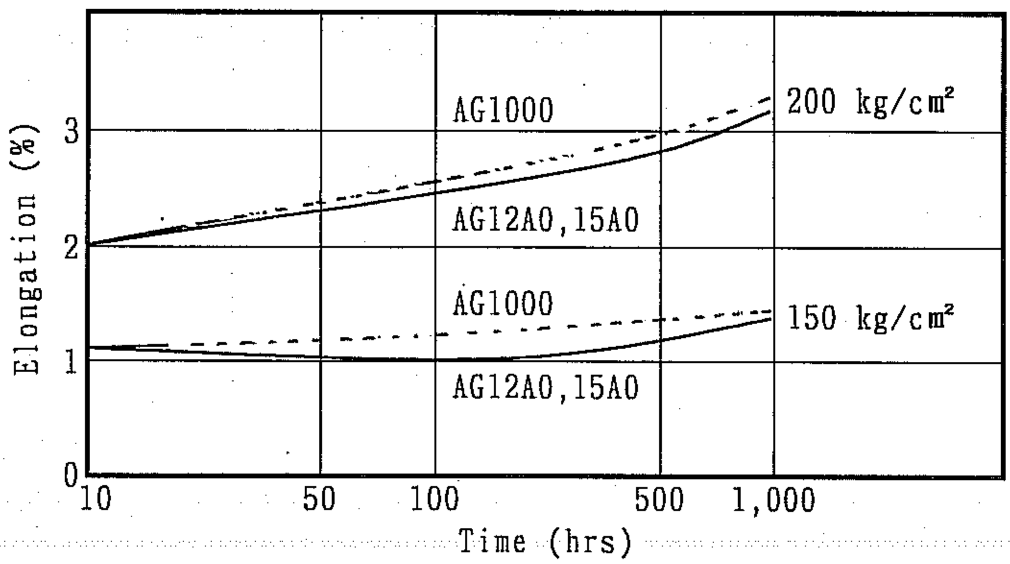


Figure 9. Izod impact strength vs temperature ASTM D256
Test specimen: 6.3×12.7×63.5mm

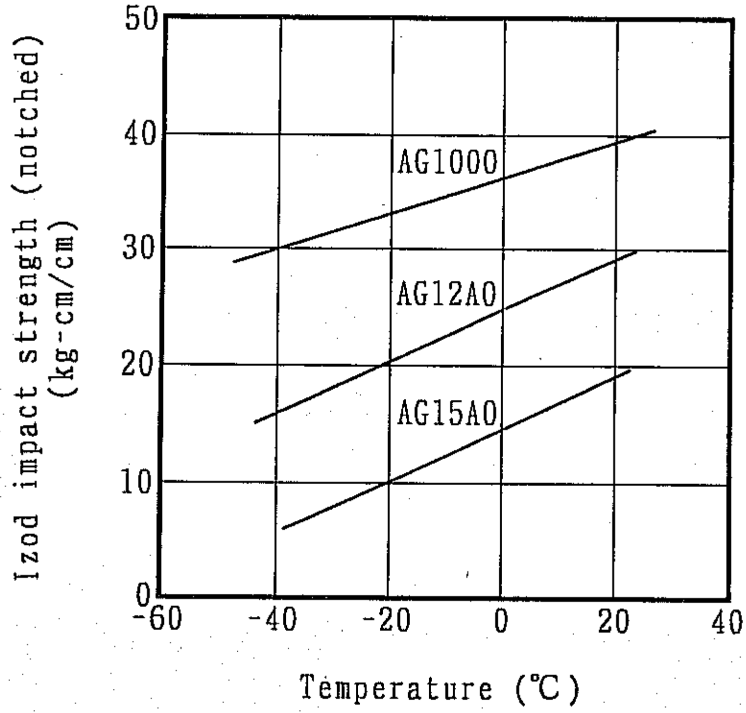


Figure 10. Charpy impact strength vs temperature ASTM D256
Test specimen: 6.3×12.7×127mm

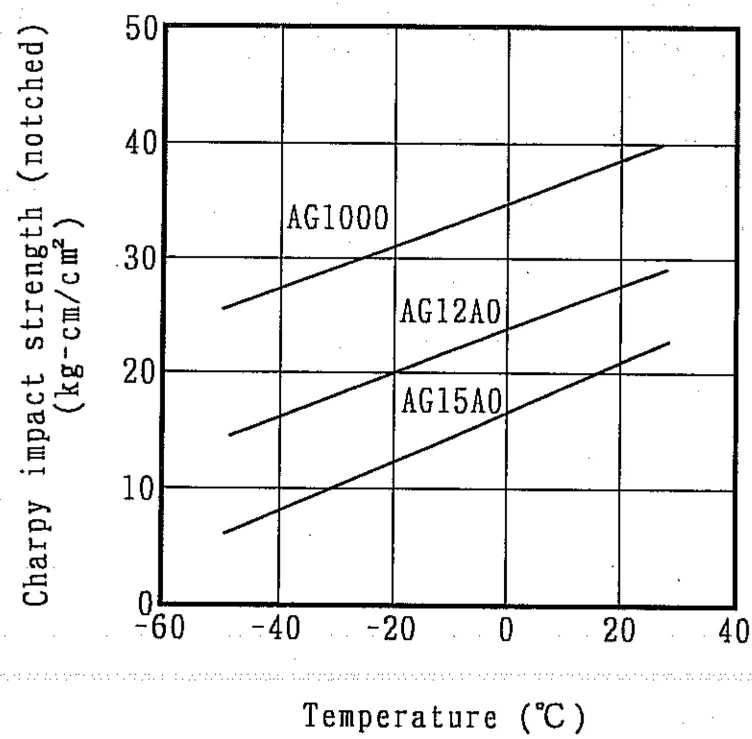


Figure 11. Flexural fatigue curve
Testing condition: 23℃
RH 65% 1720 rpm

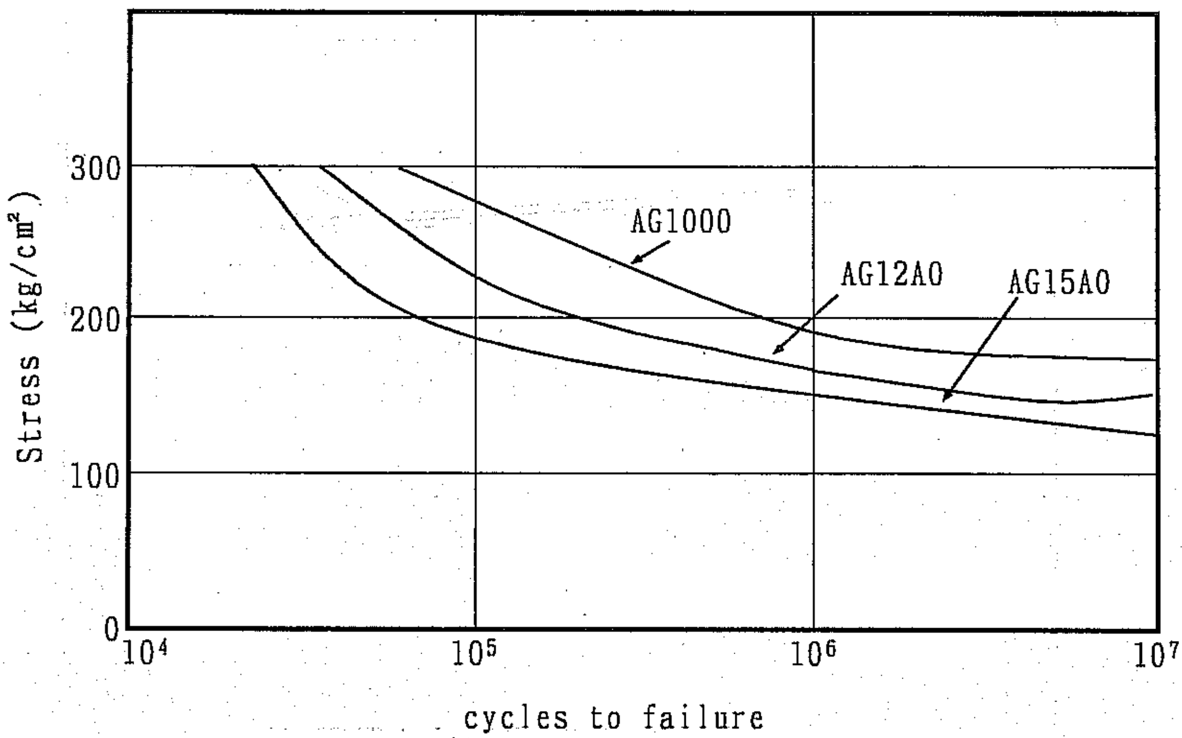


Figure 12. Heat deflection temperature vs fiber stress ASTM D648
Test specimen: ½"×½"×5"

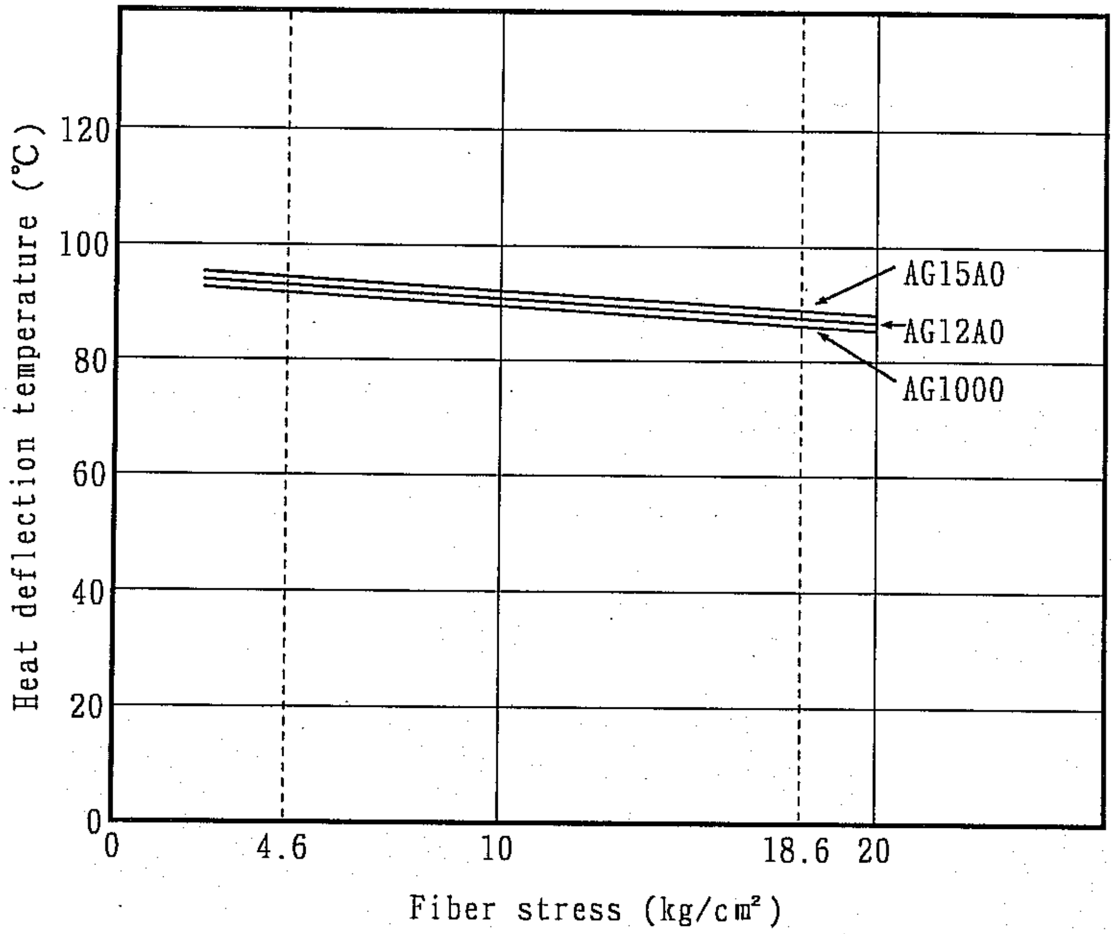


Figure 13. Thermal shrinkage of molded products
Test specimen: ASTM dumbbell type I
Heating time : 2 hours

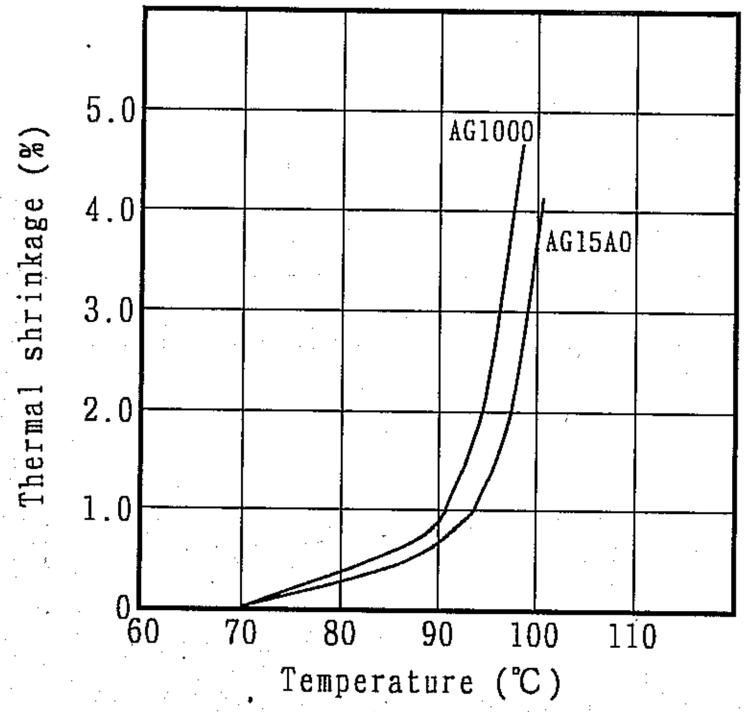


Figure 14. Tensile strength vs carbon arc exposure time on accelerated weathering test
Carbon arc exposure
Temperature : 35℃
Test speed : 50 mm/min
Test specimen: ASTM dumbbell type I
spray cycle : 18 min/120 min

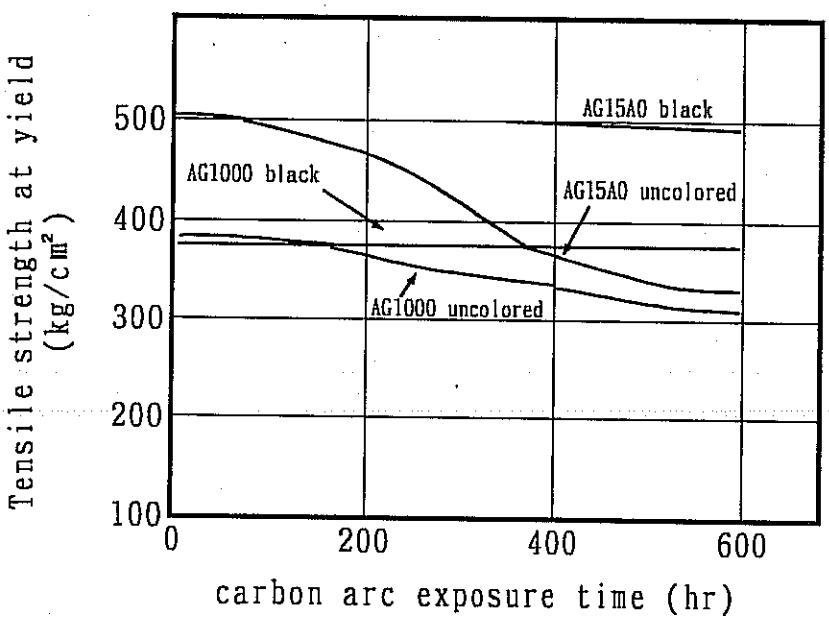


Figure 15. Izod impact strength vs carbon arc exposure time on accelerated weathering test (Uncolored)

Test conditions
Carbon arc exposure time
Temperature : 35℃
Test specimen : 6.3×12.7×63.5 mm
Water spray cycle: 18 min./120 min.

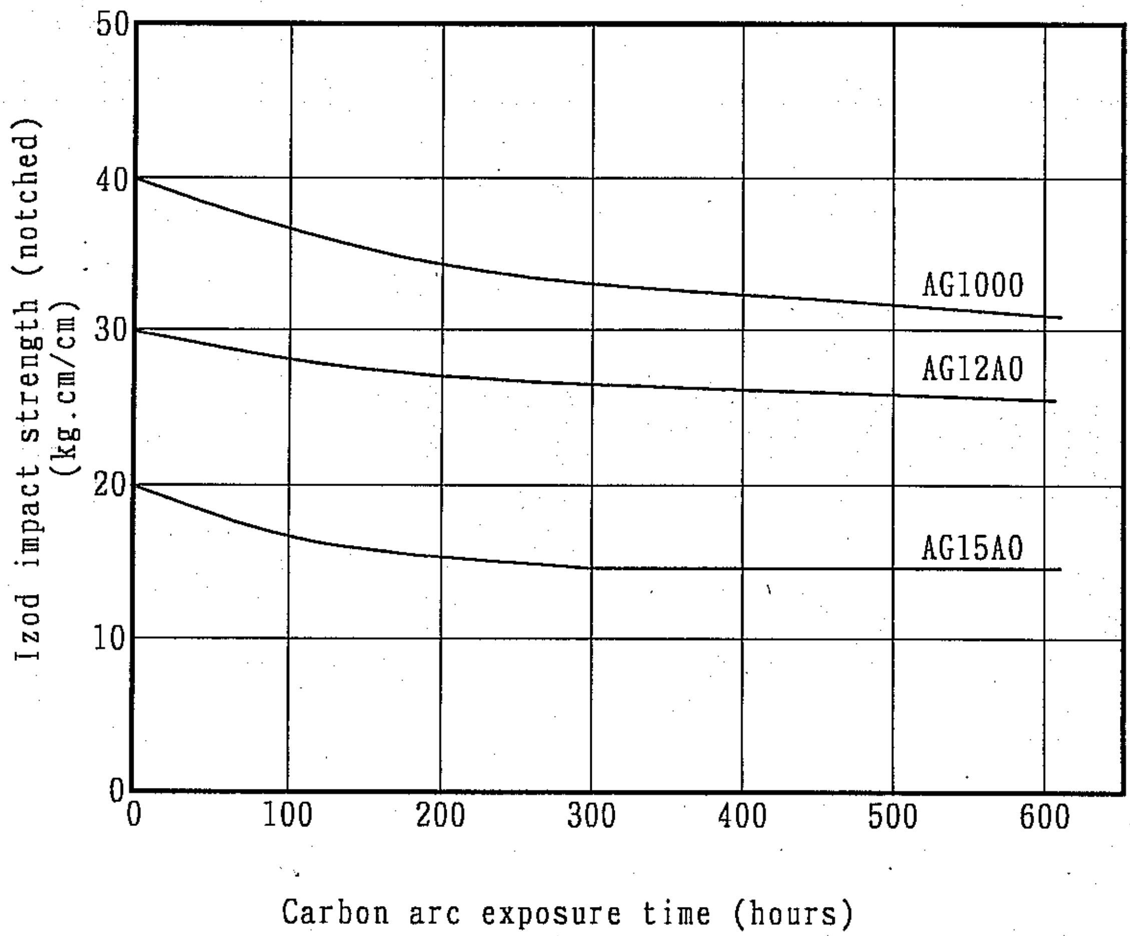


Figure 16. Falling dart impact strength vs carbon arc exposure time on accelerated weathering test

Test conditions

Carbon arc exposure time

Temperature : 35℃

Water spray cycle: 18 min./120 min.

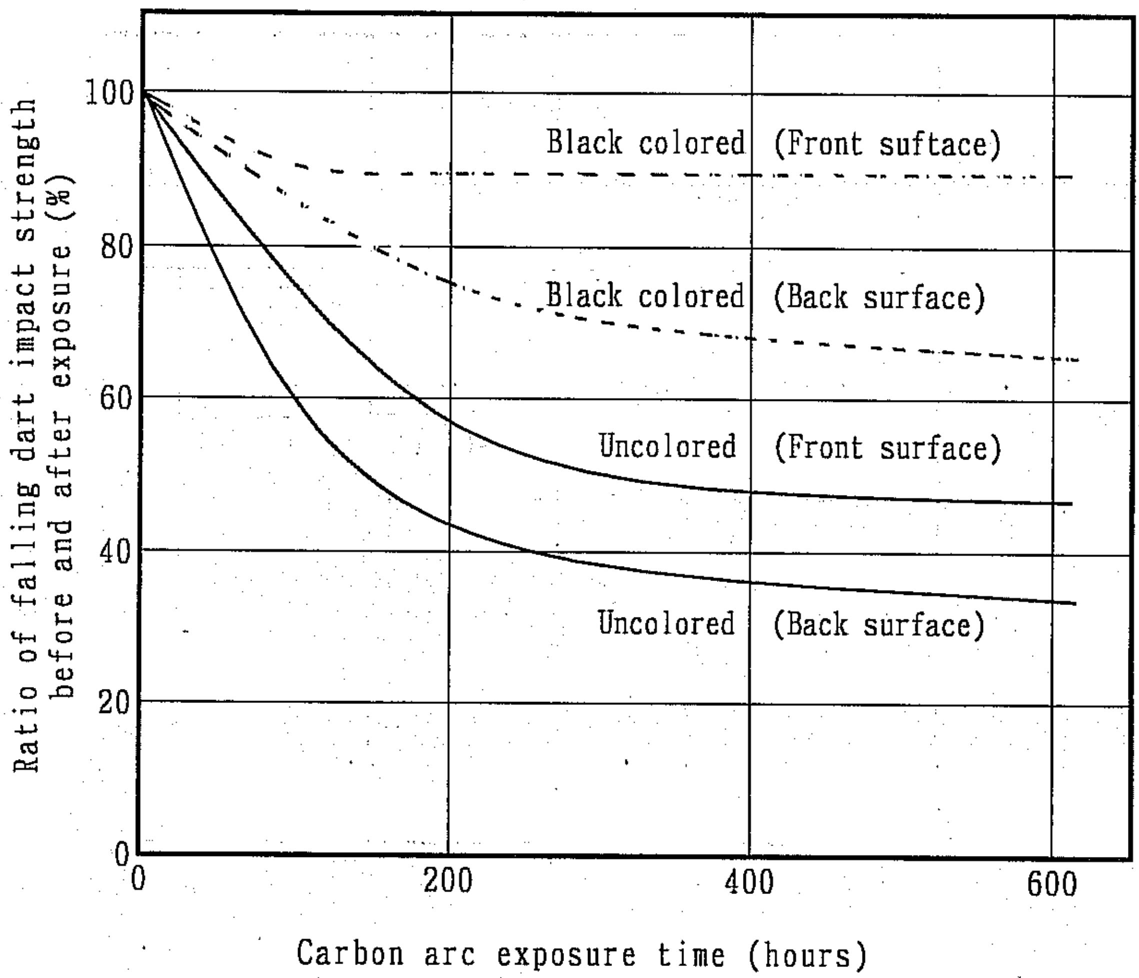


Figure 17. Painting effect to Izod impact strength (notched) on accelerated weathering test

Test conditions

Carbon arc exposure

Temperature : 35℃

Water spray cycle: 18 min/120 min

Paint : Acryl paint

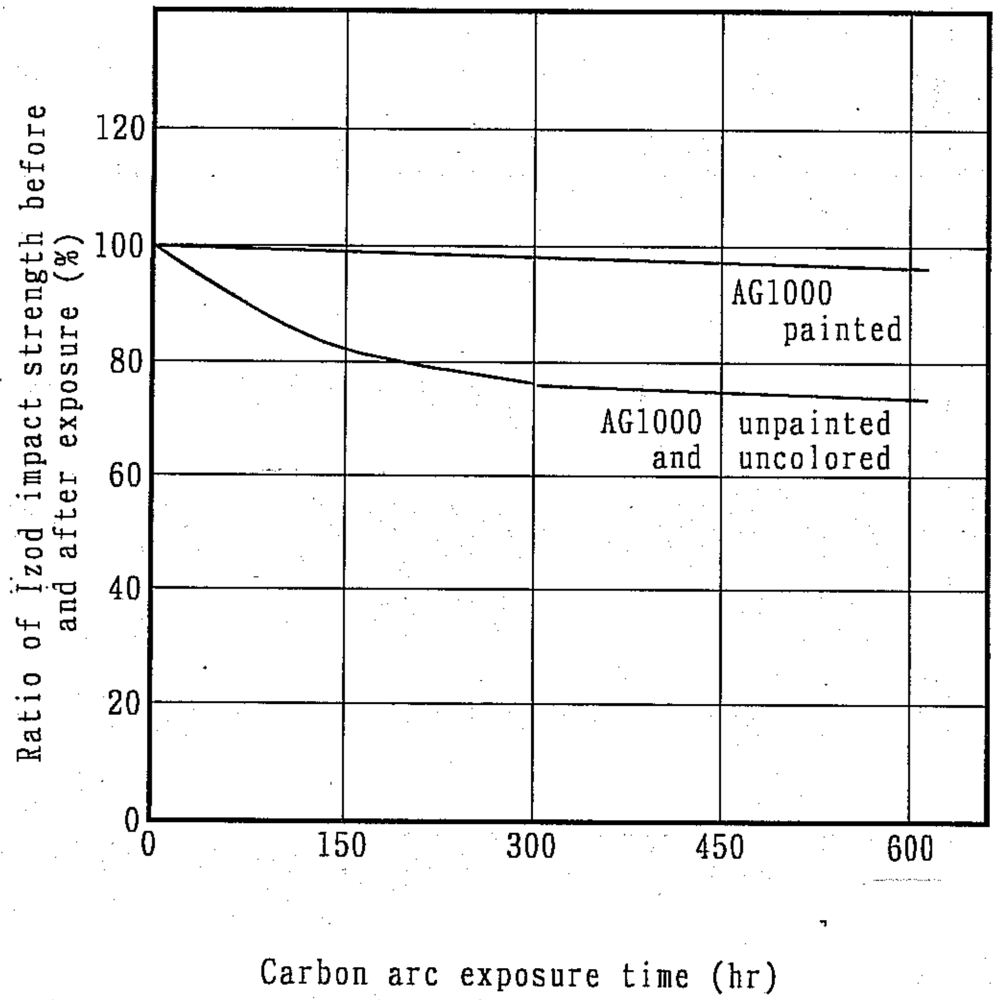


Figure 18. Spiral flow length vs temperature / oz screw type injection molding machine

Mlod temperature: 50℃

Molding pressure: 900 kg/cm²

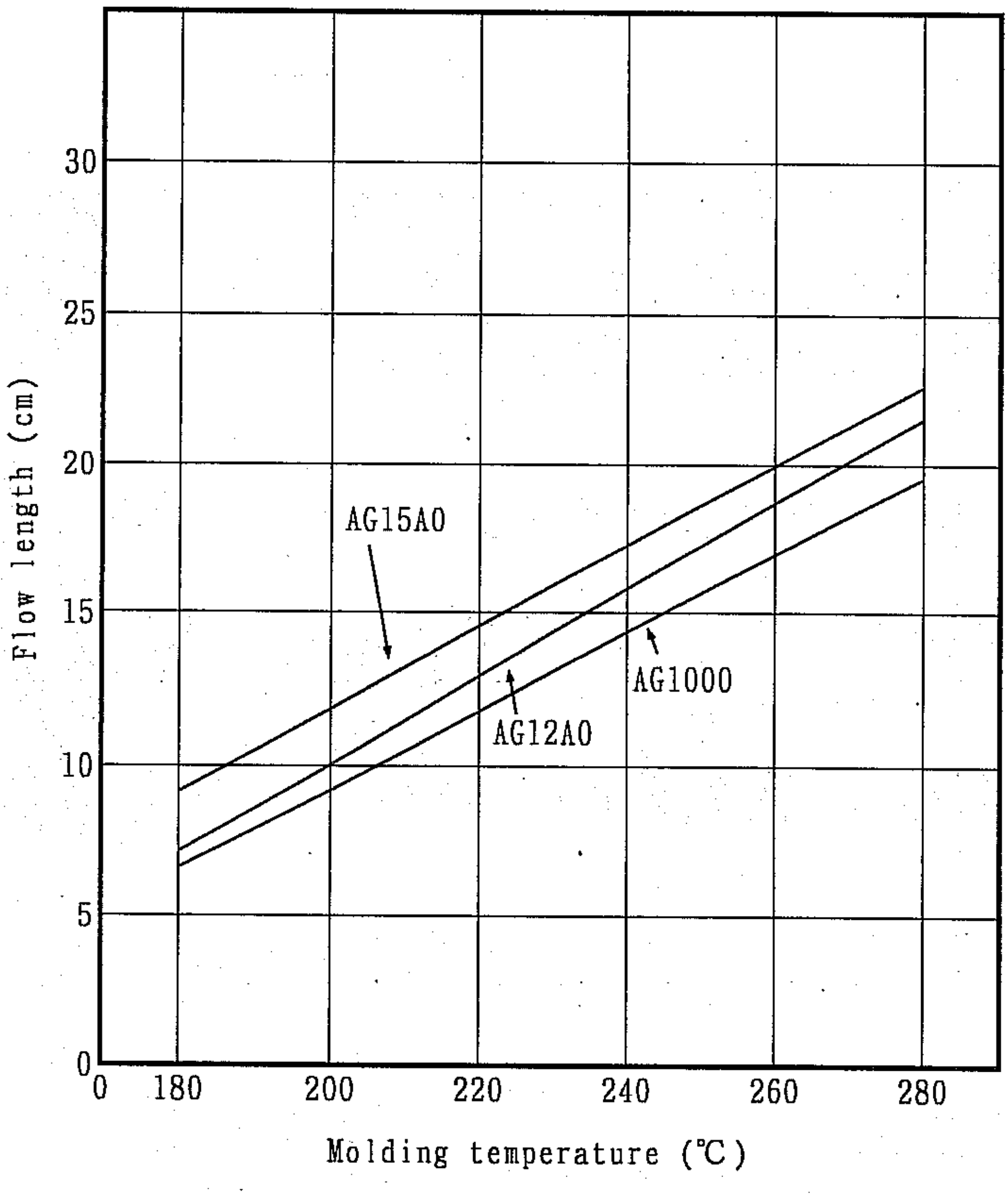


Figure 19. Ratio of flow length to thickness of molding products vs molding temperature / oz screw type injection molding machine

Mlod temperature: 50℃

Molding pressure: 900 kg/cm²

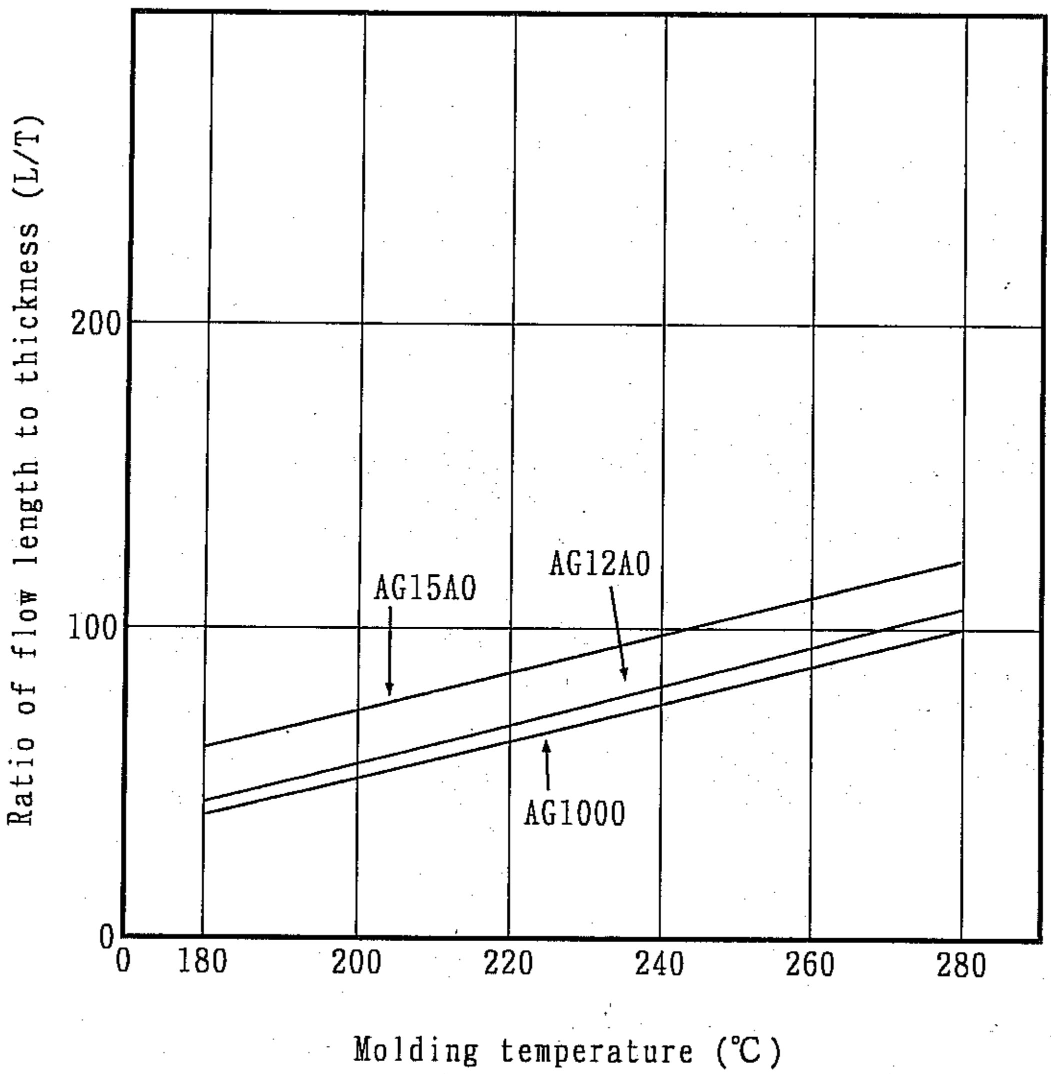


Figure 20. Drying and water absorption curve of FCFC ABS General Purpose Grades

Test drying condition : 80℃ in the dryer

Test absorption condition: 70% R.H.

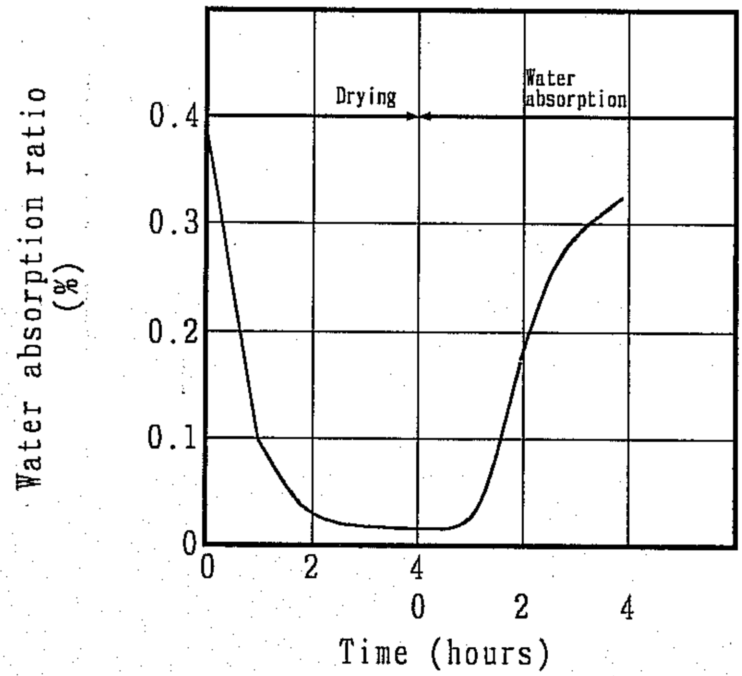


Figure 21. Molding temperature vs tensile strength

Test speed : 50 mm/min.

Test specimen: ASTM dumbbell, type I

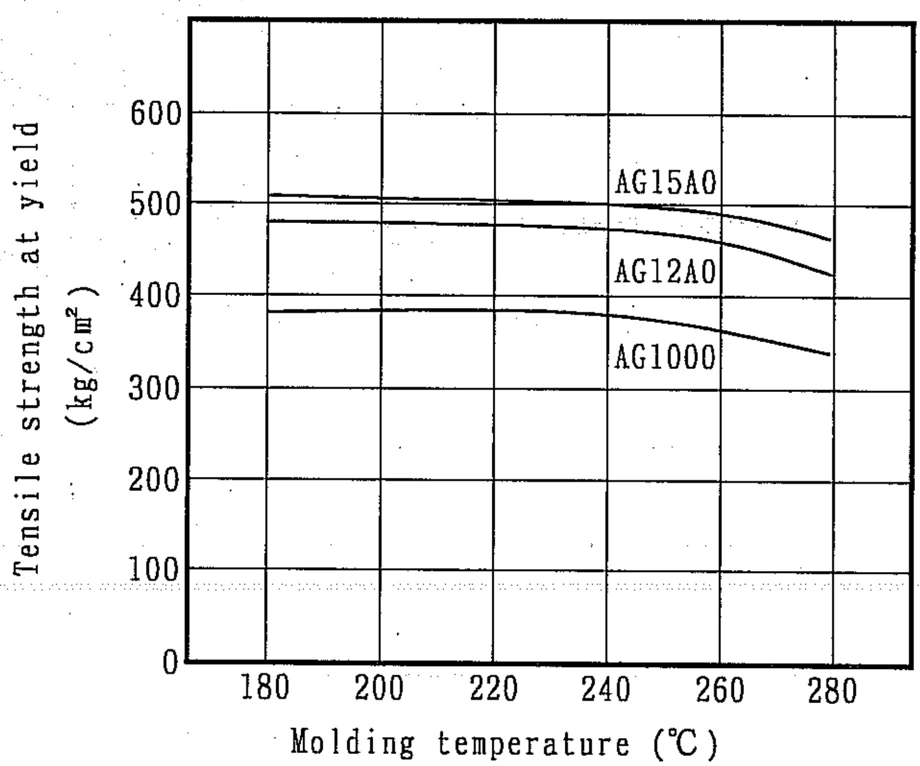


Figure 22. Molding temperature vs Izod impact strength ASTM D256
Test specimen: 6.3×12.7×63.5mm

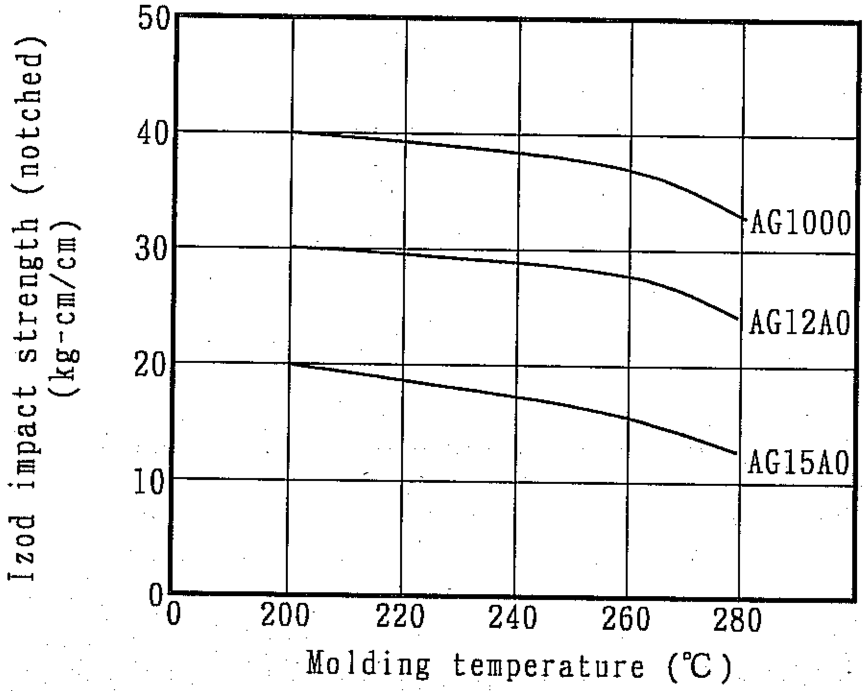


Figure 23. Izod impact strength vs stock residence time in the cylinder
FCFC AG1000
ASTM D256
Test specimen:6.3×12.7×63.5mm

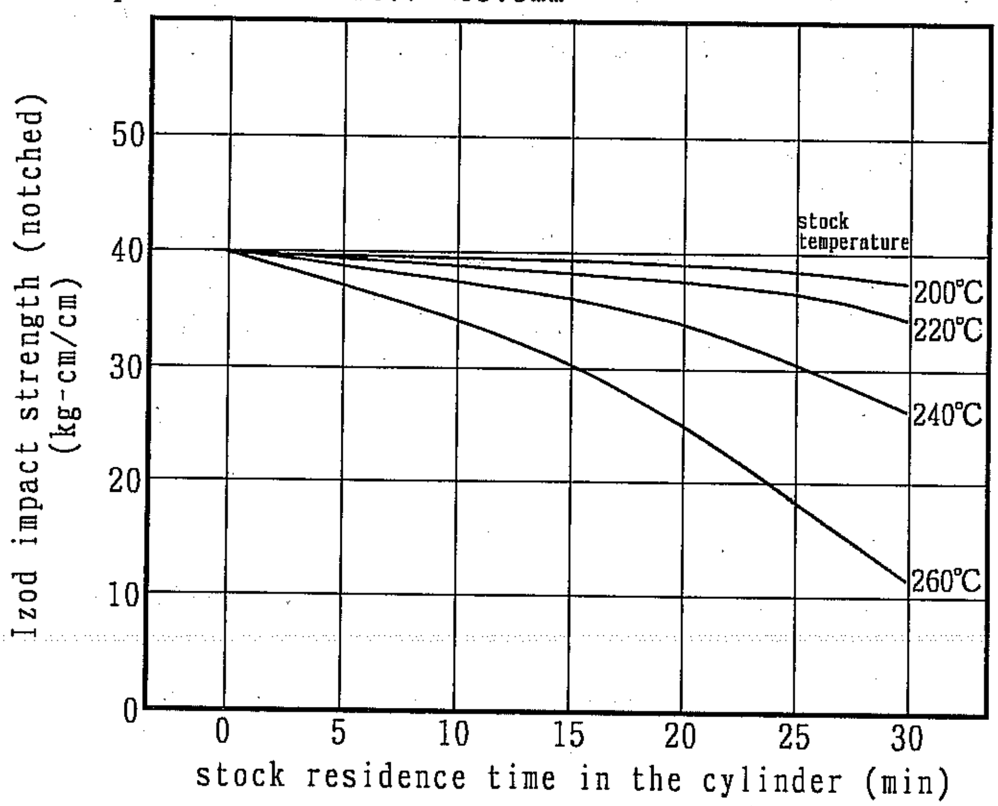


Figure 24. Izod impact strength vs stock residence time in the cylinder

AG15A0

ASTM D256

Test specimen: 6.3×12.7×63.5mm

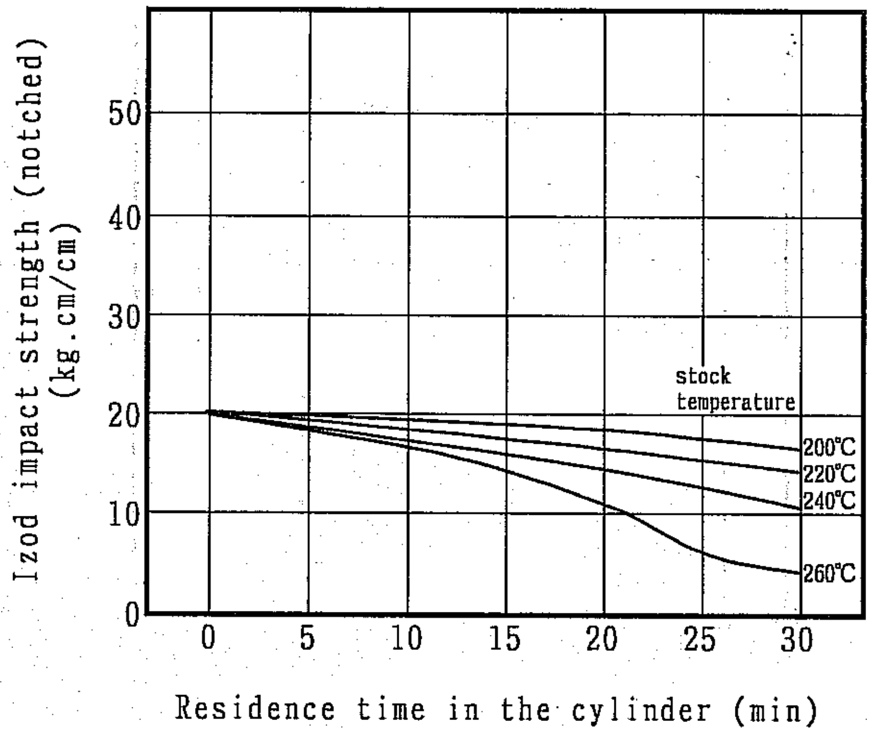


Figure 25. Mold shrinkage vs injection pressure

1 oz screw type injection molding machine

Stock temperature: 50℃

Test specimen : ASTM dumbbell type I

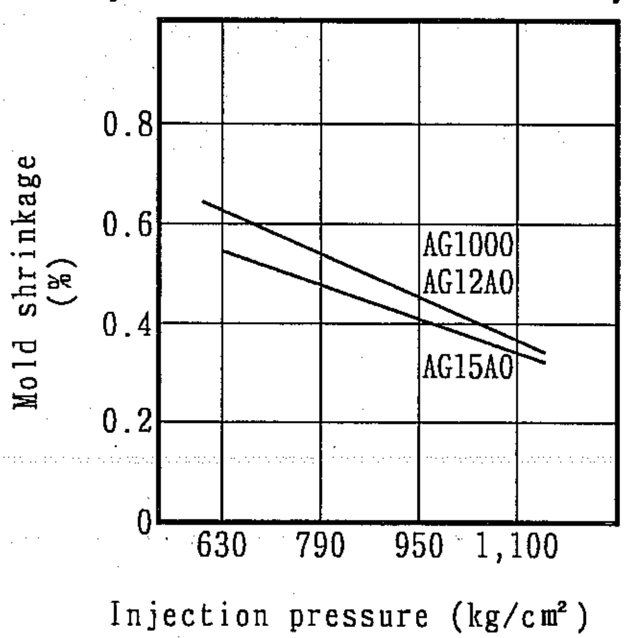


Figure 26. Gloss vs mold temperature
10 oz inline screw injection molding machine
Molding temperature: 220℃
Molding pressure : 700 kg/cm²

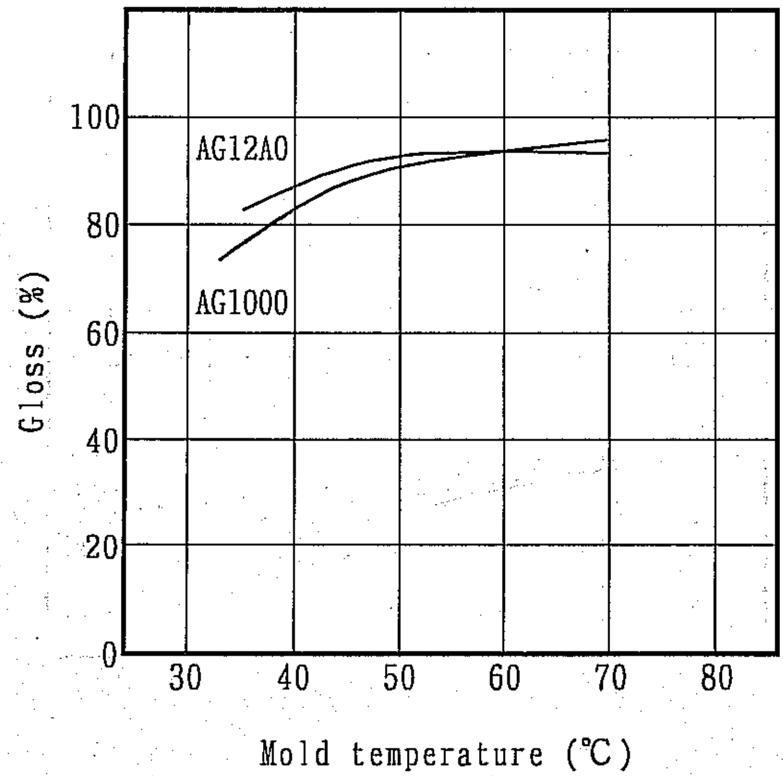
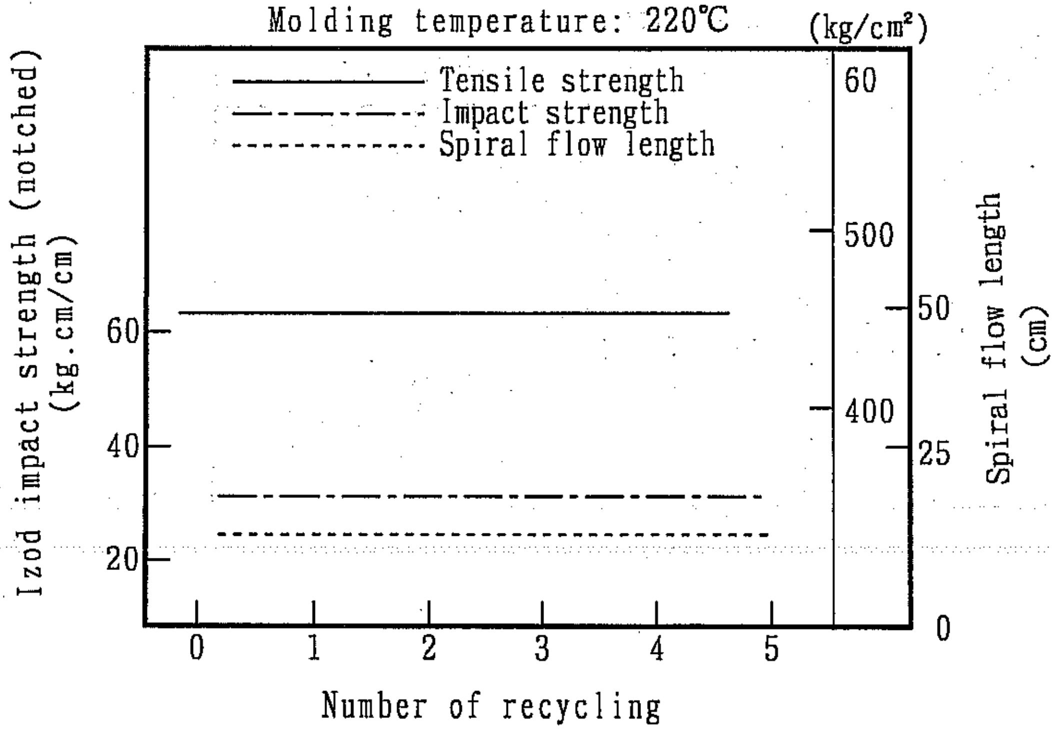


Figure 27. Properties vs number of recycling
FCFC AG12A0
Molding temperature: 220℃



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Appendix 6

MBA Polymers 4124 100% Recycled ABS Data Information

Technical Data Sheet

ABS 4124

MBAPOLYMERS
BECAUSE SUSTAINABILITY MATTERS

Description

A post-consumer recycled acrylonitrile-butadiene-styrene copolymer for general use. Available in standard black (reference 90/04).

Material Properties

	Value	Unit	Test Method
Physical			
Density	1.05	g/cm^3	MBA Method
Rheological			
Melt Flow Rate (230°C / 3.8 kg)	6	g/10 min	ISO 1133
Melt Flow Rate (220°C / 10.0 kg)	22	g/10 min	ISO 1133
Mechanical			
Tensile Stress at Yield (23°C)	40	MPa	ISO 527-2/50
Flexural Modulus (23°C)	2100	MPa	ISO 178
Impact			
Notched Izod Impact Strength (23°C)	10	kJ/m^2	ISO 180/1A
Thermal			
HDT A (1.80 MPa), unannealed	80	ºC	ISO 75-1A
Vicat softening temperature VST/A/50	104	ºC	ISO 306
Vicat softening temperature VST/B/50	95	ºC	ISO 306

Note:

The data above is provided in good faith and represents typical properties based on our current knowledge and experience. Product properties may be changed without notice. These properties are provided as a guide and should not be construed as binding specification limits or minimum values. This document does not create any liability, warranty or guarantee of product performance. It is the buyer's responsibility to determine the suitability of MBA Polymers products for the intended application. We DO NOT recommend our materials for toys or for applications that involve food contact or human oral contact or for medical applications.

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E-mail: salesuk@mbapolymers.com

Technical Data Sheet

ABS 4124

Processing Information

	Value	Unit
Preprocessing		
Drying Temperature	80	°C
Drying Time	2-4	hr
Moisture Content	<0.05-0.10	%
Injection Moulding		
Melt Temperature Range	200-230	°C
Recommended Melt Temperature	215	°C
Mould Temperature Range	40-60	°C
Recommended Mould Temperature	50	°C
Extrusion		
Melt Temperature Range	200-220	°C
Recommended Melt Temperature	210	°C

Note:

The processing parameters listed above are general guidelines based on our current knowledge and experience. The suitability of the data for a specific processing method can only be ensured with investigations and tests by the end user.

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Appendix 7

Injection Moulding Machine Settings Data

Machine Condition Settings – Test Strip Virgin Natural

Customer Dmu	**Machine 6** Arburg 500-210-320-0	**Tool No** DMU001/a	**Material** ABS	**Colour** Natural
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** Tairilac AG15A1	**Dye Ref**
Description BT Test Piece		**Part Weight** 10	**Impressions** 1	**Shot Weight g** 14

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1st[nd] Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 12	Inject 1[st] Stage 54	Inject 1st 65
2[nd] Injection /	Zone 2 230	2[nd] Stage /	Inject 2[nd] Stage /	Inject 2nd /
Holding Pressure 1 5	Zone 3 220	Holding Pressure 10	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1[st] 2[nd] 3rd 4[th]	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1[st] 2[nd] 3rd 4[th]		
Cycle Time 25	Water Moving 55	Eject 1st /	Eject /	Eject 1[st] Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 13			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings – Test Strip Virgin Black

Customer	Machine 6	Tool No	Material	Colour
Dmu	Arburg 500-210-320-0	DMU001/a	ABS	Black 3%
Part No	**Bolster**	**Bolster No**	**Material Ref**	**Dye Ref**
		STDB003	Tairilac AG15A1	Clariant OM0055P
Description		**Part Weight**	**Impressions**	**Shot Weight g**
BT Test Piece		10	1	14

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1stnd Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 12	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 5	Zone 3 220	Holding Pressure 10	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 25	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 13			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings Test Strip 100% Recycled Natural

Customer Dmu	**Machine 6** Arburg 500-210-320-0	**Tool No** DMU001/a	**Material** Repro ABS	**Colour** Natural(dark grey)
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** 4124 90/04	**Dye Ref**
Description BT Test Piece		**Part Weight** 10	**Impressions** 1	**Shot Weight g** 14

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1stnd Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 12	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 5	Zone 3 220	Holding Pressure 10	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 25	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 13			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings – Test Strip 100% Recycled Black

Customer Dmu	**Machine 6** Arburg 500-210-320-0	**Tool No** DMU001/a	**Material** Repro ABS	**Colour** BLACK 3%
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** 4124 90/04	**Dye Ref** Claryant OM0055P
Description BT Test Piece		**Part Weight** 10	**Impressions** 1	**Shot Weight g** 14

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1st[nd] Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 12	Inject 1[st] Stage 54	Inject 1st 65
2[nd] Injection /	Zone 2 230	2[nd] Stage /	Inject 2[nd] Stage /	Inject 2nd /
Holding Pressure 1 5	Zone 3 220	Holding Pressure 10	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1[st] 2[nd] 3rd 4[th]	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1[st] 2[nd] 3rd 4[th]		
Cycle Time 25	Water Moving 55	Eject 1st /	Eject /	Eject 1[st] Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 13			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings – Plaque Virgin Natural

Customer Dmu	**Machine 6** Arburg 500-210-320-0	**Tool No** DMU001/b	**Material** ABS	**Colour** Natural
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** Tairilac AG15A1	**Dye Ref**
Description BT Plaque		**Part Weight** 20	**Impressions** 1	**Shot Weight g** 24

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1stnd Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 16	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 6	Zone 3 220	Holding Pressure 14	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 28	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 15			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings – Plaque Virgin Black

Customer Dmu	**Machine 6** Arburg 500-210-320-0	**Tool No** DMU001/b	**Material** ABS	**Colour** BLACK 3%
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** Tairilac AG15A1	**Dye Ref** Clariant 0M0055P
Description BT Plaque		**Part Weight** 20	**Impressions** 1	**Shot Weight g** 24

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1st[nd] Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 16	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 6	Zone 3 220	Holding Pressure 14	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 28	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 15			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Machine Condition Settings – Plaque 100% Recycled Natural

Customer	**Machine 6**	**Tool No**	**Material**	**Colour**
Dmu	Arburg 500-210-320-0	DMU001/b	ABS	Natural (Dark Grey)
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** Reprocessed Abs 4124 90/04	**Dye Ref**
Description BT Plaque		**Part Weight** 20	**Impressions** 1	**Shot Weight g** 24

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1st[nd] Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 16	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 8	Zone 3 220	Holding Pressure 14	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 28	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 15			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

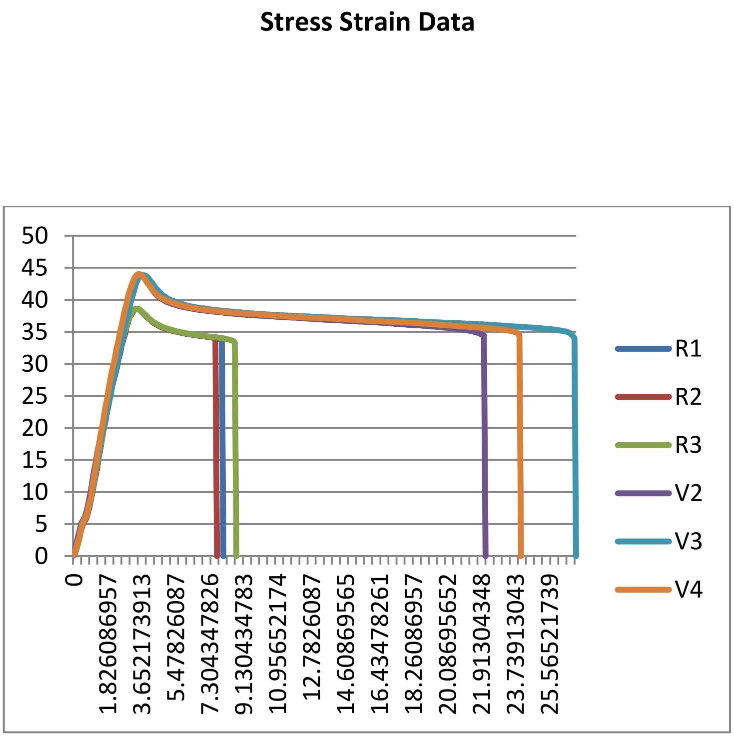
Machine Condition Settings – Plaque 100% Recycled Black

Customer	**Machine 6**	**Tool No**	**Material**	**Colour**
Dmu	Arburg 500-210-320-0	DMU001/b	ABS	BLACK 3%
Part No	**Bolster**	**Bolster No** STDB003	**Material Ref** Reprocessed Abs 4124 90/04	**Dye Ref** Clariant 0M0055P
Description BT Plaque		**Part Weight** 20	**Impressions** 1	**Shot Weight g** 24

Time secs	Temp deg c	Limit Settings mm	Pressure %	Speed %
1st[nd] Injection /	Zone 1- nozzle 220	Plasticise Limit-Dose 16	Inject 1st Stage 54	Inject 1st 65
2nd Injection /	Zone 2 230	2nd Stage /	Inject 2nd Stage /	Inject 2nd /
Holding Pressure 1 6	Zone 3 220	Holding Pressure 14	Holding 1 25	Holding 1 25
Holding Pressure 2 0	Zone 4- 205	Mould close stage 1st 2nd 3rd 4th	Holding 2 /	Holding 2 /
Shots Per Hr		Mould open stage 1st 2nd 3rd 4th		
Cycle Time 28	Water Moving 55	Eject 1st /	Eject /	Eject 1st Speed /
Sprue Break ON/OFF on	Water Fixed 55	Eject 2nd /		Eject 2nd Speed /
Cooling 15			Back Pressure 18	Screw Speed 40

Any Special Requirements or Comments:-

Appendix 8



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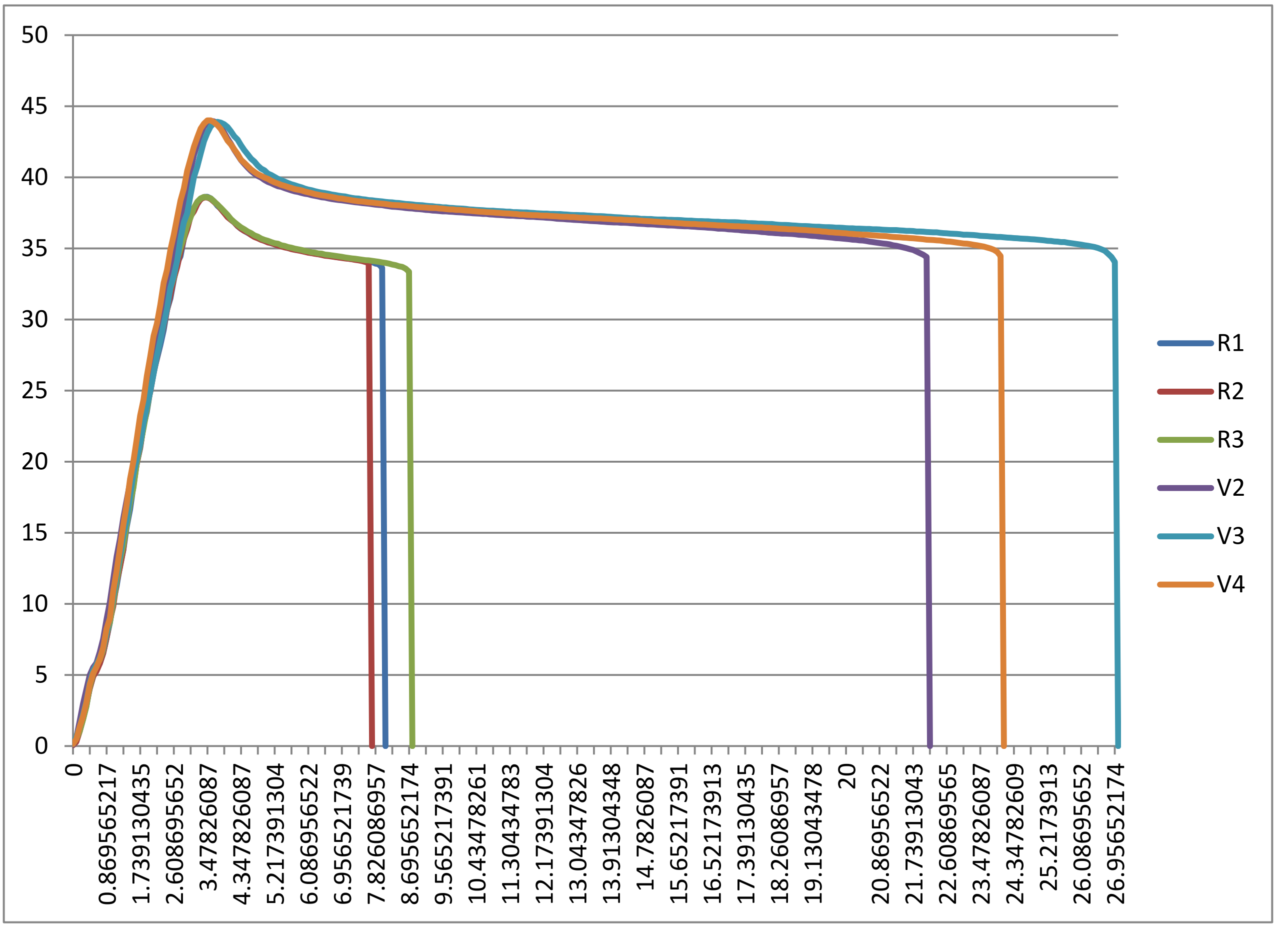
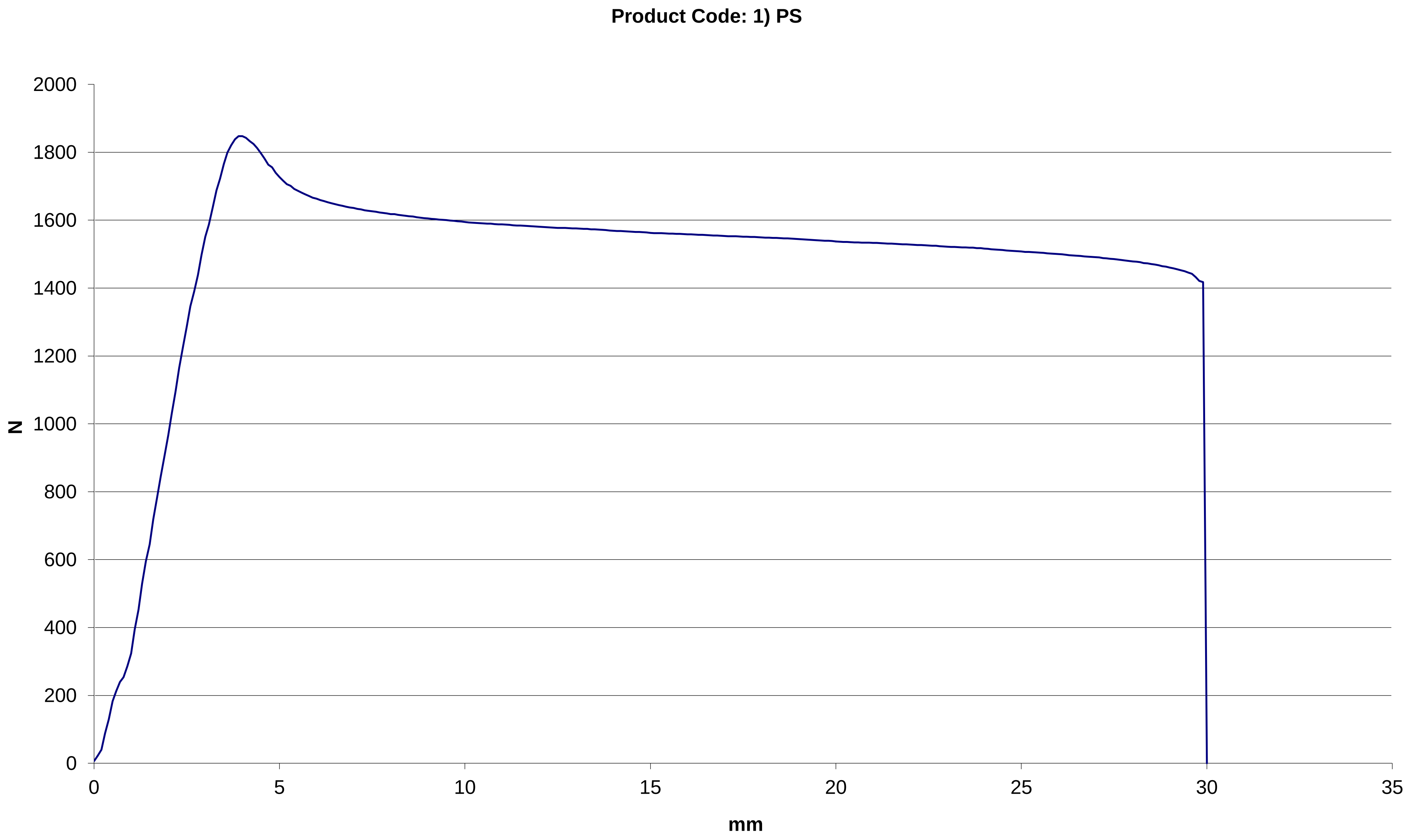
3 Virgin and 3 100% Recycled Compared



10 Virgin ABS Test Strip Results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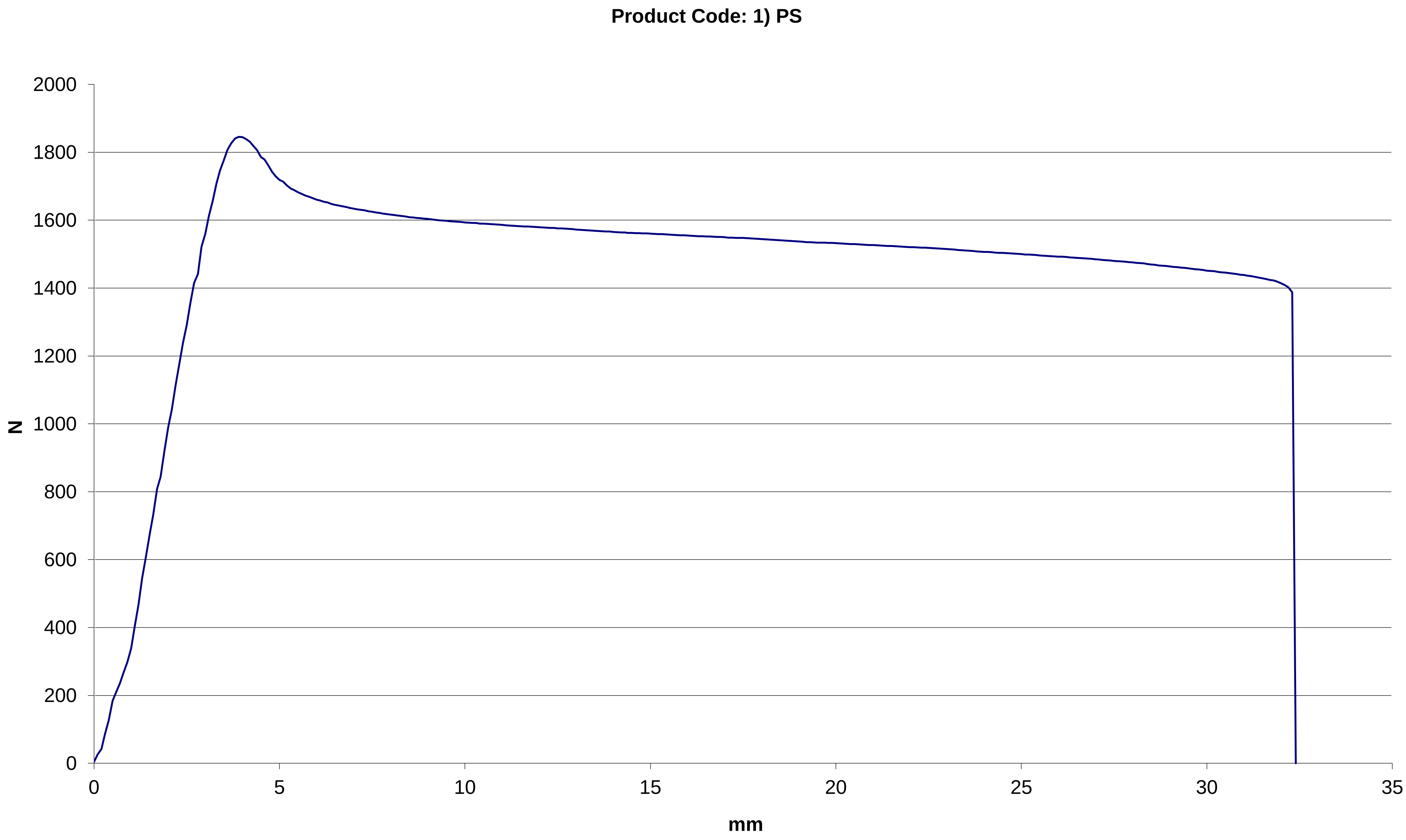
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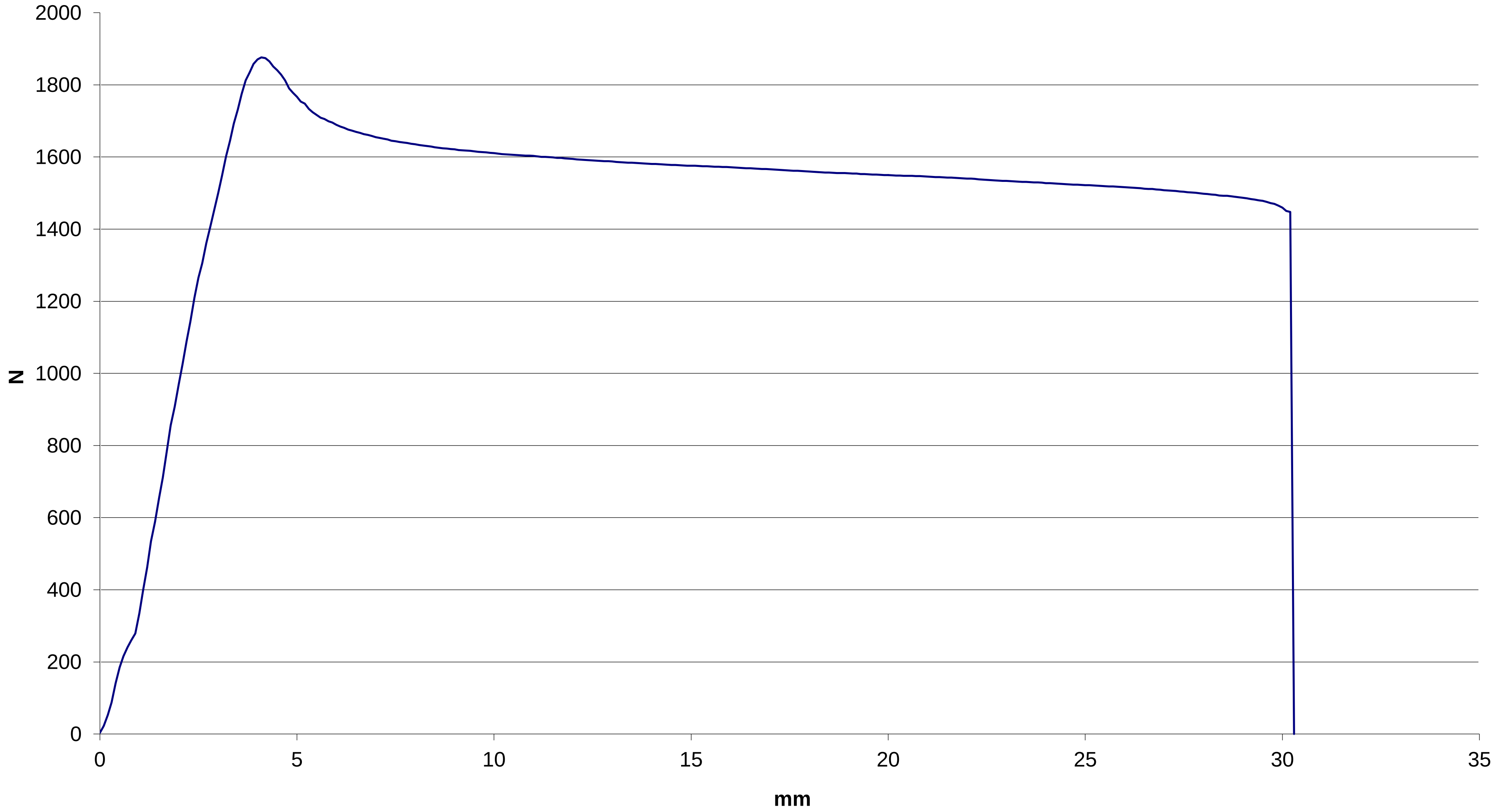

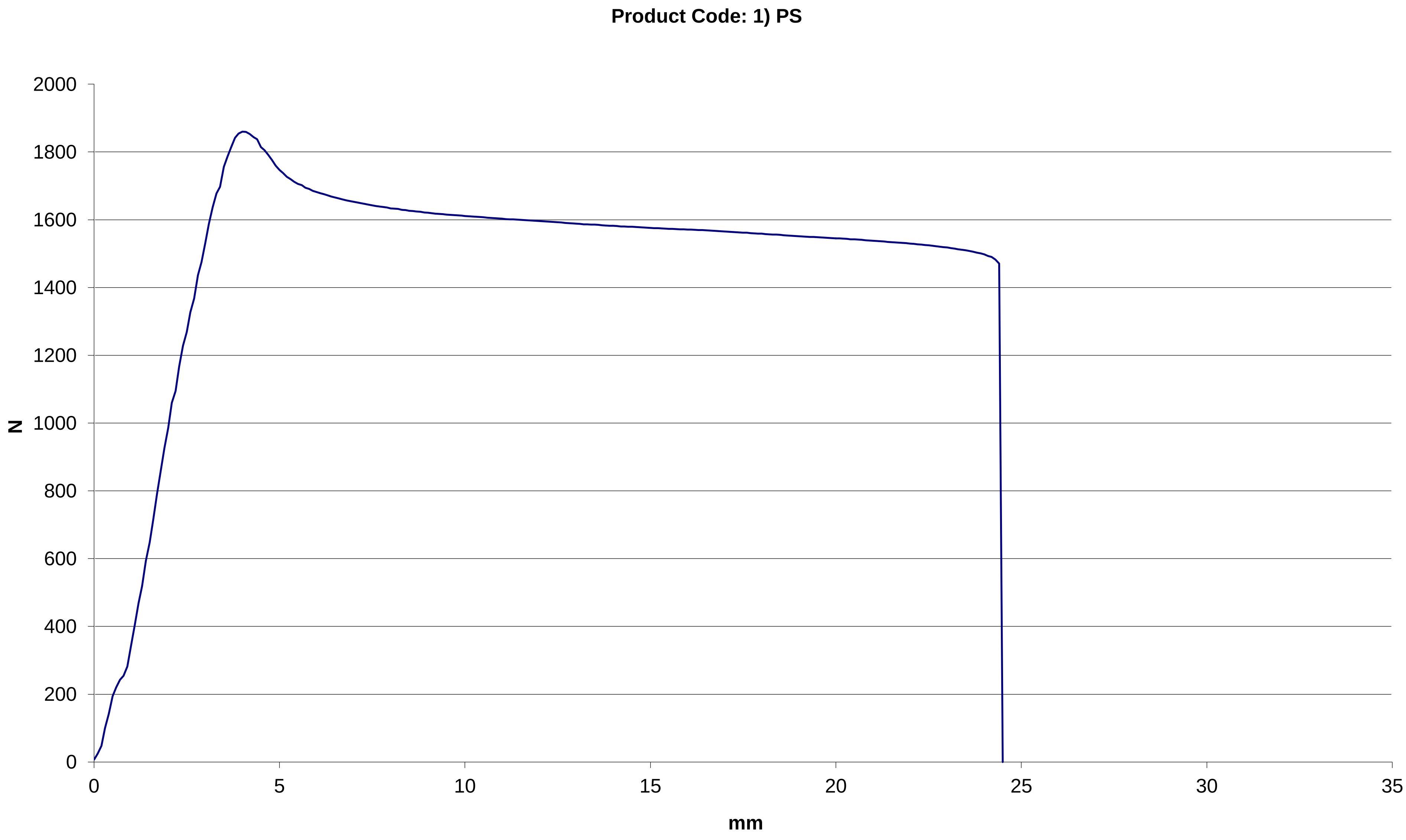
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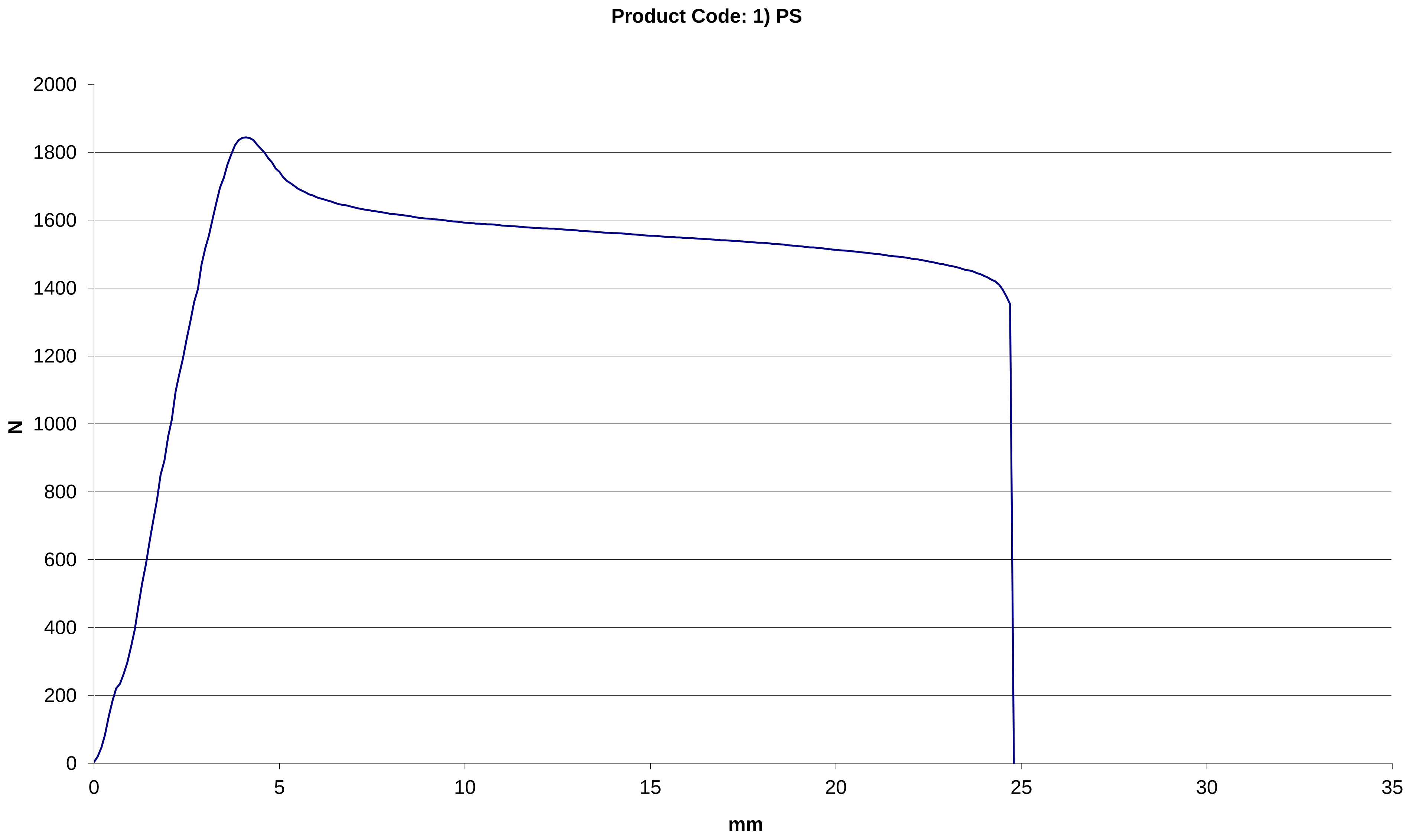

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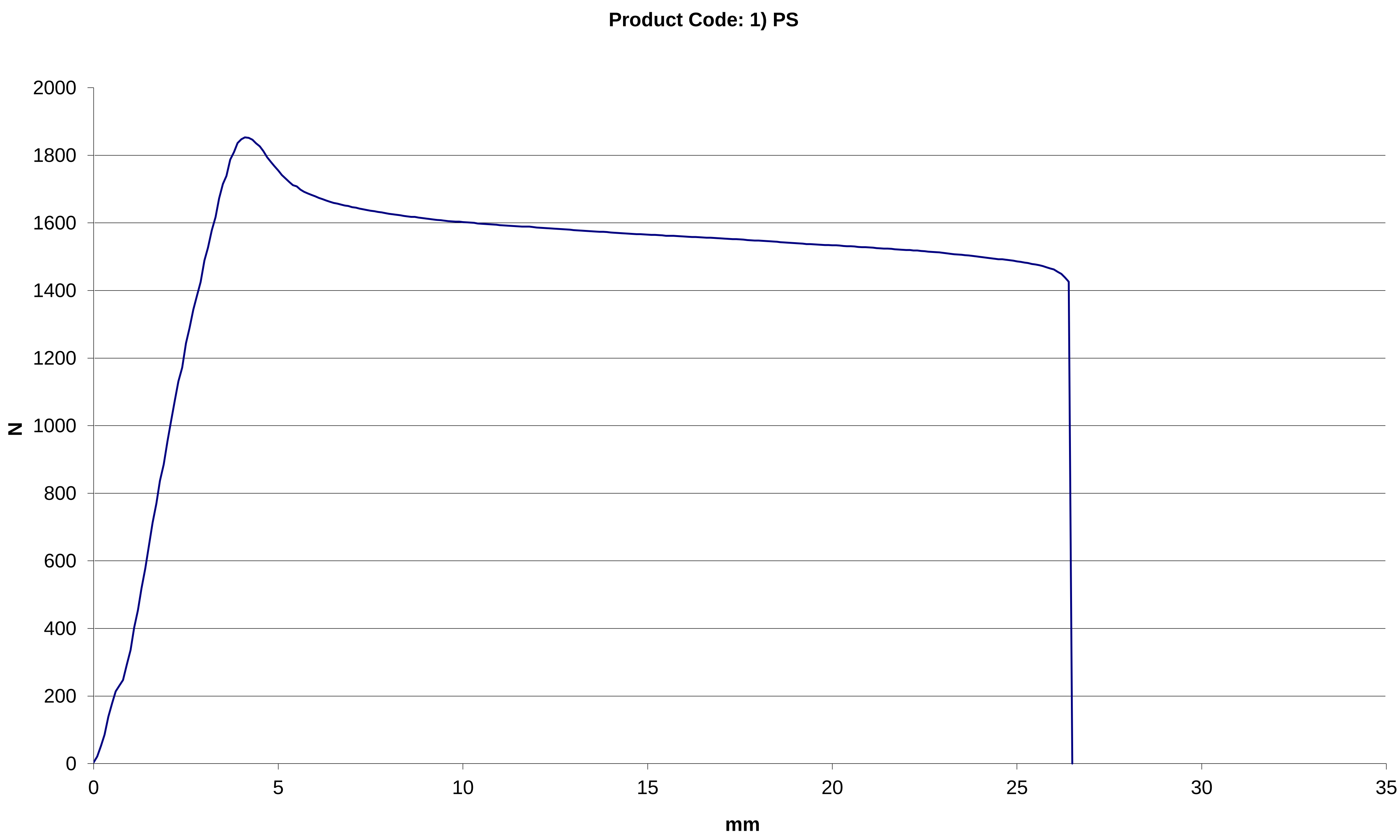
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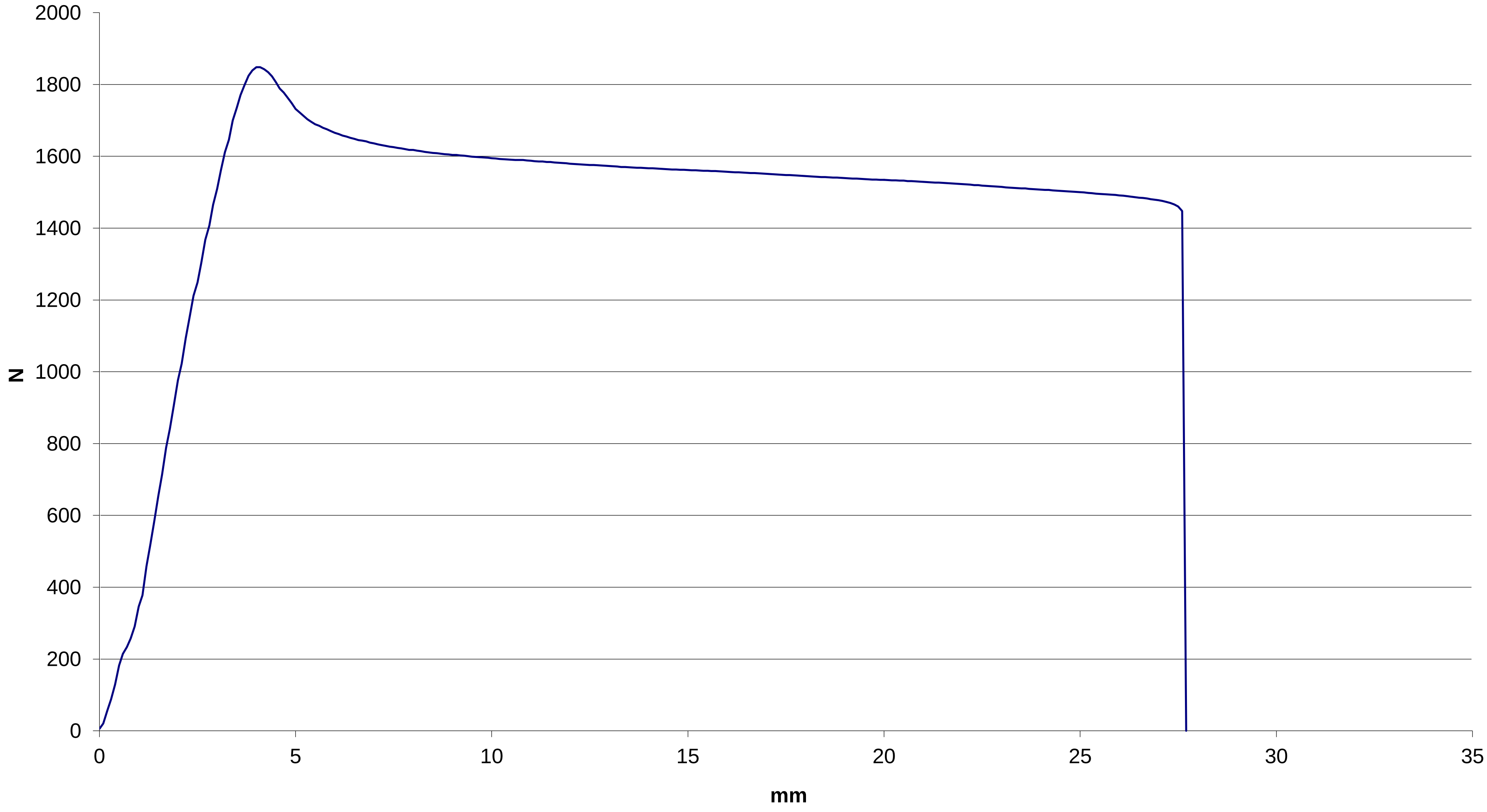

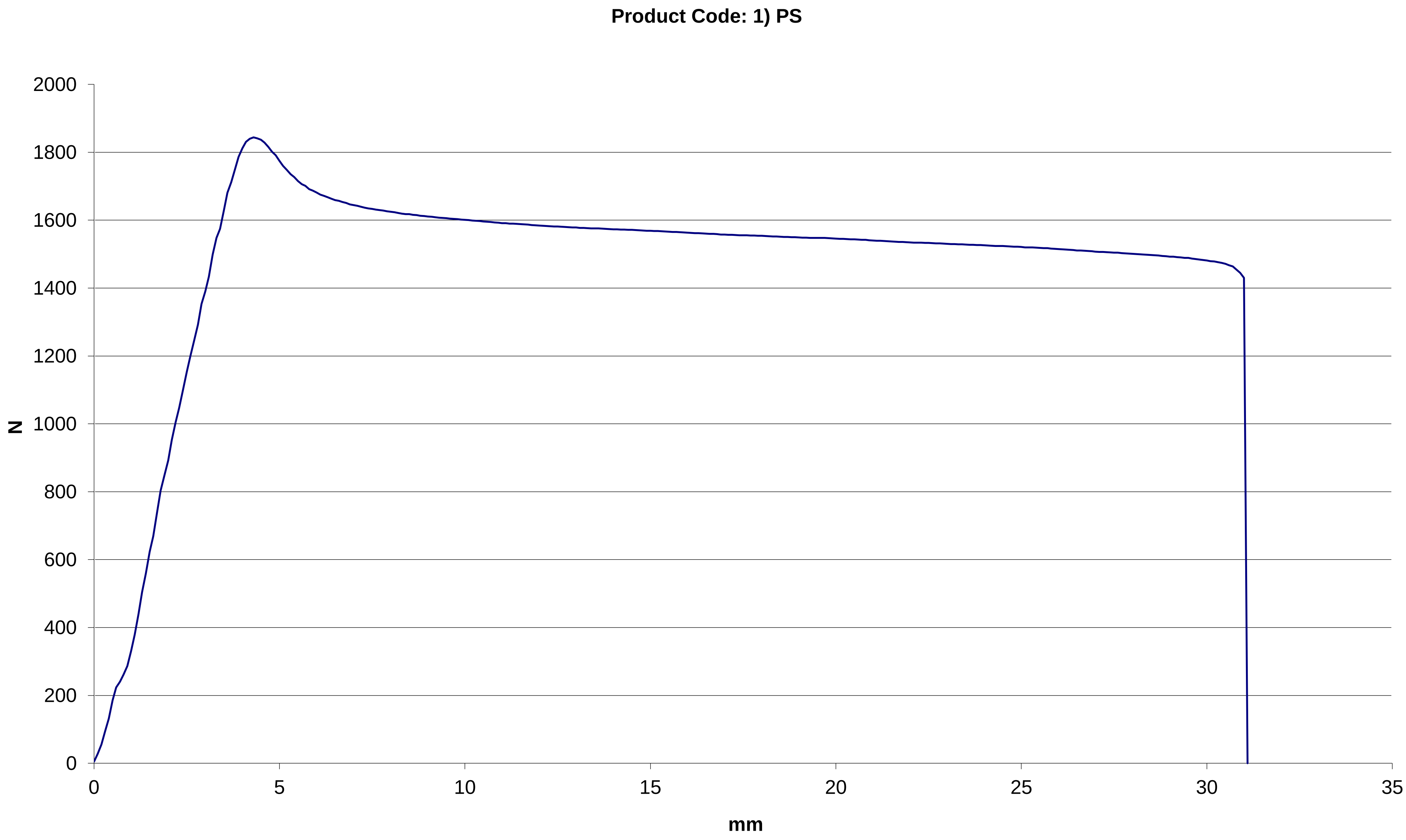
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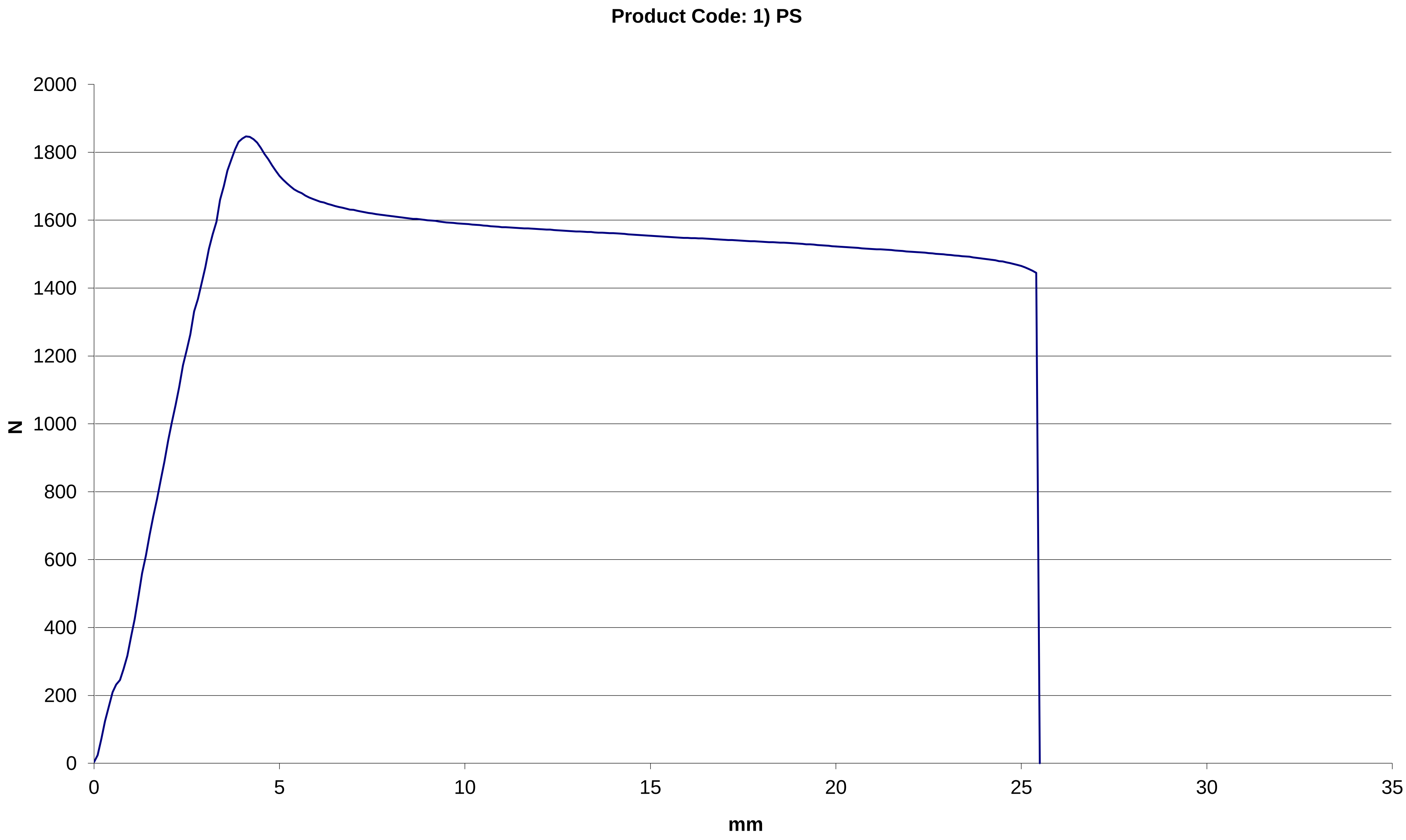
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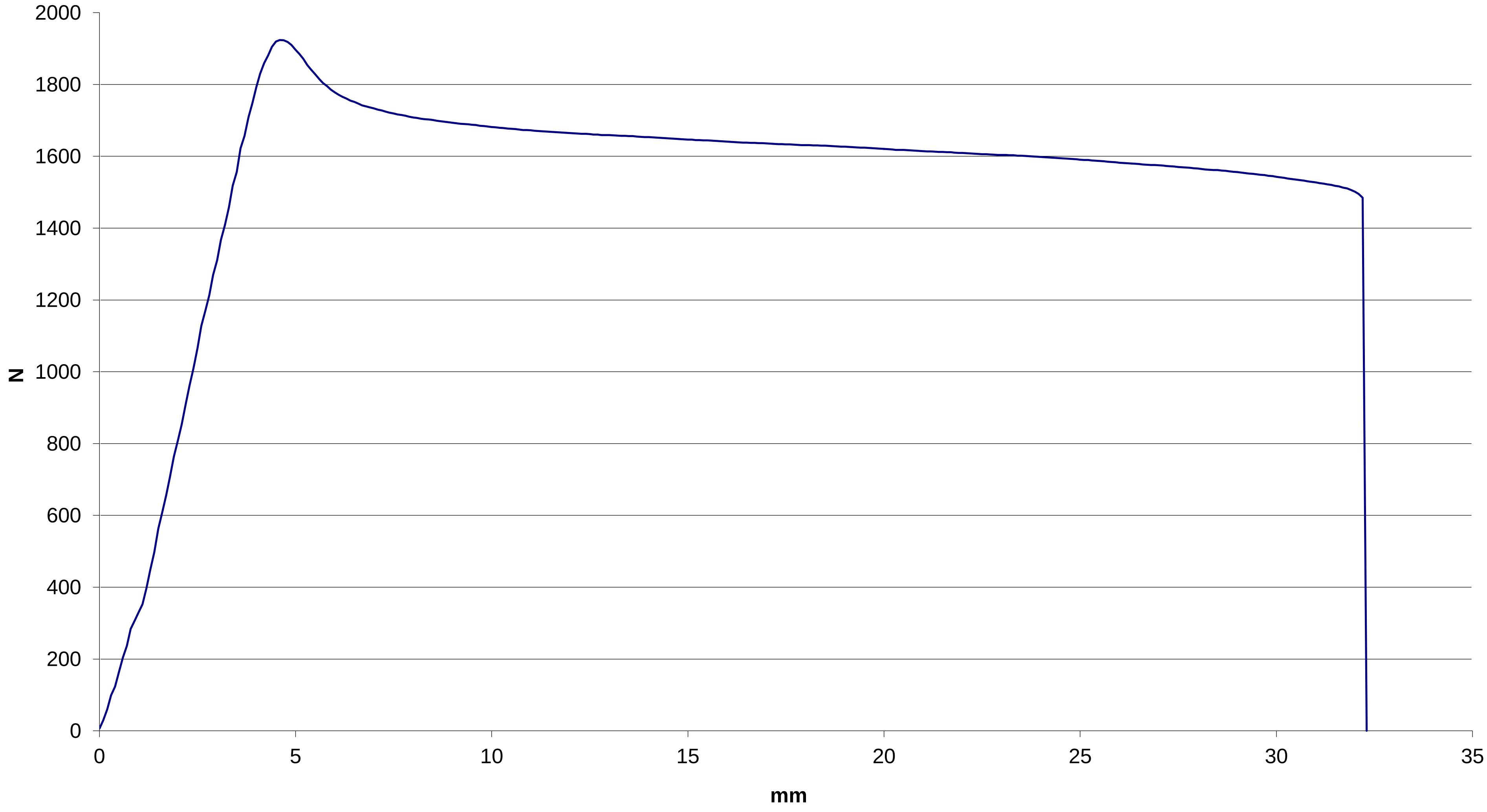

10 100% Recycled ABS Test Strip Results

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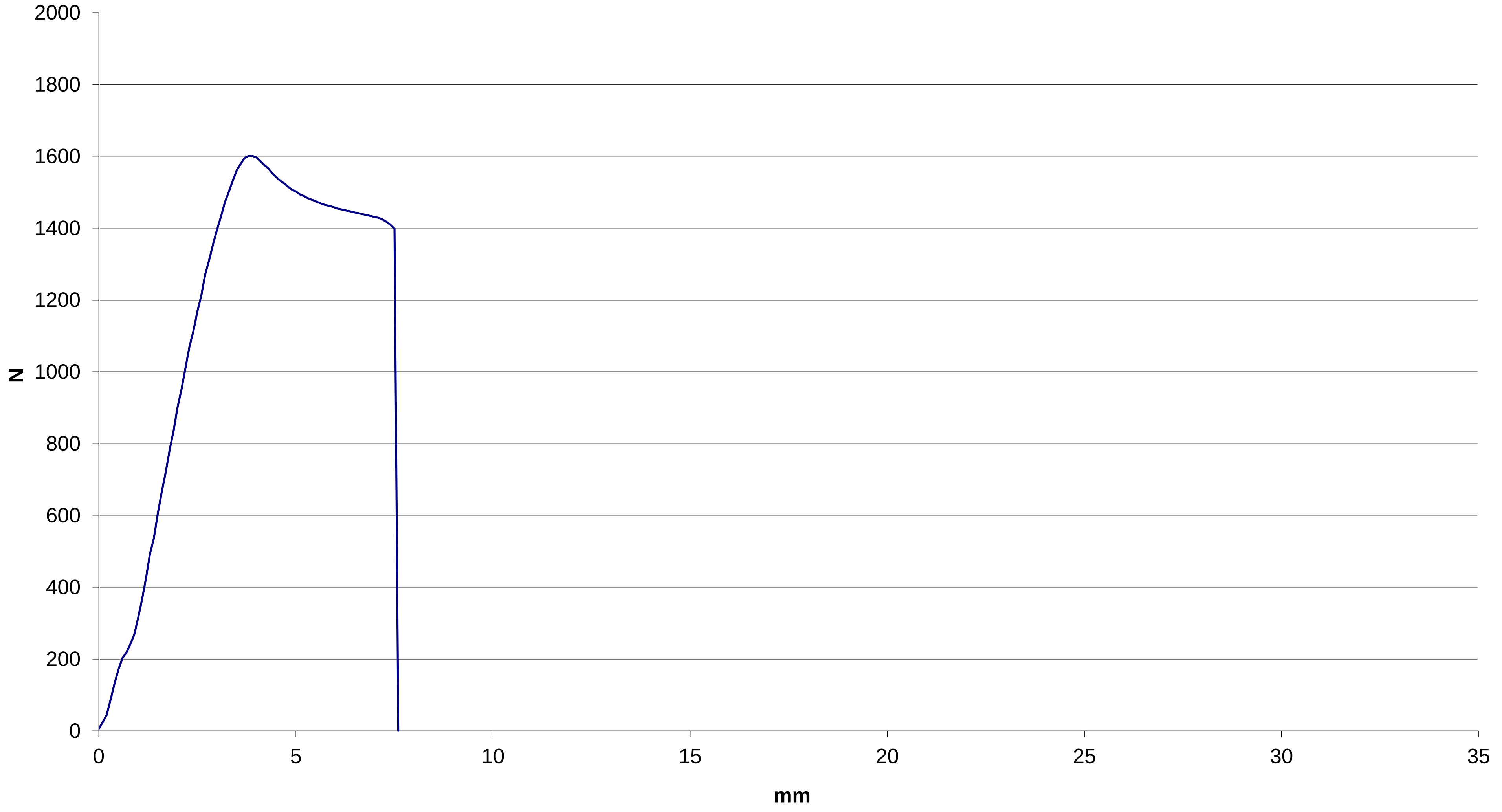

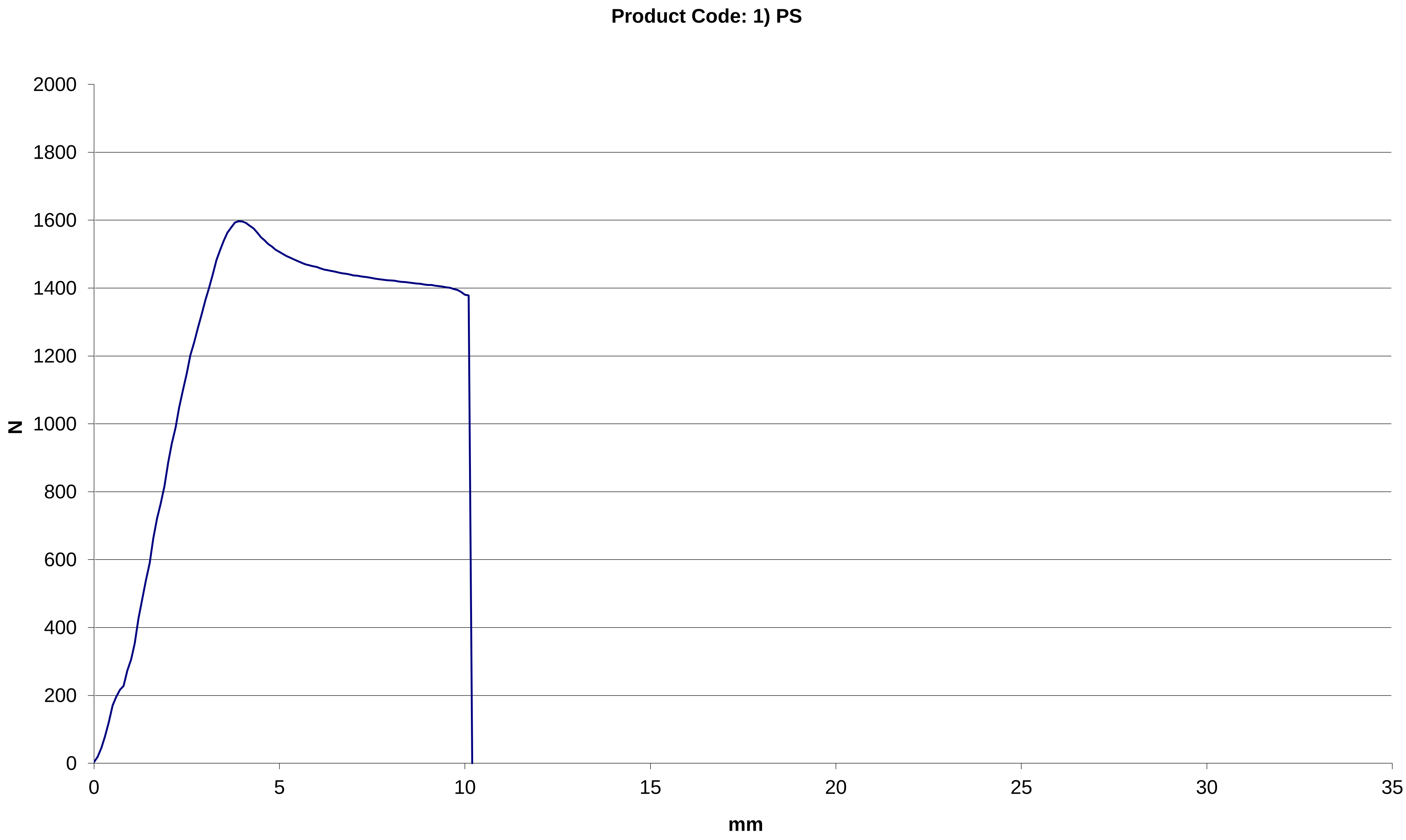
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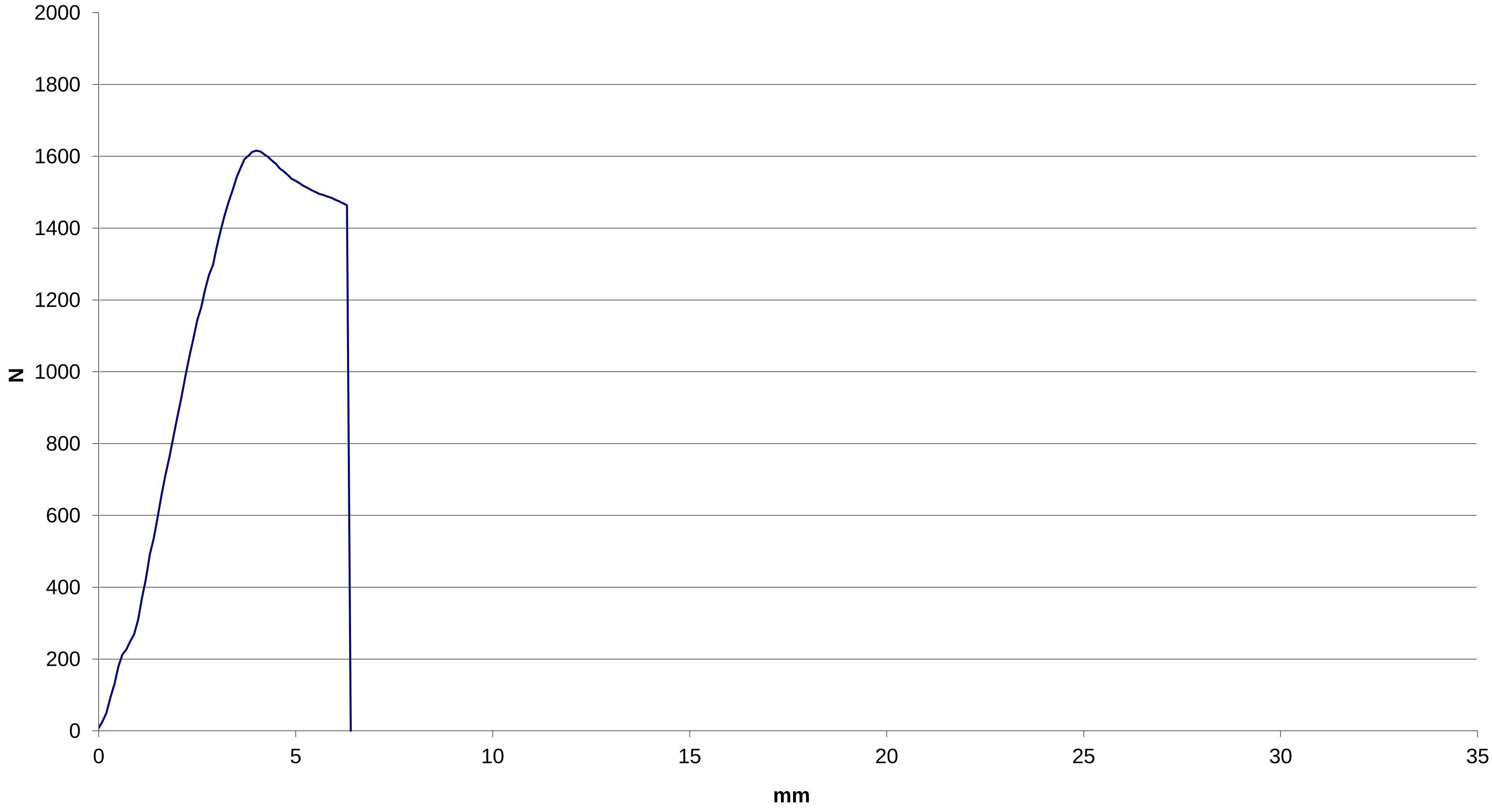

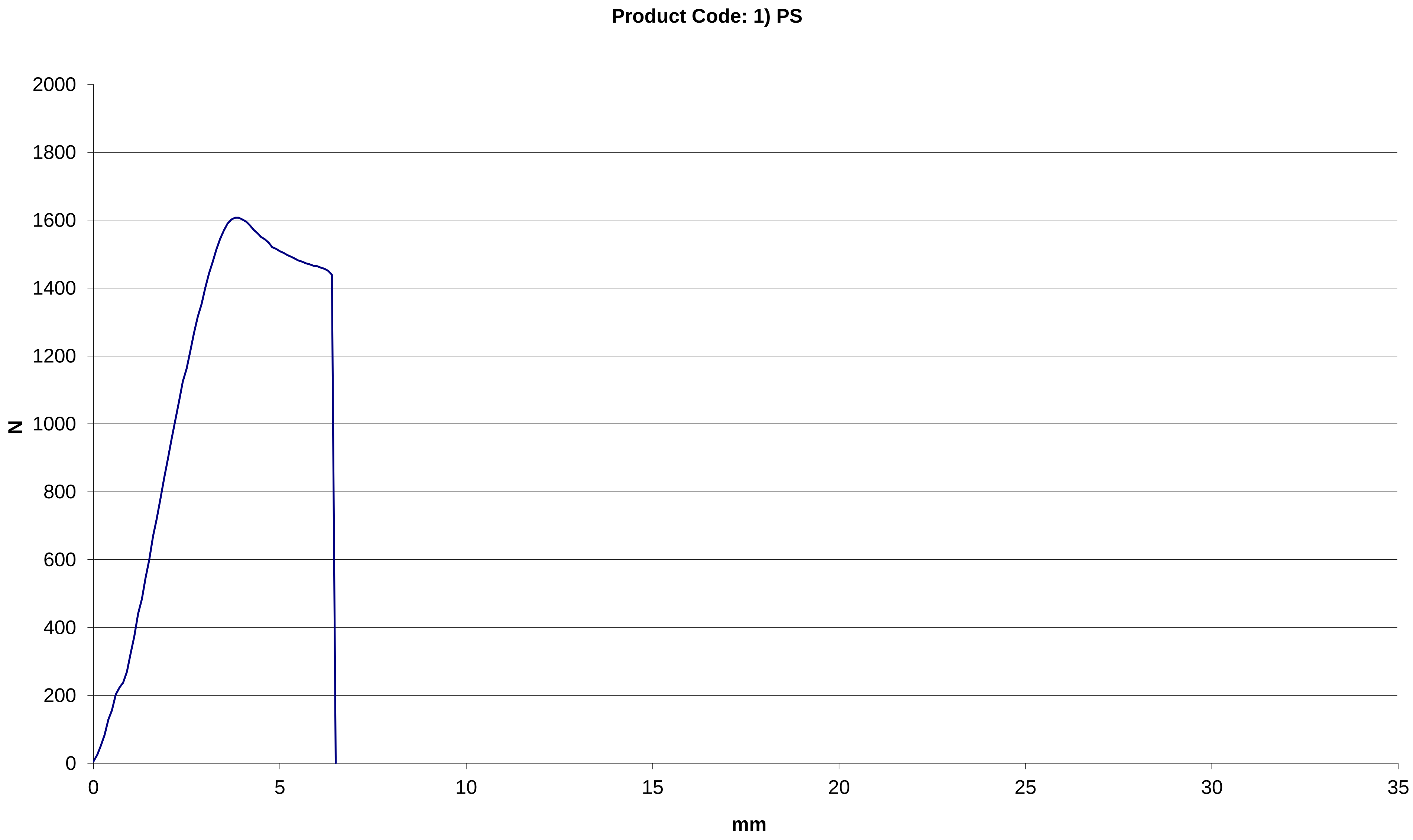
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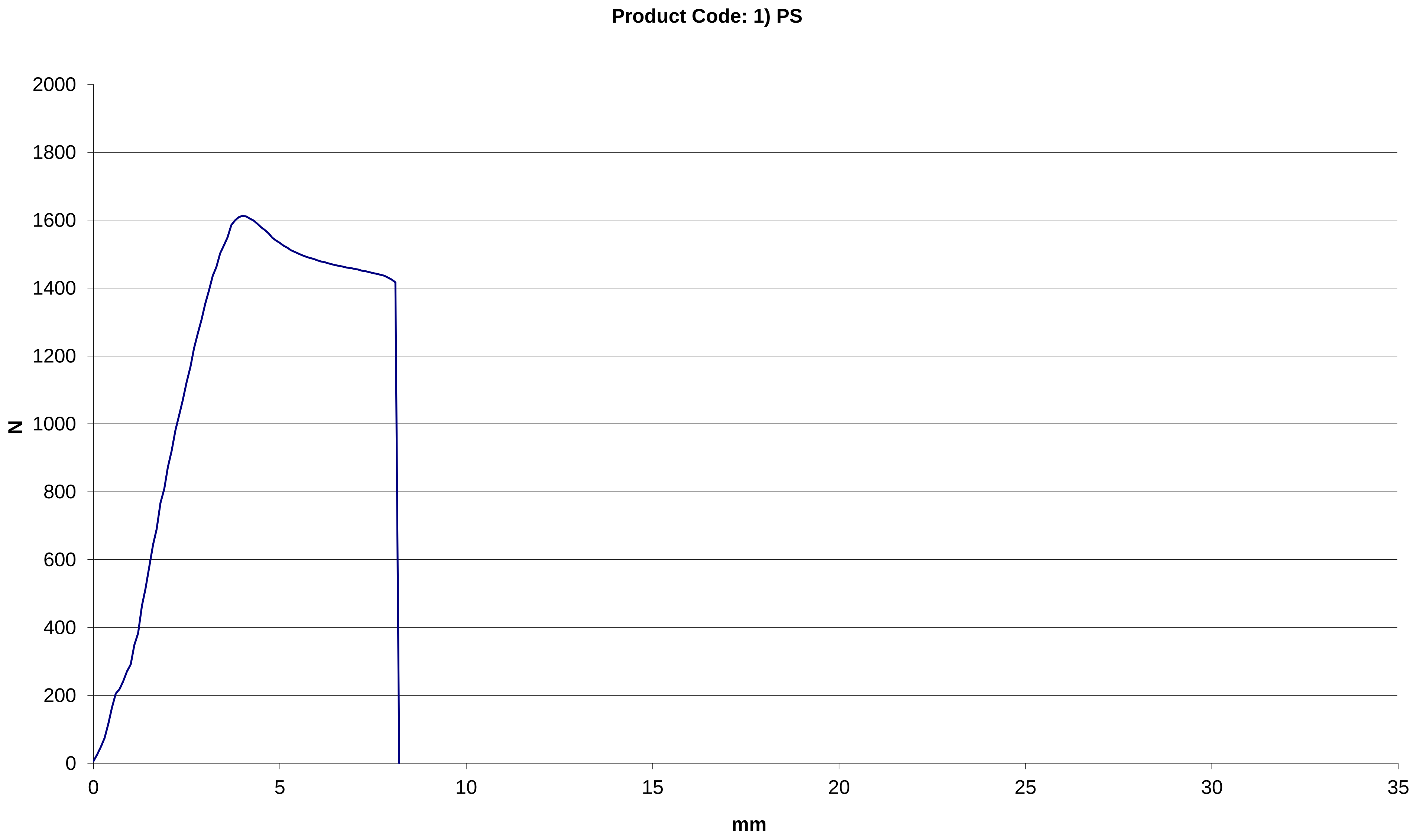
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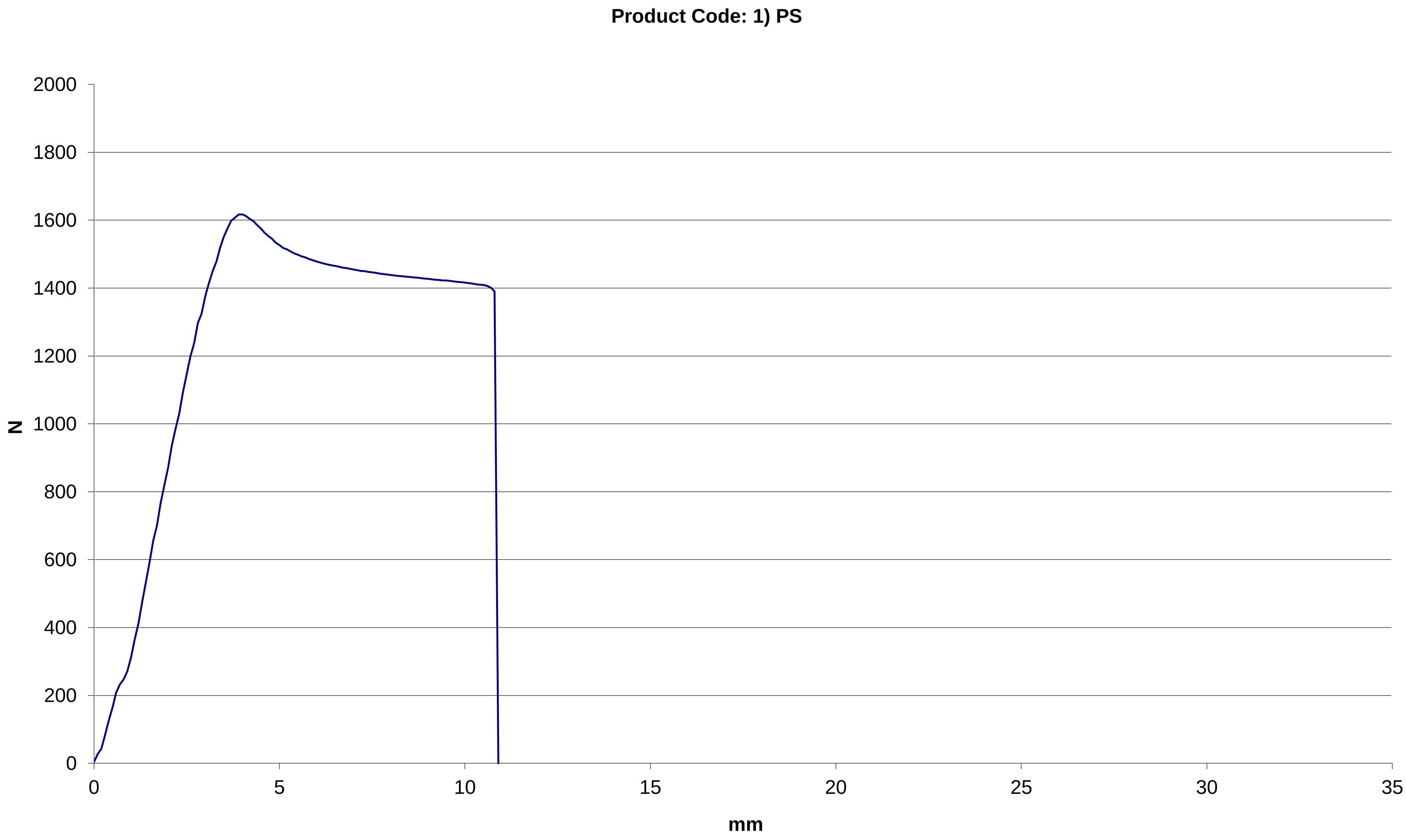
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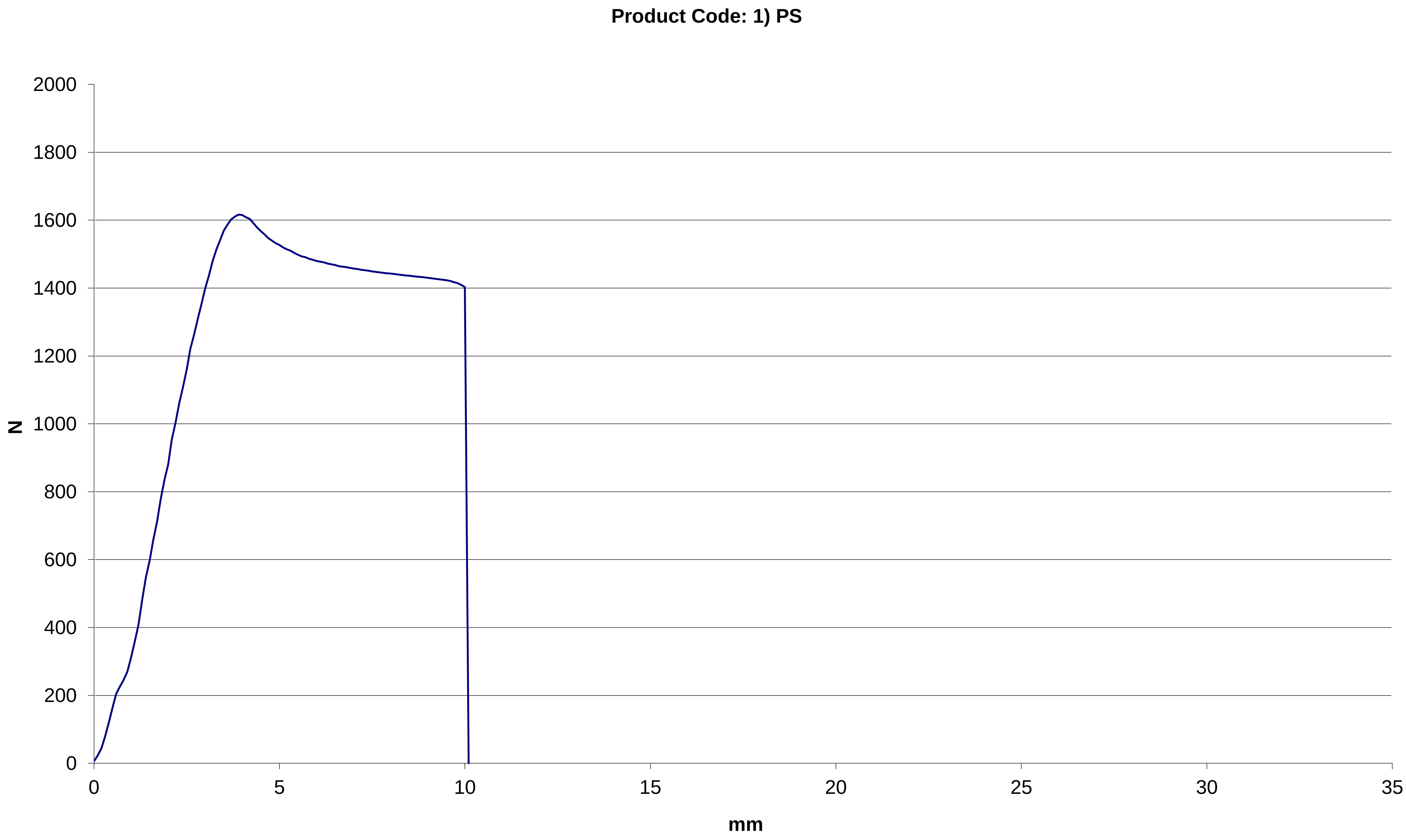
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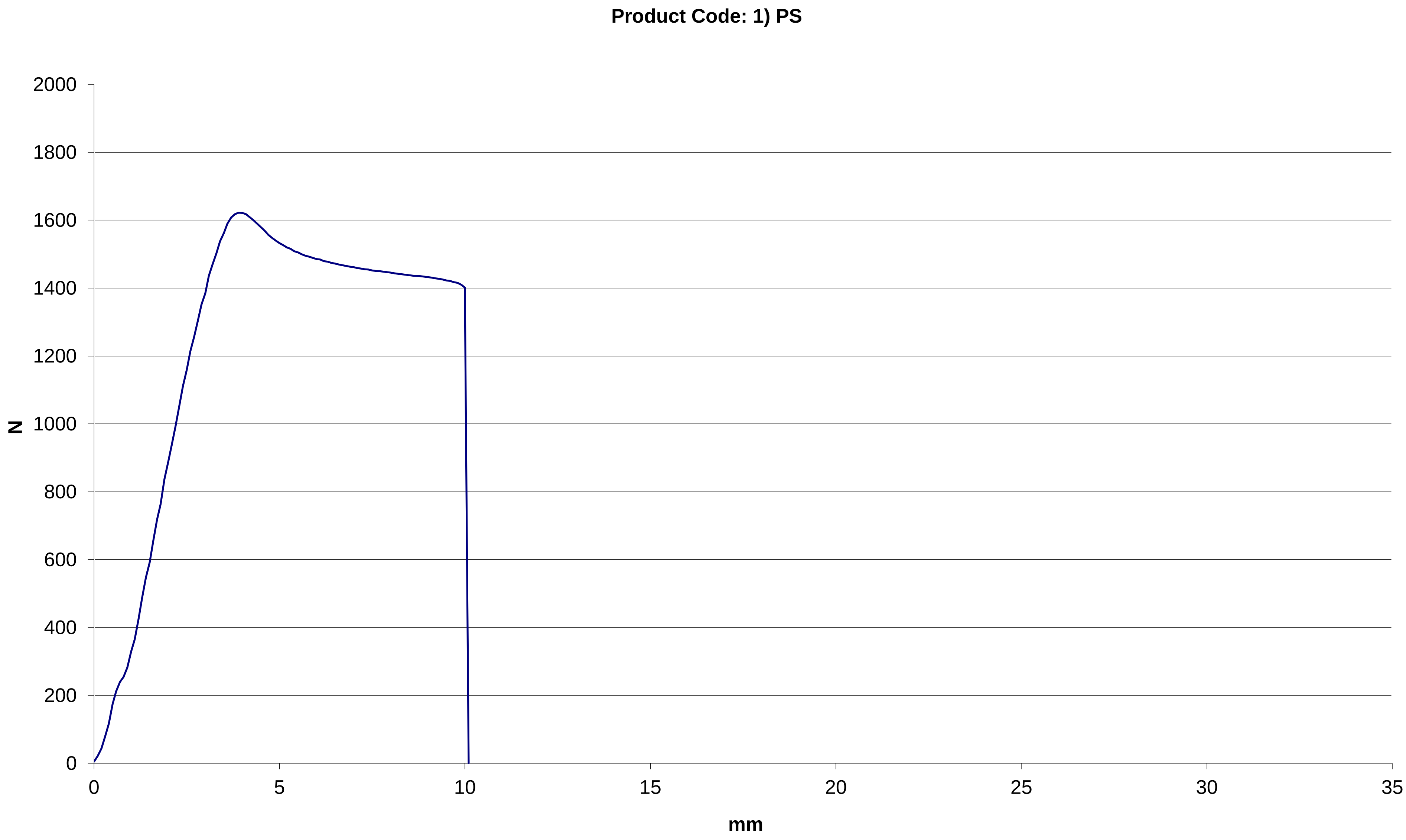

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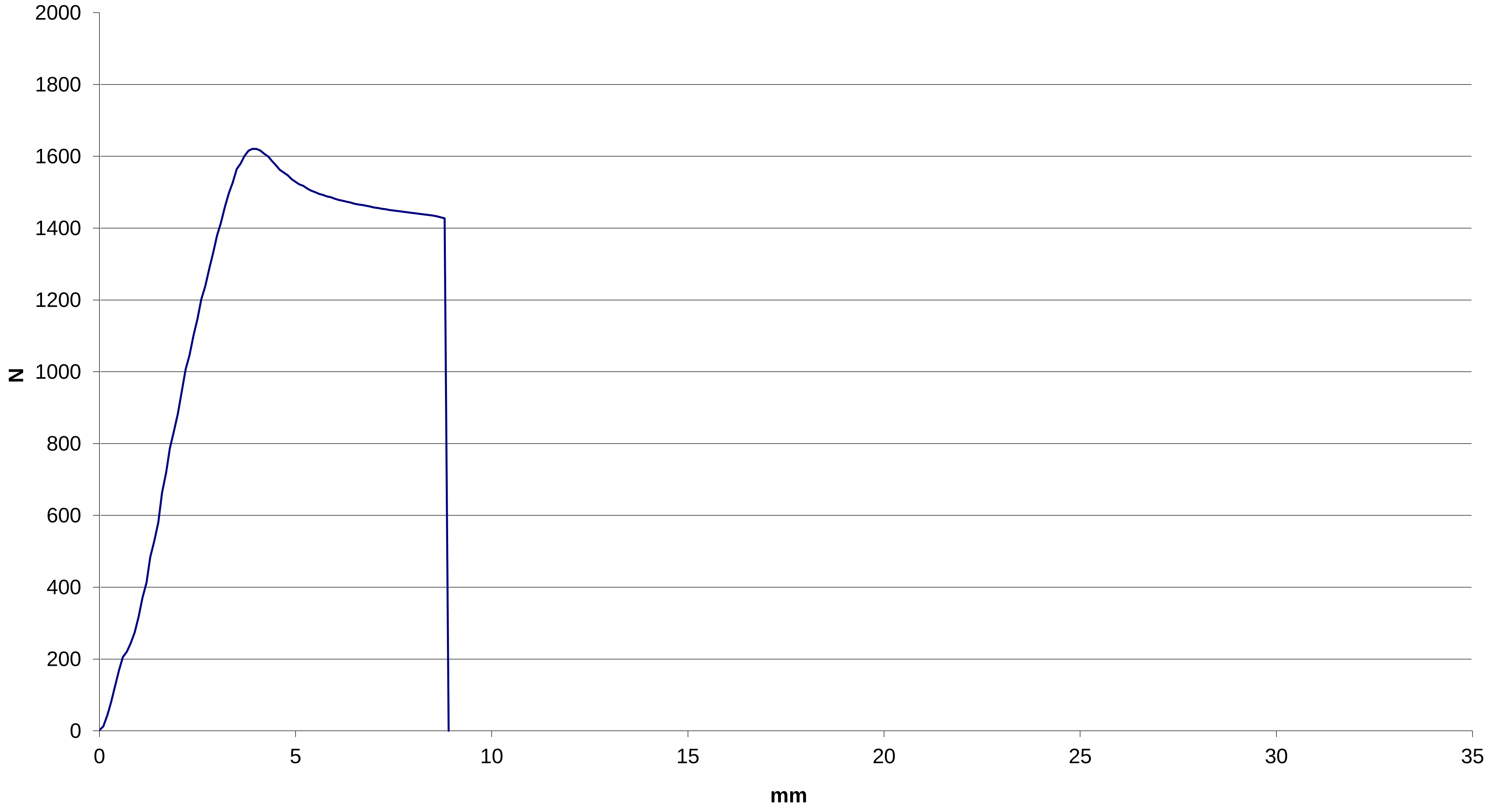

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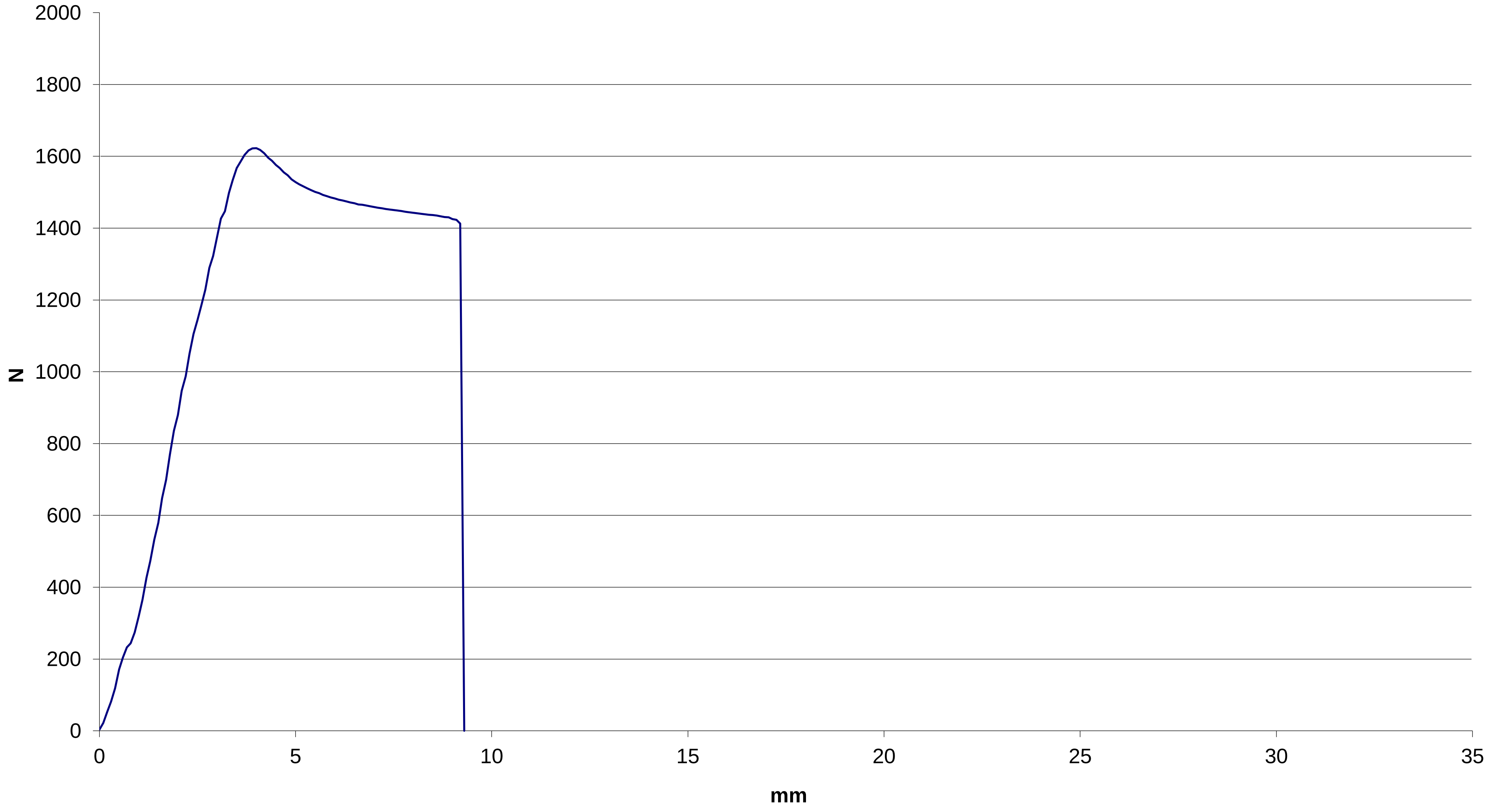
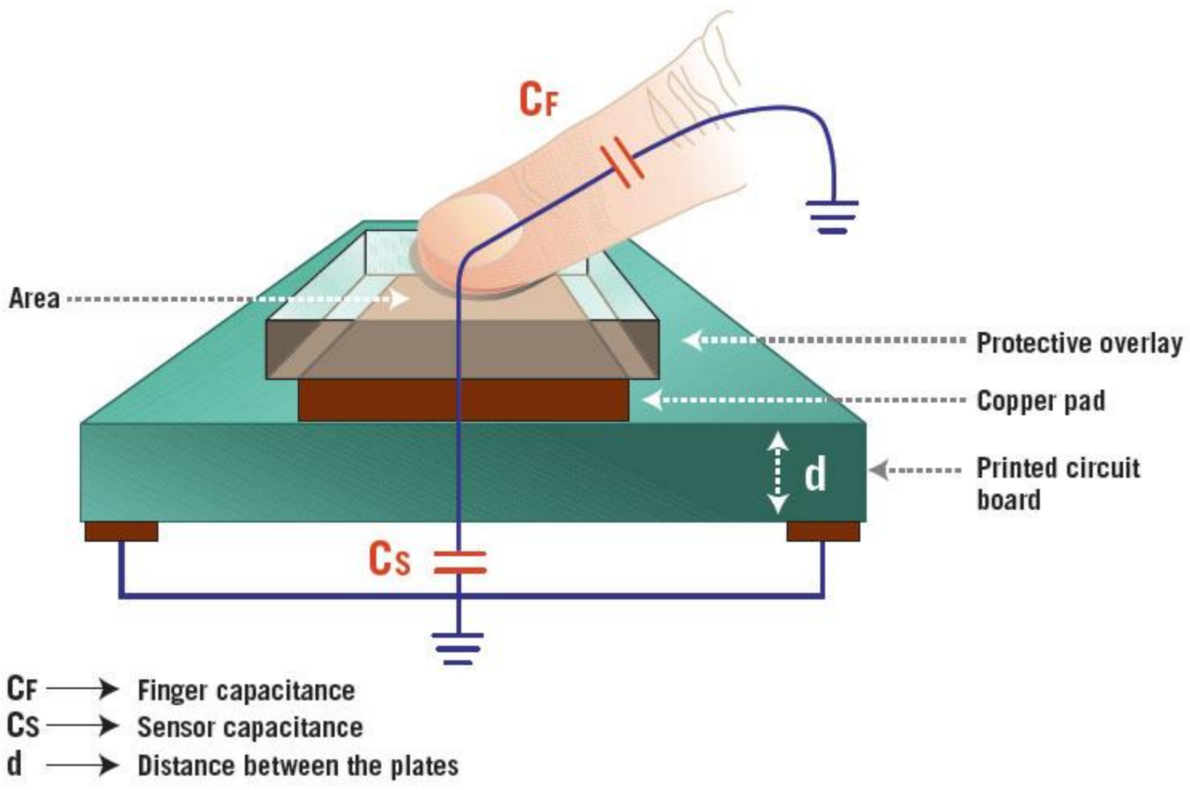
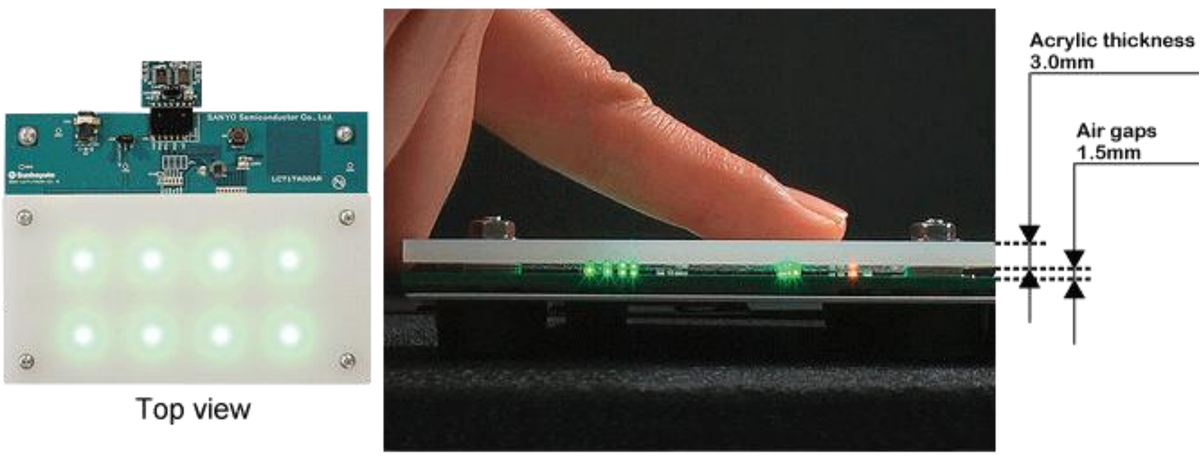


Appendix 9

Capacitive Touch Screen Information

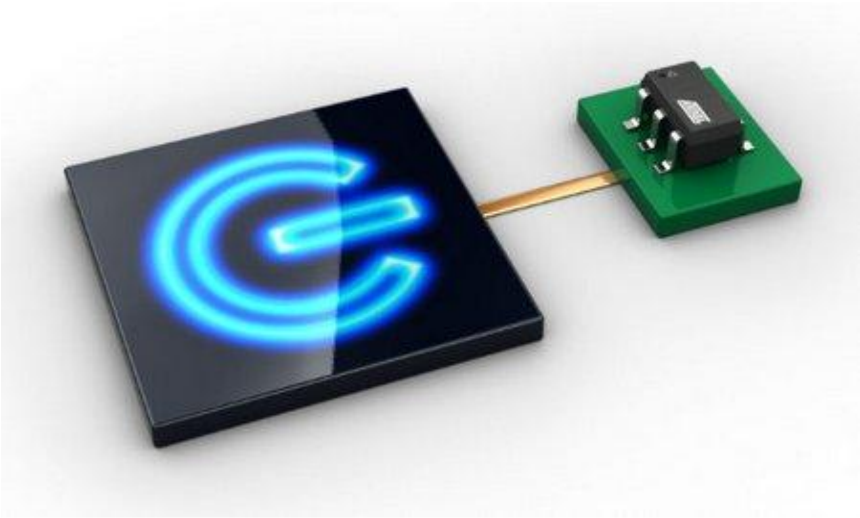
The principles of capacitive touch sensing.

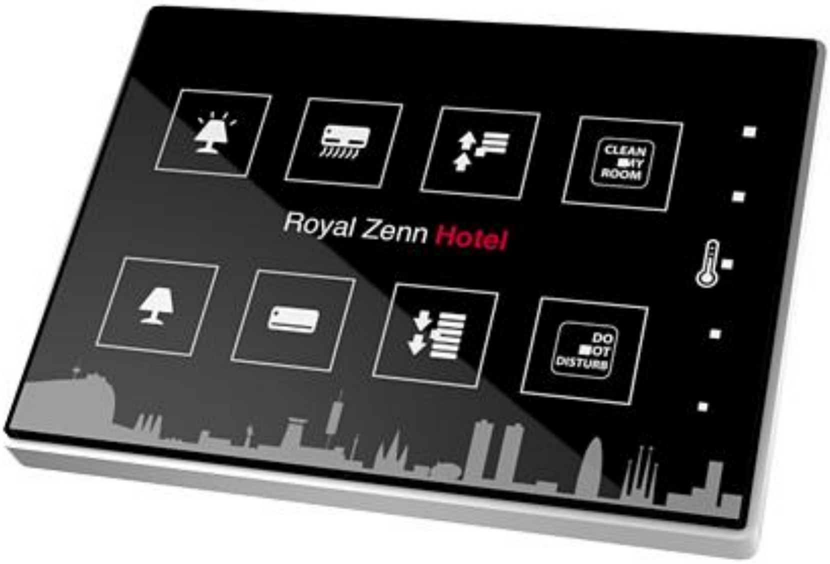




Top view

Side view




Royal Zenn Hotel

SANYO

Product Introduction
LC717A Series

Mar. 2013 Ver.1.05

Sanyo Semiconductor Co., Ltd.

If you are interested in the SANYO Touch Sensor LSI, please access the following URL.

http://www.sanyosemi.com/en/touch-sensor/index.php

Advantages of using LC717A Series

Advantages of using LC717A Series

Advantages of replacing Mechanical Switches with “Touch Switches”

Efficiency
Innovative use with intuitive operation!

Waterproof
Keep out water without moving parts.

Design
Smooth surface. Design can be Improved!

Productivity
Production efficiency increased with reduced parts!

Durability
Endurance improved without moving parts.

Clean
Wipe over the smooth surface.

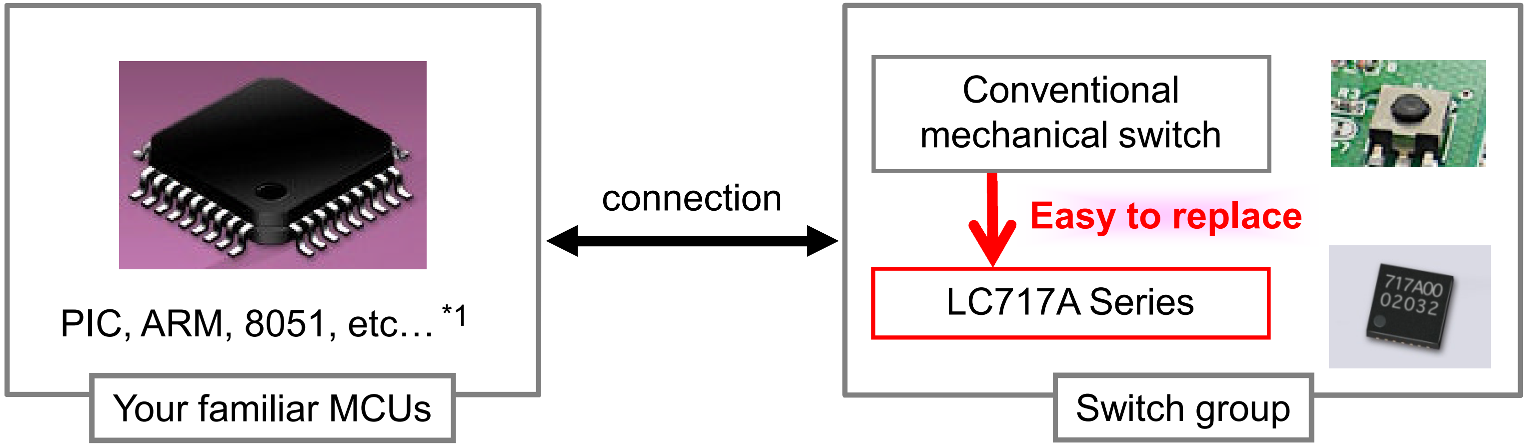
SANYO

Features of LC717A Series

Usability of LC717A Series

Can be replaced without changing usability & price of mechanical switches!!

- Can be determined touch ON/OFF without program, available to use immediately.
- Just like mechanical switches, can be connected directly to a familiar MCU.
- Very easy to use unlike other touch sensor built-in MCU.
- Fuss-free! troublesome adjustment, correction algorithm are all built into the LSI.
- Low cost ➡ No external components. Price comparable to mechanical switches.
- Crammed full of know-how in the FAQ, strong support to introduce the touch sensor. Significant cut of labor hour and costs required to introduce.

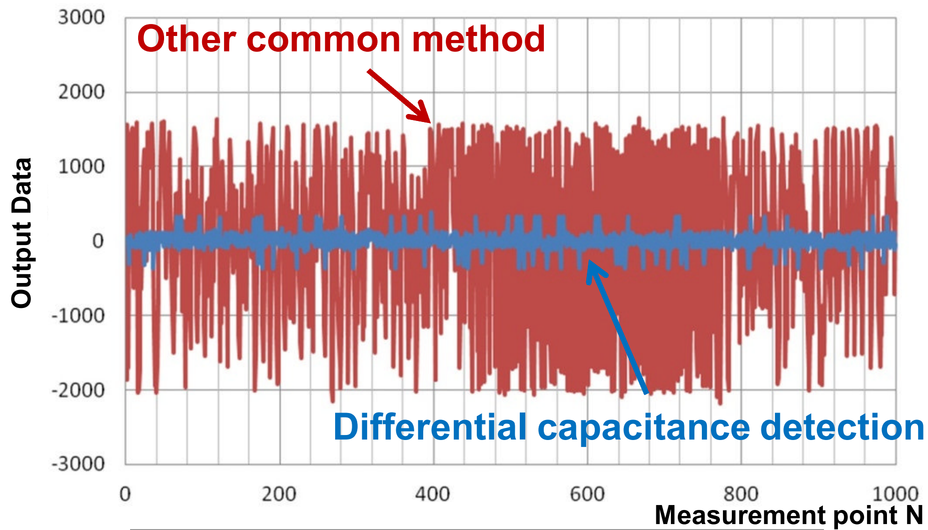


*1: All MCU names are registered trademarks of their respective companies.

Performance of LC717A Series

High sensitivity, High noise immunity by the “Differential capacitance detection (patent pending)”!!

- Can be operated with gloves.
- Can be operated without touching directly the surface (proximity operation).
- Can be operated with air space between the sensor board & the touch surface.
- Thick glass cover can be attached.
- Fewer restrictions of the switch shape, easy to make the sensor board.
- Strong for common mode noise by the “Differential capacitance detection”.



Variations in the output data
when common-mode noise is applied.

Operation with groves

Comparison table of LC717A Series

Item	LC717A Series	
	LC717A00AR/ LC717A00AJ(new product)	LC717A10AR(new product)/ LC717A10AJ(new product)
Operating supply voltage	2.6 ~ 5.5 V	2.6 ~ 5.5 V
Number of Sensing Inputs	8ch	16ch
Number of Sensing Outputs	8ch	-
Capacitive detection resolution	8bit	8bit
Proximity Sensing	Yes	Yes
Environment calibration	Yes	Yes
Noise cancel	Yes	Yes
I/F	I2C*1/SPI	I2C*1/SPI
Automotive quality	No	No
PKG	VCT28(AR)/SSOP30(AJ)	VCT28(AR)/SSOP30(AJ)

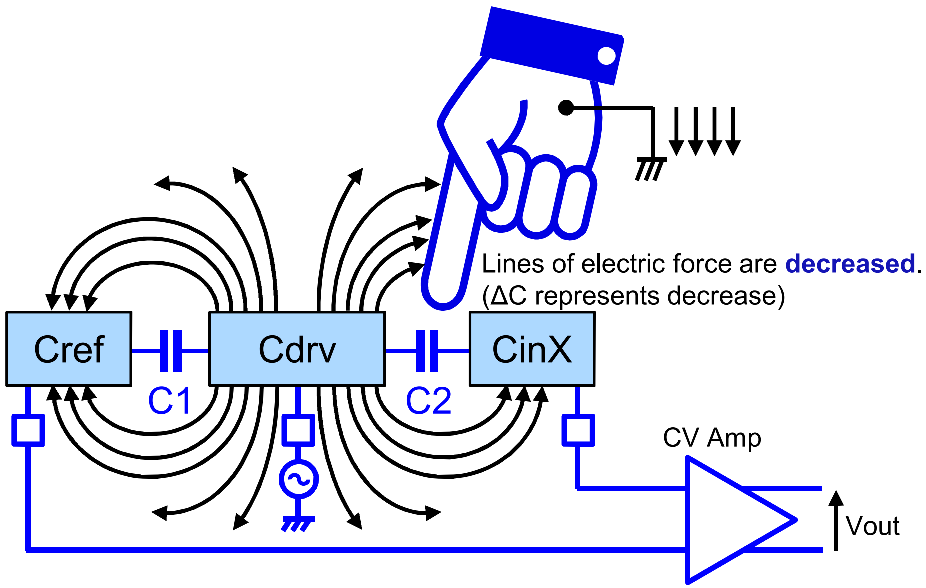
**1:* I^2C is a registered trademark of Philips Corporation.

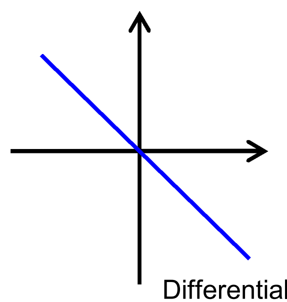
SANYO

Operating Principle of LC717A Series

Basic Principle of Operation

When putting your finger closer to the sensor input pin (CinX), line of electric force is released from Cdrv pin is reduced, the capacitance between Cdrv and CinX will be changed. This capacitance change (ΔC) is amplified by the differential CV amplifier, comparing the judgment threshold value, switch ON/OFF is determined.

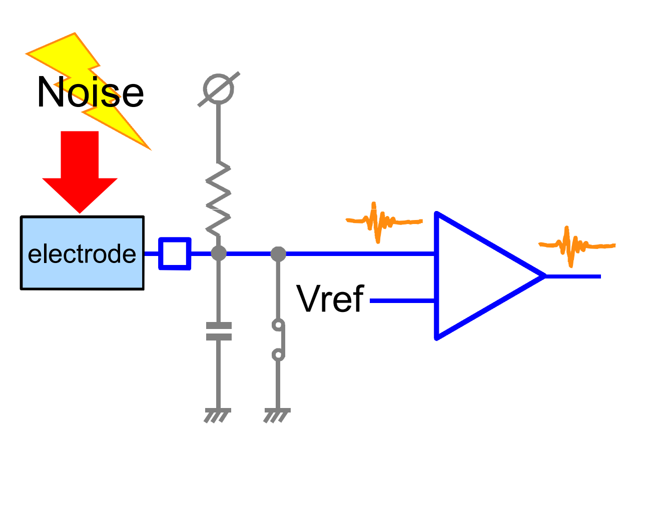




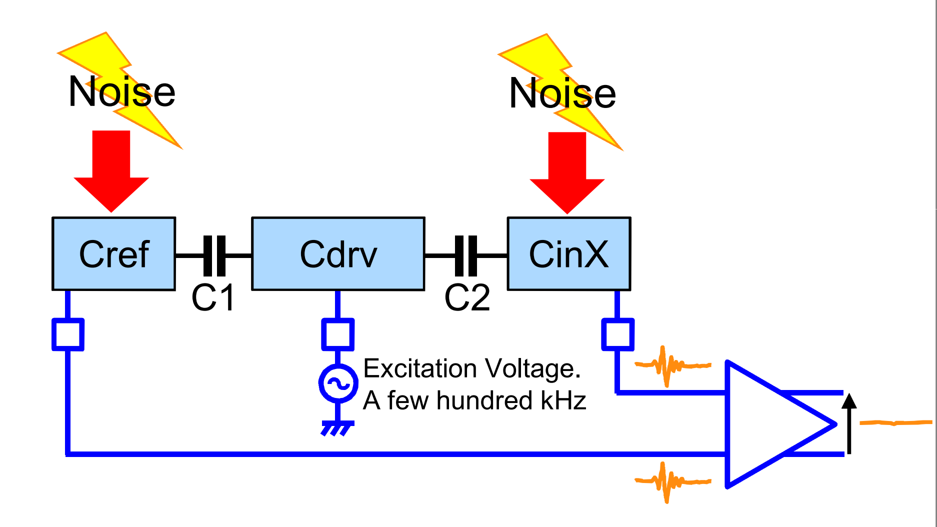
Because electric field is shielded, the lines of electric force are decreased. (ΔC represents decrease)

Description of Differential capacitance detection (patent pending)

The differential capacity (ΔC) between the two electrodes (between Cref & Cdrv, between CinX & Cdrv) is converted to a voltage using the unique technology of CV conversion amplifier. Unlike other common method, if similar noises are contained between the two electrodes, the Differential capacitance detection is less affected by the noise.



Other common method



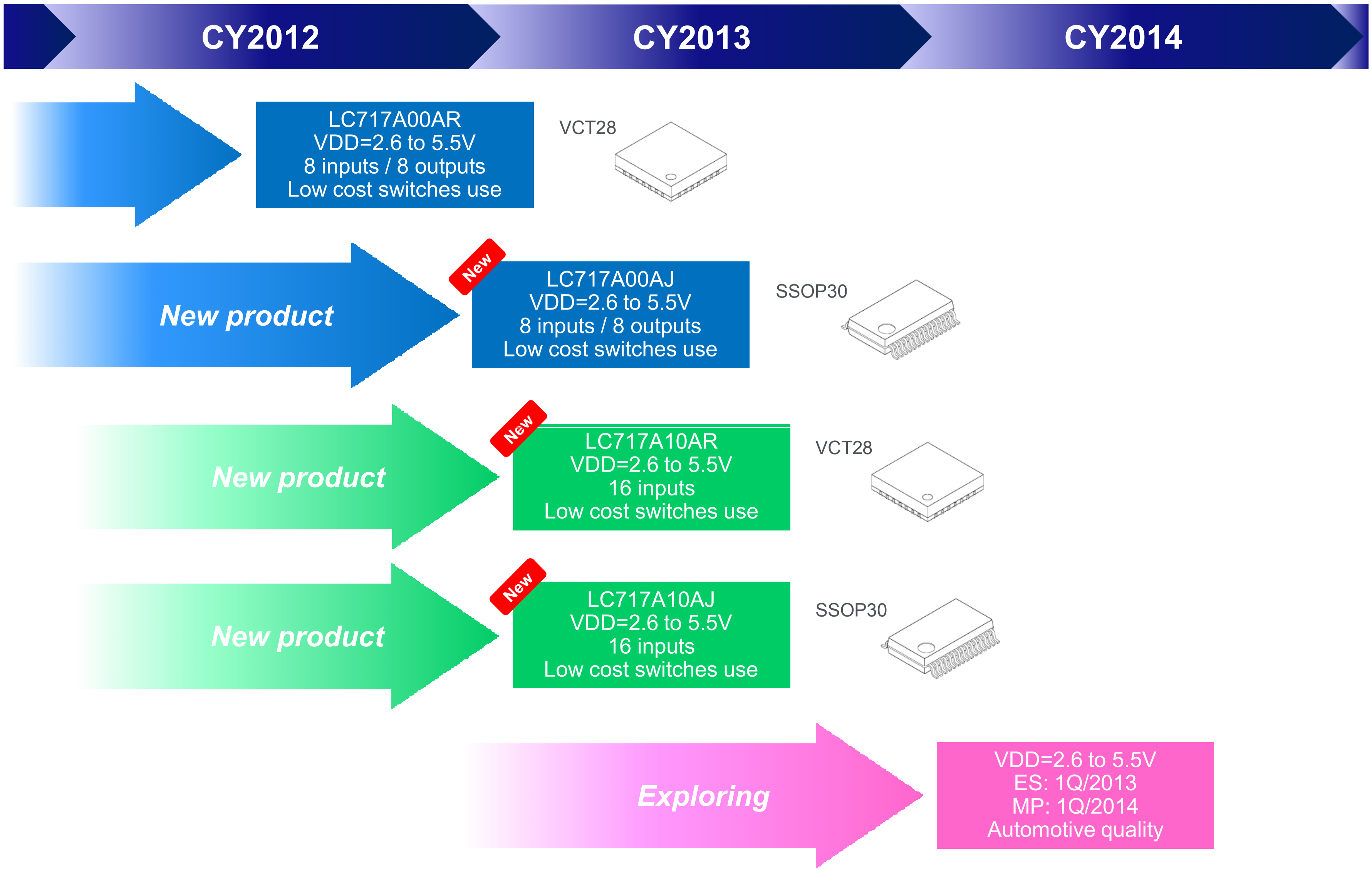
Differential capacitance detection

Differential capacitance detection is strong for noise!

SANYO

Roadmap of Sanyo Touch Sensor LSI

Roadmap of Sanyo Touch Sensor LSI



*1: This development roadmap is subject to change without notice.

SANYO Semiconductor Co., Ltd.

An ON Semiconductor Company

If you are interested in the SANYO Touch Sensor LSI, please access the following URL.

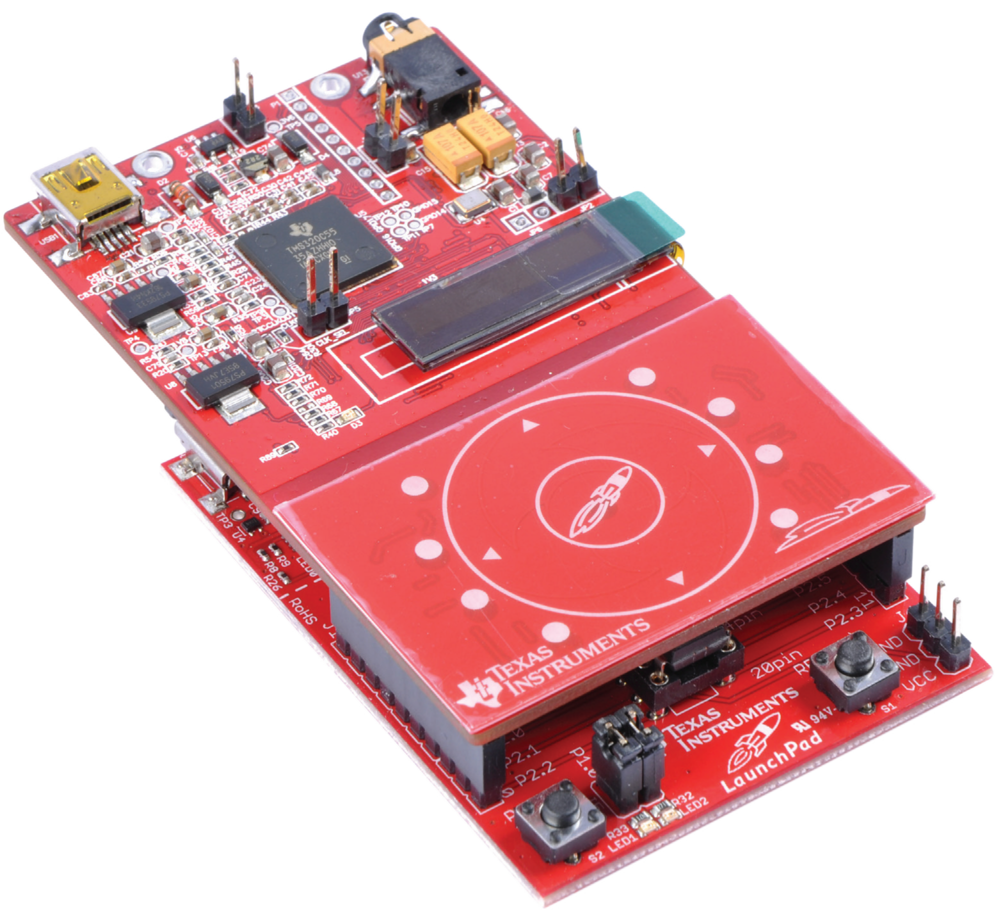
http://www.sanyosemi.com/en/touch-sensor/index.php

C5000™ Ultra-Low-Power DSP Audio Capacitive Touch BoosterPack

Product Bulletin

For MSP430™ Value Line LaunchPad Development Kit

The Audio Capacitive Touch BoosterPack (ACTBP) is a plug-in board for the LaunchPad development kit and MSP430 Value Line microcontrollers. The kit offers a complete reference design for capacitive touch solutions, using the capacitive touch I/O ports of select MSP430 Value Line microcontrollers. This reference design allows designers to easily control the C5000 ultra-low-power DSP using TI's MSP430 microcontroller for crystal clear playback and record of MP3 audio/voice files. Using the Audio BoosterPack, programmers realize the power and efficiency of the C5000 DSP without having to learn how to program the DSP. And the combination of the lowest standby power microcontroller (MSP430) with the lowest total power DSP (C5000) allows manufacturers to deliver ultra-low-power devices with extremely long battery life.



Key benefits

- Includes MSP430G2553IN20 Value Line microcontroller – pre-programmed with demo firmware to easily control complex DSP algorithms
- Includes the TMS320C5535 digital signal processor (DSP) – lowest active power for crystal clear audio/voice MP3 encode and decode
- Supported by a user interface for OLED display and MP3 playback/record application APIs
- Capacitive touch scroll wheel, proximity sensor and on-board LEDs
- Supported by a complete capacitive touch software library
- Stereo single-jack headset connector (supports stereo/mono headphones with built-in mic)
- microSD card with pre-programmed DSP code for MP3 playback, record and music storage (file storage)
- USB mass storage device capability for the microSD card with provided USB cable
- OLED display (monochrome, 96×16 pixels)
- Quick Start Guide included

Technical Details

The Audio Capacitive Touch BoosterPack allows quick evaluation and simplified design of audio capacitive touch products and includes:

- BoosterPack board with ultra-low-power C5000 DSP for crystal clear playback and recording of MP3 audio and video files
- microSD card pre-programmed with the DSP function code -- MP3 playback, record and music storage (file storage)
- Mini-USB cable for connection with a computer to power up the system
- Stereo single-jack headset connector (supports stereo/mono headphones with built-in mic)
- Initial demo headset with integrated microphone
- MSP430G2553 Value Line Microcontroller pre-programmed with the ACTBP host demo application – this will replace the MSP430 on the separate LaunchPad (not included).
- Supported by a user interface for OLED display and MP3 playback/record application APIs
- Capacitive touch scroll wheel, proximity sensor and on-board LEDs
- Supported by a complete capacitive touch software library
- USB mass storage device capability for the microSD card with provided USB cable
- OLED display (monochrome, 96×16 pixels)
- Quick start guide

Software

Through the MSP430 LaunchPad (not included), designers can interface with integrated software environments such as Code Composer Studio version 4 or IAR Embedded Workbench. These free IDEs include an assembler, linker, simulator, source-level debugger and C-compiler to help developers integrate new and customized audio and voice applications. TI also offers a complete capacitive touch software library, enabling designers to quickly and easily prototype and test new designs.

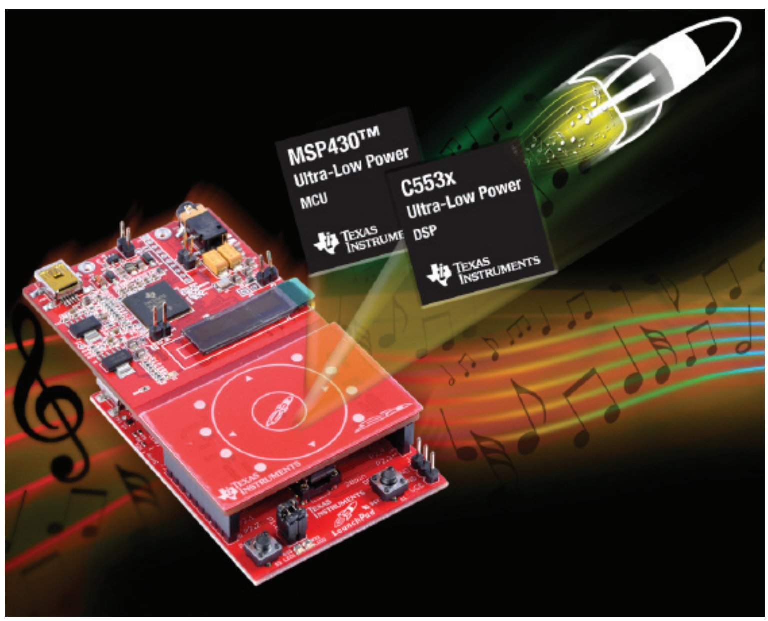
Support

With the Audio Capacitive Touch BoosterPack designers also get unlimited access to the LaunchPad Wiki. This Wiki promotes collaboration and simple sharing of solutions and ideas, making LaunchPad along with the BoosterPack a complete development environment for audio capacitive touch designs. This active and growing online community supplements the hardware and software components of the LaunchPad and BoosterPack package and provides instant support, projects and helpful hints that will be shared through the Wiki pages and E2ETM forums.

For customers looking for extra support for the C5000 DSP, TI offers complete support by TI's extensive Developer Network, as well as a complete Chip Support Library, comprehensive application notes, reference designs, application guides, videos and online communities.

Get Started Today

Easily upgrade low-power applications with TI's new C5000 DSP-based Audio Capacitive Touch BoosterPack for the MSP430 LaunchPad development kit. For the first time, new functionalities can be enabled on the DSP and controlled solely by the MCU, including crystal clear audio capabilities.
For more information on the C5000 Audio Capacitive Touch BoosterPack, please visit **www.ti.com/audioboosterpack.**



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Appendix 10

Shrink Film Information


PACKED
WITH VITAMINS
LocoEnergy
PACKED
WITH VITAMINS
LocoEnergy


ENERGIE-GETRÄNK
re:
vitalize
fruit punch
Ginger
ALE
ANTIOXIDANTE
DON
SIMON
FRUTAS CON
ANTIOXIDANTES
NATURALES


iced italian
espresso smoothie
Mocha Latte
nutritious premium organic
espresso smoothie with a rich blend
of chocolate and cream

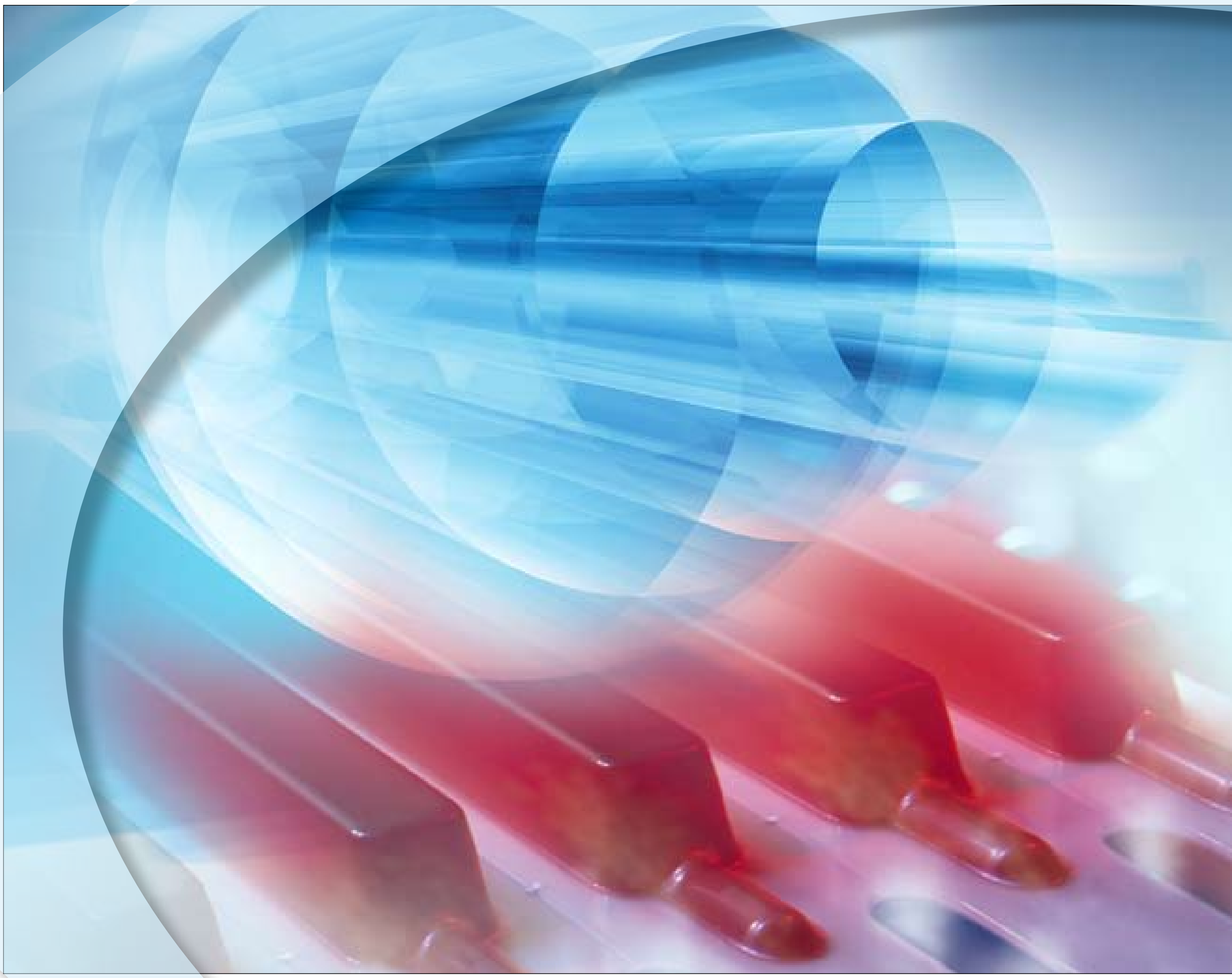

ENO
Gets to work in 6 seconds
Lifebuoy
HAND WASH
care
Sugar Free Natura
Surf excel
kissan
Vatika


A-TASTE
爱洛·特
chinaprintinservice.com

TOPAS®

Cyclic Olefin Copolymer (COC)

PACKAGING



TOPAS

Advanced Polymers

TOPAS Advanced Polymers

TOPAS Advanced Polymers manufactures and markets TOPAS® COC (cyclic olefin copolymer) for advanced packaging, medical, optical and other applications worldwide. The company is a joint venture of Daicel Chemical Industries Ltd., and Polyplastics Co., Ltd. Headquartered in Frankfurt, Germany, it operates a U.S. subsidiary in Florence, Kentucky, USA, and a 30,000 metric ton per year plant, the world's largest, in Oberhausen, Germany. TOPAS Advanced Polymers was launched January 1, 2006 following the purchase of the TOPAS business from Ticona, a subsidiary of Celanese Corporation.

Important

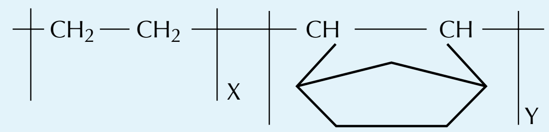
The properties of articles can be affected by a variety of factors, including choice of material, additives, part design, processing conditions, and exposure to the environment. Customers should take responsibility as to the suitability of a particular material or part design for a specific application. In addition, before commercializing a product that incorporates TOPAS, customers should take the responsibility of carrying out performance evaluations. Our company's products are not intended for use in medical and dental implants. Unless specified, the numerical values given in this literature are for reference purposes only and not for use in product design. Without exception, please follow the information and other procedures explained in this literature. This literature does not guarantee specific properties for our company's products. Please take the responsibility to verify intellectual property rights of third parties.

Contents

1. Introduction

TOPAS COC (cyclic olefin copolymer)

TOPAS is an amorphous, transparent copolymer based on the polymerization of ethylene and norbornene using metallocene catalysts. Its property profile can be varied over a wide range by adjusting the chemical structure during polymerization. These new materials exhibit a unique combination of properties whose performance benefits include:



- **High transparency and gloss**
- **Excellent moisture and aroma barrier**
- **Variable glass transition temperatures from 65°C up to 178°C**
- **High stiffness and strength**
- **Easy to extrude and thermoform**
- **Compatibility with polyolefins**
- **Excellent biocompatibility and inertness**
- **Resists hydrolysis, polar organics, acids and alkalis**

Broad use in packaging

These characteristics have made TOPAS a widely accepted packaging material that enhances packaging performance over a broad range of applications. TOPAS opens new opportunities by adding a new tool in the packaging engineer's toolbox. It is used as a blending component for other polyolefins to enhance performance and as a discrete layer in coextruded multilayer films.

Table 1: TOPAS packaging applications

Forming webs	improved forming window and uniformity
Soft shrink film	tough, stiff, soft shrink, halogen-free, polyolefin
Shrink sleeves and labels	high shrinkage and stiffness with low shrink force
Slip additive	non-migrating for reduced ambient and hot COF in polyolefin film
Sealant films	additional stiffness, improved seal strength and hot tack
Twist wrap	high end clarity and gloss, excellent deadfold
Bags/pouches	increased stiffness at room temperature and under hot-fill conditions, easy tear, retort performance
Medical trays	high moisture barrier, deep draw, clarity
Paperboard coating	increased moisture barrier, reduced curl
Zipper closures	reduced warping and camber, increased opening force
Blister packs	high moisture barrier, deep draw, halogen-free

2. Product portfolio

TOPAS is a high purity, colorless, transparent polymer often processed by extrusion. TOPAS F-series grades give optimum performance in extruded sheet, cast film and blown film (Table 2). TOPAS grades differ primarily in their glass transition (Tg) and the related heat deflection temperature (HDT/B), i.e., those with higher norbornene content have higher heat resistance. Flow characteristics may be adjusted independently of heat resistance with molecular weight.

Table 2: Standard TOPAS film grades

TOPAS 9506F-04	High clarity extrusion grade for use in food and medical packaging as either a discrete layer in multilayer film or in blends with polyethylene (PE). It has a low glass transition temperature (Tg) and provides excellent clarity, stiffness, water vapor barrier and good thermoformability. TOPAS 9506 is especially recommended for use as discrete layers in blown films due to its higher molecular weight and increased melt strength for better bubble stability.
TOPAS 8007F-04	High clarity extrusion grade for pharmaceutical, medical and food packaging. It is most often used in coextruded cast film applications, e.g., blister film, and offers excellent clarity, stiffness, water vapor barrier and thermoformability. This grade has the broadest range of regulatory approvals within the packaging portfolio.
TOPAS 8007F-400	Standard extrusion grade with a broader extrusion processing window (equipment and conditions) and is recommended for the extrusion of discrete 100% TOPAS layers or high (> 65%) COC content blends. It is especially recommended for use in grooved feed extruders.
TOPAS 6013F-04	High clarity extrusion grade having high temperature resistance for pharmaceutical, medical and food packaging. It has a high glass transition temperature (Tg) and provides excellent clarity, stiffness, water vapor barrier and thermoformability. It can be used in coextruded films as a discrete layer or in blends with PE.
Further development grades may be available upon request; please consult your TOPAS representative.	

3. Product performance

3.1 Physical properties

TOPAS is a family of olefinic polymers containing ethylene and typically 30 to 60 mole% norbornene. Unlike most polyolefins, TOPAS is an amorphous thermoplastic having a glossy, crystal clear appearance with high modulus and low shrinkage. It is available with glass transition temperatures (Tg) ranging from 65 to 178°C and maintains high modulus at temperatures approaching its Tg. Film grades of TOPAS have Tg's ranging from 65 to 138°C. TOPAS is the only polyolefin having heat deflection temperatures (HDT) as high as 170°C (338°F) at 0.45 MPa (66 psi).
For all TOPAS grades, HDT is about 10°C lower than Tg values. Other properties associated with the various grades of TOPAS are given in Table 3.

Table 3: Physical properties of TOPAS

Property	Unit	Test method	9506F-04	8007F-04	8007F-400	6013F-04
Density	kg/m³	ISO 1183	1020	1020	1020	1020
Melt Volume Rate (MVR) · at 230°C, 2.16 kg load · at 190°C, 2.16 kg load	cm³/10 min	ISO 1133	6.0 1.0	12.0 2.0	11.0 2.0	1.0 –
Melt Flow Rate · at 230°C, 2.16 kg load · at 190°C, 2.16 kg load	g/10 min	*	5.5 0.9	11.0 1.9	10.1 1.8	0.9 0.1
Water absorption (23°C - sat)	%	ISO 62	0.01	0.01	0.01	0.01
Thermal properties						
Glass transition temperature (10°C/min)	°C	ISO 11357 -1, -2, -3	65	78	78	138
Test specimen production (film)						
Type of extrusion			cast	cast	cast	cast
Thickness of specimen	µm		70	70	70	70
Mechanical properties (film)						
Tensile modulus · machine direction · transverse direction	MPa	ISO 527-3	1700 2000	2200 1800	2100 1700	2400 2250
Tensile strength at break · machine direction · transverse direction	MPa	ISO 527-3	55 55	57 50	55 50	55 45
Elongation at break · machine direction · transverse direction	%	ISO 527-3	2.9 3.6	2.9 3.0	3.4 3.4	2.4 2.2
Elmendorf tear strength · machine direction · transverse direction	g	ISO 6383-2	230 240	225 230	– –	9 9
Dart Drop Impact Strength, F50		ISO 7765-1	< 36	< 36	–	< 36
Optical properties (film)						
Gloss 60°	%	ISO 2813	> 100	> 100	>100**	> 100
Haze	%	ISO 14782	< 1	< 1	>2**	< 1
Barrier properties (film)						
Water vapor permeability (38°C, 90% RH)	g-100 µm/ (m²-day)	ISO 15106-3	0.8	0.8	0.8	1.3
Oxygen permeability (23°C, 50% RH)	cm³-100 µm/ (m²-day-bar)	ASTM D3985	170.0	200.0	–	280.0

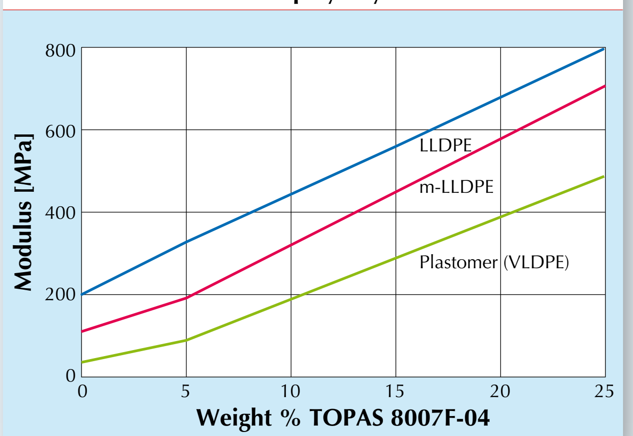
* Calculated from ISO 1133 MVR using a melt density of 0.92.
** Haze level will depend on processing conditions.
The above values are representative values and not guaranteed values for quality or design purposes.

3.1.1 Mechanical properties of blends

TOPAS is a stiff (high modulus) amorphous polymer with a density of 1.02 g/cc. It is available in a wide range of glass transition temperatures and molecular weights. Like other glassy amorphous polymers, it has low elongation to break. For this reason, it is not usually used as a monolayer 100% TOPAS structure unless exceptional optics are needed.

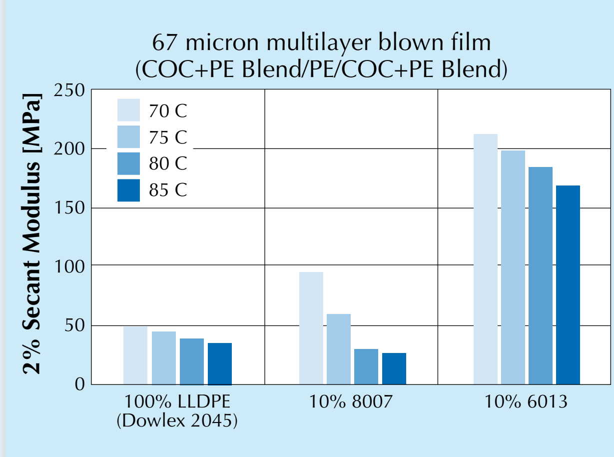
TOPAS grades have an average tensile modulus in the range of 2000 MPa (300 kpsi). They significantly enhance the stiffness of polyolefin film when used as a blend component, which greatly improves the performance of PE bags, pouches and other packaging. This occurs even at low addition levels as illustrated in Figure 1. For example, a 10% blend of TOPAS with polyethylene raises film stiffness more than 100% while preserving a low haze level. The added stiffness allows downgauging to thinner and less costly film structures. When high-Tg grades are utilized, these modulus improvements are maintained up to temperatures approaching the Tg of the TOPAS, improving hot-fill performance and elevated temperature capability as shown in Figure 2.

Figure 1: Effect of TOPAS content on room temperature modulus of polyethylene blends



Adding TOPAS to PE films also boosts thermal resistance and significantly decreases Elmendorf tear values, especially in the machine direction, enabling the design of "Easy Tear" and "Linear Tear" products. Adjusting the TOPAS level in PE films can yield a desired tear resistance while increasing puncture resistance in monolayer PE films. For instance, the force needed to puncture 150 or 300 micron (6 or 12 mil) monolayer octene LLDPE film containing a LLDPE/TOPAS blend increases almost linearly as TOPAS increases from 0 to 30%. As a discrete layer in multilayer extruded and laminated films, TOPAS offers high clarity, stiffness and moisture barrier.

Figure 2: Effect of high-Tg TOPAS content on elevated temperature modulus of polyethylene blends

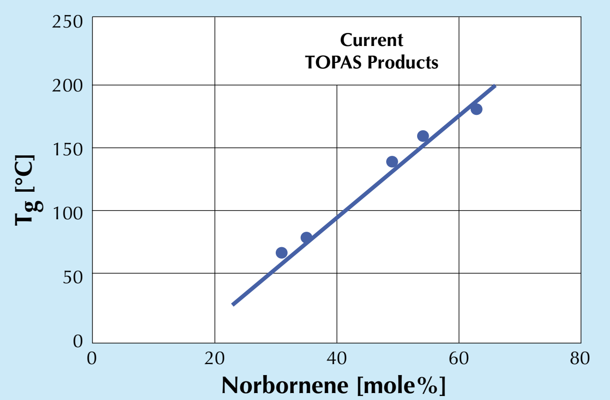


3.1.2 Thermal properties

Norbornene content is the key to controlling the thermal properties of TOPAS. The norbornene molecule is much bulkier than ethylene, and has a rigid ring structure. Norbornene is incorporated randomly on the main chain which prevents crystallization and makes the TOPAS structure amorphous. TOPAS does not exhibit a crystalline melting point. Norbornene also stiffens and strengthens the polymer and increases its Tg in proportion to its presence in the chain.

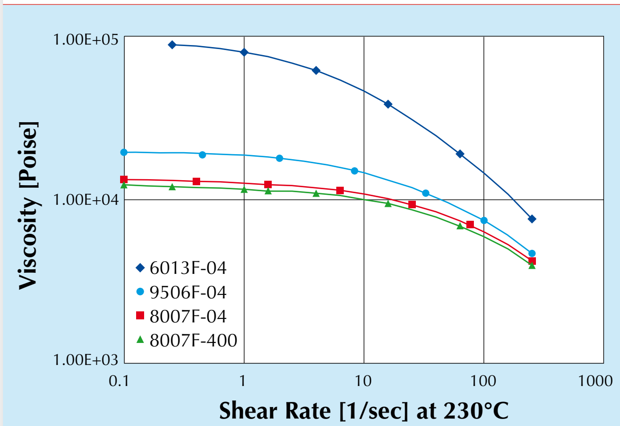
The advanced metallocene process for producing TOPAS is flexible and allows for various norbornene/ethylene ratios. The higher this ratio, the higher the Tg and HDT. Commercial TOPAS grades have Tg's

Figure 3: TOPAS glass transition temperature (Tg) as a function of norbornene content



from 65 to 178°C and HDT's from 60 to 170°C respectively. Although modulus is slightly higher for the higher Tg grades, the application-dependent use temperature is typically the major determining factor in grade selection.

Figure 4: Viscosity as a function of shear rate for various TOPAS grades

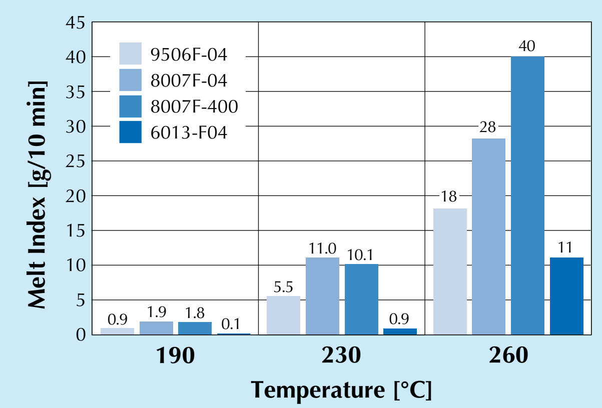


3.1.3 Rheology

The melt viscosity of TOPAS is a function of molecular weight and Tg at any given measurement temperature. The relationship between viscosity and shear rate is illustrated in Figure 4.

TOPAS is often utilized as a blend component or coextruded with conventional polyolefins for which melt index (MI) is commonly utilized to match flow characteristics. Several grades of TOPAS have MI values in the range most often utilized in extrusion grades of polyethylene as illustrated in Figure 5. Due to its amorphous structure the temperature dependence of MI is higher for TOPAS than for typical semicrystalline polyolefins, a fact which needs to be considered when choosing materials and process temperatures.

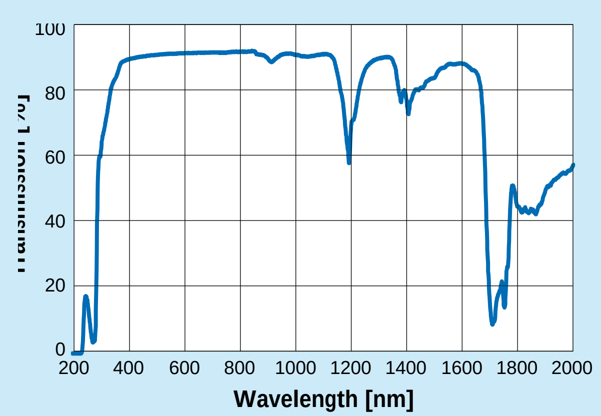
Figure 5: Melt Index (g/10 min) of TOPAS at standard polyolefin measurement conditions



3.1.4 Optical properties

TOPAS forms clear, colorless films which are finding utility in optical films for a variety of uses such as retardation, polarization, and brightness enhancement. Their light transmittance as shown in Figure 6 extends through the visible spectrum into the near UV and exceeds that of polystyrene (PS), polycarbonate (PC), and nearly equals that of polymethyl methacrylate (PMMA). TOPAS films have low birefringence and very low haze.

Figure 6: Light transmission of TOPAS 8007F-04

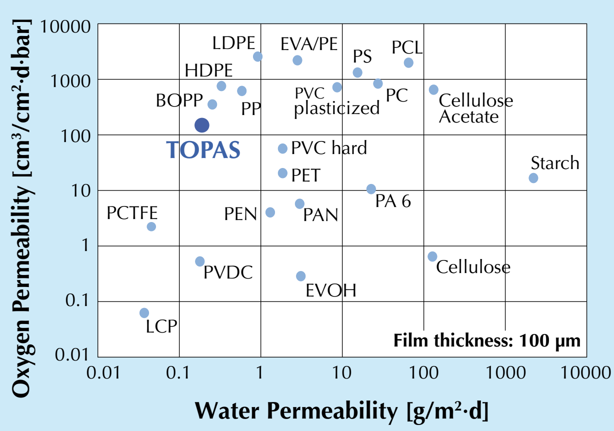


3.1.5 Barrier properties

TOPAS is being increasingly utilized as a barrier material in packaging. Packaging must preserve the taste, flavor and composition of packaged foods and the composition of non-food items such as fragrances. It must prevent excessive amounts of oxygen, water, solvents, flavors, aromas and other gases or liquids from leaving or entering a package. This has become more important as food packaging has moved away from heavy, inflexible glass and metal containers to those made of plastic. Such packaging often involves sophisticated, multilayer structures containing high-barrier polymers like EVOH and PVdC. These structures can be costly, require adhesive polymers, advanced and expensive processing equipment, and reduce the potential for recycling.

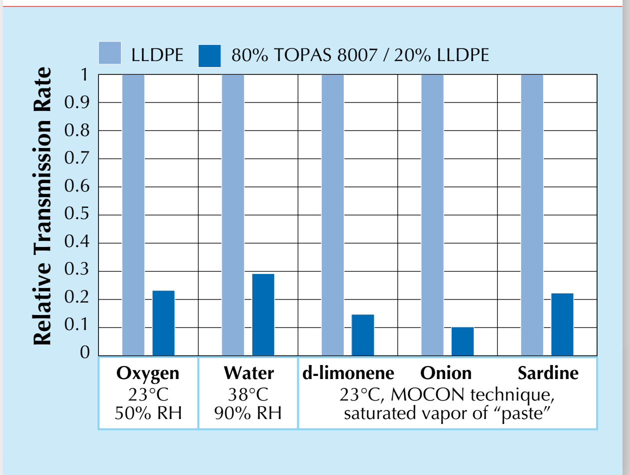
TOPAS has one of the highest moisture barriers of any polymeric material. While not considered a high barrier to oxygen or other gases, it is a significantly better barrier than polyethylene and can be used in blends to modify oxygen, carbon dioxide and other gas transmission rates to target specific values such as those required by fruits and vegetables.

Figure 7: TOPAS is one of the best polymeric water vapor barriers



TOPAS has four to five times better barrier than LDPE over a broad range of permeants and does not require an adhesive in combinations with polyethylenes. Blends with polyethylene having more than 70% TOPAS typically provide over 90% of the barrier of pure TOPAS. This can dramatically improve the performance of a packaging film in preserving the original characteristics of a package's contents or moderating the transfer or loss of aromas and odors as illustrated in Figure 8. TOPAS barrier layers can compensate for the poor water vapor transmission performance of commonly used oxygen barrier materials such as nylon and EVOH.

Figure 8: Relative transmission rate of TOPAS/LLDPE blends compared to those of pure LLDPE



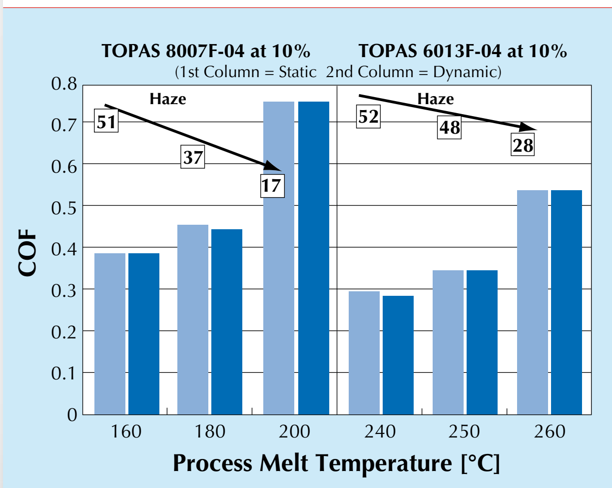
3.1.6 Deadfold

TOPAS has a high modulus which can be utilized to produce a film with the deadfold characteristics required by twist-wrapped candy. These applications often require an expensive cellophane film. A film having thin outer TOPAS layers (20 to 40% of total thickness) and a PE core has excellent deadfold, clarity, recyclability and a high gloss surface with good metallizability. These TOPAS-based twist films have proven to be processable on commercial high-speed wrapping lines designed for cellophane where conventional polyolefin films fail.

3.1.7 Coefficient of friction

TOPAS can reduce the coefficient of friction (COF) to commercially acceptable levels in cast PE films. Blending in ~10% TOPAS by weight can produce medium-slip films useful for vertical form-fill-seal operations (a COF of 0.2 to 0.4). A process melt temperature of no more than about 180°C is needed for blends containing low Tg TOPAS grades, while a higher process melt temperature of up to 240°C can be used for blends with high Tg material. TOPAS resins are thus viable alternatives as non-migratory, non-contaminating slip additives when processed at relatively low temperatures. Lower temperature processing may affect haze, but does not affect printability or sealing properties.

Figure 9: COF reduction in LDPE using TOPAS



3

3.2 Chemical resistance

TOPAS is very pure because the metallocene catalyst used in its production is filtered from most grades after polymerization. It also is extremely low in extractables, e.g. hexane extractables are 0.3% or less and ash is nearly zero. It easily passes the European Pharmacopoeia Section 3.1.3 extractable test for polyolefins. It has excellent organoleptic properties. Tests with various food components have yielded lower extractables and similar scalping levels to those of standard PE resins.

As a non-polar material, TOPAS is highly resistant to polar compounds such as water, alcohol and acetone. Like most polyolefins, it is less resistant to nonpolar materials. TOPAS should be tested against specific compounds when chemical resistance is critical in an application.

Table 4: Chemical resistance of TOPAS

pH < 7 (acidic/aqueous)	hydrochloric acid 36%	+
	sulfuric acid 40%	+
	nitric acid 65%	+
	acetic acid > 94%	+
pH = 7 (neutral/aqueous)	water	+
	aqueous solution of soap	+
	saline solution	+
pH > 7 (basic/aqueous)	sodium hydroxide 50%	+
	ammonia (aq. sol.) 35%	+
Polar organic solvents	ethanol, methanol, butanol, isopropanol (short chain alcohols)	+
	acetone, butanone (short chain ketones)	+
Aromatic solvents	benzaldehyde	o
	toluene	–
	benzene	–
	chlorinated solvents	–
Non-polar organic solvents	pentane, hexane, heptane etc. (alkanes)	–
	gasoline (petrol ether)	–
	norbornene	–
Other	oleic acid	–

+	o	–
resistant increase of weight < 3% or loss of weight < 0.5% elongation at break not substantially altered	limited resistance increase of weight 3 to 8% or loss of weight 0.5 to 5% elongation at break reduced by < 50%	not resistant increase of weight > 8% or loss of weight > 5% elongation at break reduced by > 50%

3.3 Regulatory

Many TOPAS grades comply with industry certifications and national and international regulations for food, drug, and for use in medical devices. For details in the individual grades please contact our technical representatives.

TOPAS uses no ingredients (heavy metals) regulated by CONEG and uses no ingredients listed on California Proposition 65. It also uses no ingredients listed on the following EU Directives: WEEE – EU-Directive 2002/96/EC; RoHS – EU-Directive 2002/95/EC and EU-Directive 2003/11/EC.

Food packaging

Most TOPAS grades comply with all major regulatory food contact requirements. In the US, it complies with FDA regulation 21 Code of Federal Regulations (CFR) 177.1520 “Olefin Polymers” (3.9). TOPAS can be used in films, sheets and other articles made there from that come in direct contact with food under the U.S. FDA FCN #75. This applies to all types of food and all conditions of use. It also complies with FDA FCN #405 for food contact, which covers all applications, including bottles. These notifications allow TOPAS to be used in single-use and repeat-use applications. Its conditions of use span categories A to H in Table 2 of 21 CFR 176.170(c). The Tg of some TOPAS grades produces a practical use temperature limitation.

TOPAS is also suitable for food-contact applications in Europe, where the monomers used in its manufacture are listed in the EU Plastics Directive 2002/72/EC1/2 (6 August 2002) and the German "Bedarfsgegenständeverordnung" (23 December 1972). Manufacturers who use TOPAS should check any restrictions and migration rate limits on the finished article.

Pharmaceutical and medical packaging

TOPAS has undergone testing for use in medical and pharmaceutical applications. A U.S. FDA Drug Master File (DMF #12132) and a FDA Device Master File (MAF #1043) have been established for most TOPAS grades. In addition, several TOPAS grades have passed United States Pharmacopoeia (USP) Class VI biocompatibility protocols, including acute systemic, intracutaneous and implantation tests. Some grades have passed other biocompatibility tests as defined in ISO 10993, including those for sensitization, physicochemical effects, cytotoxicity and hemolysis. Certain grades have passed similar tests in accord with EU and Japanese protocols.

In the pharmaceutical sector, a structure containing TOPAS 8007F-04 has been used in and been in contact with a CDER-approved solid oral dose. TOPAS is widely used in medical devices and in medical device packaging.

3.4 Recycling

Most TOPAS packaging applications involve mixed structures with other polymers. Processors can blend TOPAS-containing scrap into their products at various rates. In general, this approach is most successful when TOPAS is blended with olefin-based polymers.

Post-consumer recycling depends on the polymers with which TOPAS is combined. Although many blends and multilayered structures should be coded "7" under the SPI system, certain PE combinations may use the code of the majority PE component. For instance, a LDPE structure having a minor amount of TOPAS may retain a SPI recycle code of "4".

If it is not practical to recycle a TOPAS-containing product, TOPAS may safely be incinerated in municipal waste disposal systems. It contains only carbon and hydrogen (no chlorine or other halogens are present). When combusted completely, it yields carbon dioxide and water and releases well over 23,000 kJ/kg (10,000 BTU/lb).

4. Processing

4.1 Drying

TOPAS requires no drying. It should not be stored in an extremely high temperature environment, as pellet sticking may result.

Extrusion of discrete layers of high Tg grades (TOPAS 6013F-04) may call for degassing to remove oxygen that can cause bubbles in the melt. This is best done by heating the polymer in a vacuum dryer or a nitrogen-purged dryer for 4 hours at 20 to 30°C below the HDT of the TOPAS grade. Alternately, use the same drying conditions with a desiccant dryer.

4.2 Cast film extrusion of TOPAS/PE blends

Each of the TOPAS grades suitable for cast film blends has its own process requirements. It is best to choose a grade based on process viscosity and the end-use properties needed. Most polyethylenes have excellent compatibility with TOPAS in blends. Good results have been demonstrated using PEs having melt indices of 1.0 to 6.0 g/10 min at 190°C and densities of 0.895 to 0.965 g/cc.

The start-up conditions in Table 5 are recommended when processing TOPAS blends as cast film at film thicknesses of 25 to 250 microns (1 to 10 mil). When extruding PE-rich blends, it is important that the extruder temperatures in the first few zones of the extruder are no lower than recommended in the table below. This will ensure thorough melting of the TOPAS pellets. Higher temperatures may be used if desired for overall processing, as TOPAS is thermally stable and has been processed at up to 320°C on extrusion coating lines. Higher melt and casting roll temperatures are recommended for best clarity with higher-Tg TOPAS grades.

- Barrier mixing screws work best, where the advancing melt pool is separated from unmelted pellets. Maddock mixing sections have proven effective.
- Use a screw L/D ratio of 24:1 or above and a low compression ratio for optimum melt homogeneity.
- Use typical coathanger dies.
- Use a draw down ratio (DDR) of 2:1 to 20:1, depending on final thickness.
- Casting roll temperatures of 40 to 50°C work well for TOPAS/PE blends.

Table 5: Cast film temperature profiles for polyethylene-rich blends (5-25% TOPAS)

TOPAS Grade 5-25%	Tg [°C]	Melt Index [g/10 min] at 190°C	Melt Index [g/10 min] at 230°C	Rear Temp. [°C]	Center Temp. [°C]	Front Temp. [°C]	Adapter Temp. [°C]	Die Temp. [°C]
9506	65	0.9	5.5	190-200	200-210	200-210	200-210	200-210
8007	78	1.9	11.0	200-210	220-230	220-230	220-230	220-230
6013	138	0.1	0.9	200-210	250-260	250-260	250-260	250-260

4.3 Cast film extrusion of discrete TOPAS layers

As an amorphous thermoplastic, TOPAS lacks crystallinity and a defined melting point. It softens as temperature rises over a range depending on Tg. For discrete TOPAS layers or TOPAS-rich blends, process temperatures usually depend primarily on the Tg of the TOPAS grade. The minimum processing temperature for extrusion processing TOPAS is generally 120°C or more above the Tg of the grade used. Best solids conveying occurs at relatively high rear zone temperatures. Higher melt and casting roll temperatures generally give the best clarity.

Several TOPAS grades are suitable for extruding as discrete layers in multilayer films. Choose the grade having a viscosity curve most comparable to the other polymers in a structure to minimize instabilities between film layers. TOPAS 8007F-400 is a specially formulated grade for easy processing in discrete layers over a broader range of extruder types and conditions. For other grades a low molecular weight amide wax powder lubricant dusted on pellet surfaces at 0.1 to 0.2% aids lubricity in the feed section of the extruder and can result in improved film quality. Lubricants usually are not needed in blends containing over 20% polyethylene. Other process aids can be used. Equipment recommendations are the same as for TOPAS/PE blends. Recommended start-up conditions for discrete TOPAS layers or high TOPAS content blends (> 65% TOPAS) as cast film for film thicknesses of 25 to 250 microns (1 to 10 mil) are given in Table 6.

Table 6: Cast film temperature profiles for discrete TOPAS layers

TOPAS Grade	Tg [°C]	Melt Index [g/10 min] at 190°C	230°C	Rear Temp. [°C]	Center Temp. [°C]	Front Temp. [°C]	Adapter Temp. [°C]	Die Temp. [°C]
9506	65	0.9	5.5	210-220	230-240	230-240	230-240	230-240
8007	78	1.9	11.0	210-220	230-240	230-240	230-240	230-240
6013	138	0.1	0.9	210-220	260-270	260-270	260-270	260-270

4.4 Blown film extrusion

TOPAS also performs well in blown film extrusion systems. General processing recommendations given for cast film and the cast film starting temperature profiles given in Table 5 (PE-rich blends) and Table 6 (Discrete TOPAS layers) can also be used for blown film. The key new variables are bubble stability and bubble collapsing. TOPAS has lower melt strength than LDPE and the melt strength of other polymers in the film structure will strongly influence bubble stability. Increased melt temperatures generally give the best clarity with higher Tg grades. Bubble stability will determine the maximum possible melt temperature.

Structures containing high levels of TOPAS or discrete layers of TOPAS can be stiff and cause challenges in achieving wrinkle-free layflat. In general, keeping the film warmer in the collapsing area helps the collapsing process. Collapsing equipment designed to handle stiff films such as nylons and HDPE will generally produce better results with stiff TOPAS structures. Additional equipment recommendations are as follows:

- Barrier mixing screws work best, where the advancing melt pool is separated from unmelted pellets. Maddock mixing sections have proven effective.
- A preferred screw has a screw L/D ratio (screw length to diameter) of 24:1 or above and a low compression ratio for optimum melt homogeneity. A standard blown film tower can be used.
- Grooved feed extruders are not preferred but may be used with improved processibility grades such as 8007F-400. Heated feed zones are sometimes required for good processability in grooved feed extruders.
- Use typical spiral dies and die gaps of 1.5 to 2.25 mm (60 to 90 mils).
- Recommended blow-up ratio (BUR) is 2:1, but good results have been achieved at 1.5:1 to 3.5:1.

4.5 Extrusion coating

TOPAS 8007F-400 is recommended for extrusion coating applications because of its relatively low water vapor transmission rate (WVTR), stiffness and curl control. It has four times the water vapor barrier of LDPE, the most common extrusion coating material. When used as a discrete layer (100% TOPAS or 80% or more TOPAS blended with LDPE), it significantly reduces WVTR at a low coating weight.

TOPAS as a stiff, low shrinkage, amorphous material can help reduce the shrinkage of semicrystalline polyolefins when added as a blend component. This is advantageous when coating is done on lightweight papers, which are subject to curling. Adding 10 to 20% TOPAS can make the difference between a high-curl product and a product that lays flat.

TOPAS can be processed at normal polyethylene processing conditions but lacks the melt strength of a LDPE or HDPE, so it is typically not used as a monolayer extrusion coating. In a LDPE/TOPAS/LDPE coextruded structure, the LDPE adds melt strength and the TOPAS adds water barrier. This structure does not alter the adhesion characteristics of the coating to the substrate.

Direct bonding of TOPAS to paper requires a strong pretreatment with flame, corona, ozone, or a combination of these. Blends containing at up to 40% TOPAS 8007F-400 in extrusion coating grades of LDPE (MI of 5 to 10) have good melt strength (low neck-in and good edge stability) and can be processed at the same conditions as LDPE alone but may have reduced adhesion strength.

4.6 Additives

TOPAS can be modified with additives to fit specific requirements. Its coefficient of friction and blocking properties can be modified with many of the same slips and antiblocks used in polyethylene. Specialty additives such as processing aids, antioxidants, antistats, and impact modifiers have been utilized with TOPAS and should be considered on an application dependent basis.

4.7 Purge and shutdown

TOPAS is a very stable resin, and is highly resistant to formation of "gels" as often seen in extrusion of PE and certain other resins. However, it may be desirable to purge TOPAS from extrusion equipment for transitions or shutdown. To purge equipment after running TOPAS, one may use a purge blend containing 50% 1 MI LLDPE and 50% of a typical PE purge compound. For a shutdown blend, one may use 50% 0.25 MI, LDPE and 50% of a standard PE antioxidant masterbatch. Follow these procedures for purge and shutdown:

Step 1 ▸ Reduce rear zone temperature to 205°C (400°F) and introduce the purge blend. Retain existing temperatures on the rest of the extruder and die. Purge for about 20 to 30 minutes.

Step 2 ▸ Reduce all temperatures to 177°C (350°F) and introduce the shutdown blend. Continue to run until the extrudate is clear and machine temperature is below 190°C (380°F).

Step 3 ▸ Shut down. **Do not** run the equipment dry.

Step 4 ▸ For equipment start-up, heat the extruder and other equipment to 180°C (360°F) and heat soak for the required time. Start the extruder with the shutdown blend and raise it to the desired temperature. Follow the shutdown blend with an LDPE (preferably one with a melt index between 2 and 3), run for about 15 to 20 minutes and then introduce TOPAS.

4.8 Troubleshooting

TOPAS is an easy-to-run material. If problems arise during processing, take the steps described below to resolve them. If problems persist, please contact a TOPAS technical representative.

Table 7: TOPAS film and sheet: troubleshooting guide

Issue	Potential solution	Explanation
Particles (unmelt, or 'gels') in extrudate	Raise extruder temperatures Adjust MI of PE in PE-rich blends	Temperatures in the early zones (1, 2, 3) are critical in softening the resin. Unmelts flush out readily once proper conditions are found.
	Raise extrusion pressure ("back pressure")	For lines without a melt pump, a change to finer screens at the screen pack can increase pressure. Increase screw speed.
	Preheat TOPAS pellets	A resin dryer can be used to give the resin a boost toward its Tg.
Haze/Optics	Lower extrusion temperatures, decrease cooling roll temperature	Can be effective at low TOPAS percentages (< 20%) in blends with PE and discrete layers of 8007F-400.
	Dry resin	Rare issue that can occur with high-Tg grades. TOPAS is non-hygroscopic and in this case drying is actually de-oxygenation.
	Increase extrusion temperatures	Higher melt temperatures typically give the lowest haze with grades other than 8007F-400
Purging TOPAS after run	Most PE and PP resins work well	LDPE with antioxidant concentrate can be used for shutdowns.
Degradation/Gels	Rarely encountered due to stability	"Gels" are usually unmelts (see above for solutions).
Moisture in resin	TOPAS is very moisture-resistant	If pellets themselves are wet, drying is suggested.
Surging of extruder/Pressure variation	Raise extruder temperatures	Temperatures in the early zones (1, 2, 3) are critical in softening the TOPAS resin to stabilize melting behavior. A high quality, uniform temperature melt will produce a more uniform output.
	Lower extruder temperatures (early zones)	If using a resin blend, the non-TOPAS material may start to bridge in the feed throat or plug the screw flights in the feed zone. This can often be diagnosed through visual observation.
	Raise extrusion pressure ("back pressure")	For lines without a melt pump, a change to finer screens at the screen pack can increase pressure. Usually, 10.4 MPa (1500 psi) is sufficient.
	Check filters for plugging	A coarser mesh screen may be needed in this case.
	Preheat TOPAS pellets	A resin dryer can be used to give melting a head start.
Brittleness	Use lower Tg TOPAS	Higher Tg resins are stiffer, and hence more brittle.
Curl	Use TOPAS on both sides of structure	The amorphous TOPAS resin reduces shrinkage of the structure.
Low interlayer adhesion in coex structures	Change PE type or use a tie layer	Adhesion of TOPAS to LLDPE is higher than to LDPE and HDPE. Conventional PE tie layers can also be used.
Die deposits	Dry resin and extrude under nitrogen	Rare issue, seen with high-Tg grades. Drying works by removing absorbed oxygen from the polymer. Fluoropolymer process aids can produce improvement. Vacuum venting can also reduce deposits.

5. Secondary operations

5.1 Thermoforming films and sheet

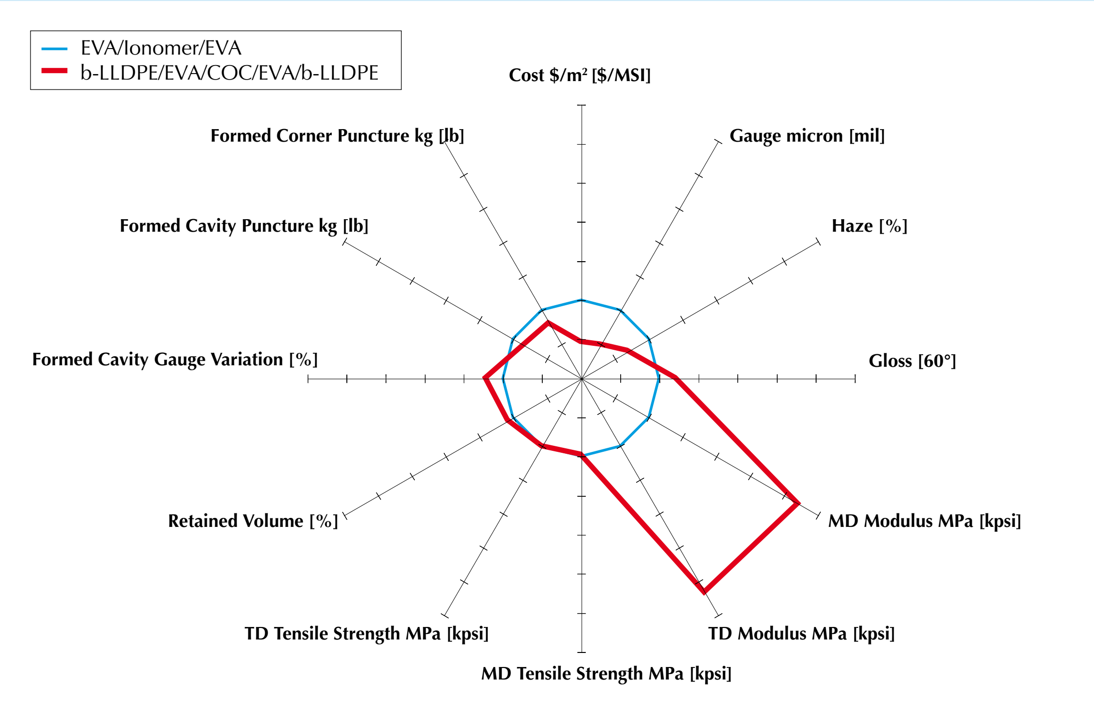
TOPAS offers many thermoforming advantages. As an amorphous polymer, its broad softening and melting range enable a wide thermal window prior to forming, unlike the narrow range typical of semicrystalline materials like HDPE, PP and PE. Its wide processing window enables good formability and less gauge variation in the formed cavity.

TOPAS thermoforming grades vary in molecular weight and have a Tg range of 65 to 138°C. TOPAS films and sheeting can be thermoformed from about 85 to 200°C, so it can be used in low- and high-temperature processes, which is markedly different than crystalline polyolefins.

5.1.1 Multilayer films

Monolayer TOPAS films and sheeting create clear and stiff packaging having exceptional moisture, alcohol and aroma barrier. These benefits can be captured in multilayer structures having one or more TOPAS layers. TOPAS can be coextruded without tie adhesive layers and adheres to LLDPE, LDPE, EVA, HDPE and SBC. Adhesion issues with these materials can usually be corrected by adjusting processing conditions and flow properties. If this does not resolve the issue, any adhesive commonly used with PE will work with TOPAS. Tie layers may be needed when it is coextruded with polypropylene homopolymer (it adheres well to polypropylene random copolymer) and when draw depth and area draw ratio is aggressive.

Figure 10: TOPAS improves stiffness, appearance and part uniformity at lower gauge



With polypropylene homopolymer, LLDPE with a MI of 4 or above is an effective tie layer, although commercial anhydride-grafted tie resins are also used.

TOPAS and PET (including PETG and APET) can be bonded with ethylene-methyl acrylate (EMA) polymers having 25% or more methyl acrylate and a melt index of 5 or above. Tie resins recommended for PE-PETG interfaces have also proven successful. For adhesion to other polymers, consult suppliers of tie layer materials and ask for tie recommendations between the polymer of interest and polyethylene.

Many multilayer structures can be made with TOPAS, which enhances formability and reduces gauge variation. Discrete TOPAS layers often improve appearance by lowering haze and increasing gloss. Such layers may enhance the stiffness of the overall structure, depending on the location of the TOPAS layer(s), which allows for downgauging and significant cost savings.

5.1.2 Monolayer blends

TOPAS is compatible with most polyolefins, so lower cost polymers not often found in thermoforming applications may be used. TOPAS can be melt blended in any ratio with LDPE, EVA, LLDPE, PP and HDPE. TOPAS-rich monolayer blend films and sheeting are usually tougher than TOPAS alone, yet retain much of the TOPAS barrier, stiffness and forming properties.

PE-rich monolayer films and sheeting have excellent forming properties. Thermoformed parts from monolayer LLDPE-TOPAS films having as little as 15% TOPAS have low gauge variation, added stiffness, and high dimensional stability with little or no snap back. Such improved performance can be expected from all grades of LLDPE, regardless of comonomer or catalyst.

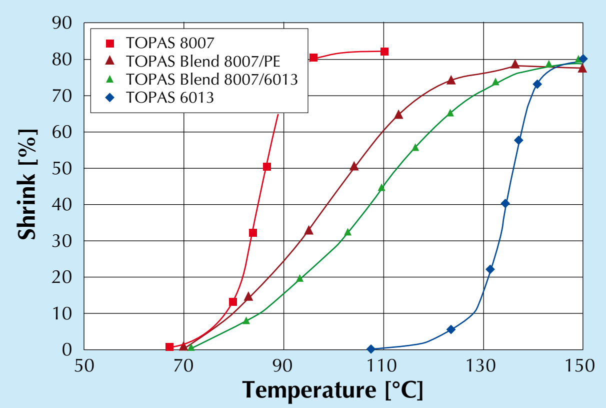
5.2 Orientation and shrinkage

TOPAS orients readily at appropriate temperatures above its Tg. Its broad grade range (Tg from 65 to 138°C) allows orientation and shrink temperatures to be tailored to a process and a product. Shrink temperature curve steepness can be controlled precisely by blending TOPAS grades, as illustrated in Figure 11. Shrinkage rates can also be influenced by blending TOPAS with other polymers.

TOPAS 8007F-04 and 9506F-04 have been monoaxially and biaxially oriented in flat (tenter, and machine direction stretcher) and tubular (double bubble) processes. Orientation increases ductility, while adding some stiffness. As a monolayer in biaxial processing, TOPAS orients best at about a 4x4 ratio. Higher orientation ratios are attainable when TOPAS is a layer or component of a multicomponent structure, e.g., skin layers of TOPAS can be oriented at a 5x10 ratio in OPP tentering and other processes.

TOPAS has high shrink recovery. In monoaxially oriented labels, shrinkage of over 80% is possible. Its shrink stress can be less than half that of competing materials, provided it is not oriented at too low a temperature. Inherent high dimensional stability is useful in shrink applications by reducing film shrinkage below its Tg, e.g., in warm storage conditions.

Figure 11: Shrinkage performance of oriented film can be adjusted with blends of TOPAS grades



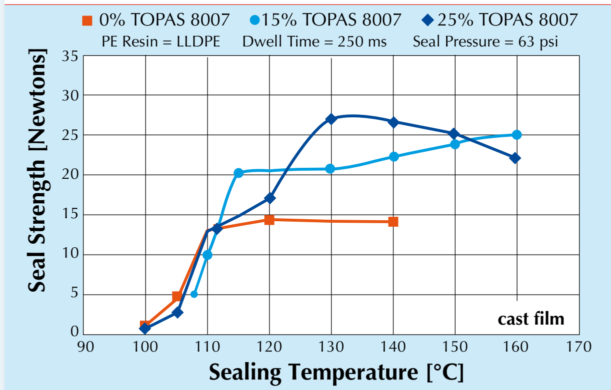
5.3 Sealing

Heat-sealing capability is usually specified by seal strength, hot tack strength and seal initiation temperature. As it cools, TOPAS transitions from a rubbery to a glassy state to create a high-modulus material at 65°C (TOPAS 9506) to 78°C (TOPAS 8007). This adds significant seal strength at temperatures where PE has low strength and modulus.

When blended with PE, TOPAS broadens the seal temperature range of many polyethylenes. Figure 12 shows a typical case where the seal range for pure LLDPE is extended and the seal strength is also noticeably higher. TOPAS often improves hot tack performance (strength of the hot seal after cooling for 0.1 sec.) as much as 100%. Hot tack strength is important in vertical form, fill and seal equipment where contents are dropped into bags while the seal is still hot. The more robust sealing performance with TOPAS is valuable in a wide range of "real-world" packaging situations.

When an all-TOPAS surface layer is used in a packaging film, the film can be sealed to itself much like a PE film. For example, TOPAS 8007F-04 seals to itself at a seal initiation temperature of 105°C (defined as seal temperature where 8.8 N seal strength is achieved). The seal strength of the TOPAS-TOPAS seal is similar to that of LDPE and LLDPE. It also has good hot-tack strength. The high modulus of TOPAS means the seal may not be as tough as that of other materials, although the seal will be hermetic.

Figure 12: Addition of TOPAS improves seal properties



5.4 Sterilization

TOPAS can be sterilized by all common methods, including gamma radiation, e-beam or beta irradiation, ethylene oxide and steam as shown in Table 10. It is relatively stable to gamma irradiation at a dosage to 5 Mrad. Its tensile strength, Izod impact strength and other mechanical properties show little change after exposure and after 12 months aging. It does yellow slightly immediately after exposure, but this fades over several days to nearly the initial color.

TOPAS 6013 can be steam sterilized, typically at 121°C for 20 minutes. The procedure for sterilizing TOPAS calls for venting the steam with dry air above 120°C. Drying should last about 60 minutes, depend-

Table 8: Sterilization of TOPAS

TOPAS	Hot steam			ETO	High-energy radiation	
	121°C	134°C	143°C		Gamma	Electrons
8007	-	-	-	+	+	+
6013	+	-	-	+	+	+

ing on size and thickness, to gain the desired clarity before cooling to room temperature. For thermal sterilization, air pressure in the autoclave should match the steam pressure.

E-beam or beta irradiation causes TOPAS to yellow slightly. The color fades to the original color in about 10 days. The intensity of the color shift is proportional to dosage. TOPAS is unaffected by ethylene oxide sterilization and the temperatures this involves (above 60°C in some cases).

5.5 Vacuum metallizing

TOPAS-based film usually outperforms other polyolefins in decorating, printing and other secondary operations. It delivers a clean, hard surface, high stiffness, and thermal stability.

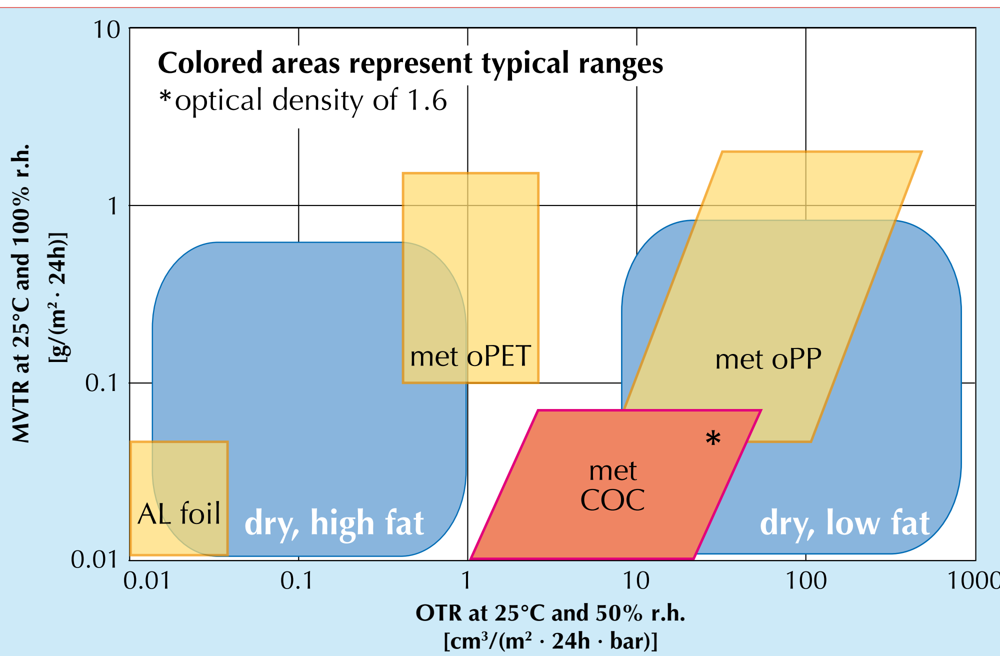
Attractive metallic coatings, usually aluminum, may be applied to TOPAS. Vacuum aluminum metallization of TOPAS has been performed without surface treatments such as flame or corona and when corona is used its effects last significantly longer than on polyethylene. The economic advantage of direct metallization without pretreatment, plus exceptionally low shrinkage over a wide range of HDTs, sets TOPAS apart from other polyolefins.

TOPAS film is ideal for aesthetic uses calling for high clarity, gloss and reflection. In twist-wrapped candies, for example, it produces a sleek, shiny, metallized surface and the excellent deadfold needed for clear twist closures.

When metallized, cast or blown films with TOPAS skins yield barriers equal or superior to metallized OPP applications for dry foods with low fat content, making TOPAS-containing film a cost-effective candidate for packaging dry foods such as crackers, rice, coffee, cereal, pet food, snacks and dry mixes.

5

Figure 13: Gas and moisture barrier of metallized TOPAS



5.6 Printing

Printing is usually difficult on traditional PE film because it lacks sufficient modulus, is not thermally stable, and must be carefully dried in an oven to drive off the ink solvent. In contrast, TOPAS provides a superior printing surface by improving flatness, increasing temperature resistance and providing a glossy, high quality surface.

TOPAS can also be blended with olefins to raise thermal resistance and modulus, which aids web handling and reduces film elongation under tension for better print registration since adding as little as 10% TOPAS to LLDPE doubles film modulus. Like other olefins, TOPAS films require pretreatment with corona or plasma before printing. Their low moisture absorption, high modulus and heat resistance can overcome film processibility problems and deliver more consistent yields. Standard polyolefin ink systems are effective for TOPAS and TOPAS/PE blends.

5.7 Electrical properties

TOPAS COC has very good electrical insulating properties and a low dissipation factor. High-Tg grades of TOPAS are particularly useful as an insulating material. The dielectric constant is around 2.35 and this value remains relatively constant in the high frequency area up to 20 GHz. Electrically, TOPAS film has a low dissipation factor that holds steady with temperature. TOPAS films have the unique property of high surface charge retention, offering electret-like performance which finds utility in applications such as air filtration media.

6. TOPAS applications

Quality packaging delivers both environmental and physical protection of the product inside the package. Environmental protection takes the form of keeping desirable components inside the package, while keeping undesirable contaminants out. This often requires some level of barrier to substances such as moisture, oxygen, chemicals or aromas. Meanwhile, physical protection is achieved through use of a sufficiently rigid or protective package structure that can withstand physical and thermal demands and still deliver the surface properties needed for an appealing, easy-to-produce package. The unique properties of TOPAS allow it to enhance both the environmental and physical aspects of a broad variety of packages, and do so in a very cost-effective manner.

Polyethylene remains one of the major polymers utilized in food packaging but it has disadvantages in that it is a relatively poor barrier and often lacks desired mechanical properties. TOPAS is now being utilized in a large variety of packaging structures that overcome limitations of previously existing packaging materials over a broad area of applications. TOPAS compatibility with polyethylene can often produce a simpler, lower cost package with improved functionality while maintaining recyclability.

6.1 Food

TOPAS improves food packaging by adding barrier, stiffness, puncture resistance, and clarity, and by improving film processibility in package production operations such as forming, sealing, cutting, and folding.

TWIST WRAP

Description:	Multilayer twist/fold wrap films for candy
Advantages:	▸ Excellent deadfold for twist retention ▸ High transparency and gloss ▸ Superior value versus cellophane, HDPE and PVC
Material:	TOPAS 8007F-04 and 8007F-400
Customer:	Constantia Flexibles

POUCH

Description:	Multilayer pouches with TOPAS/PE sealant layer
Advantages:	▸ Improved stiffness ▸ Potential for downgauging ▸ Excellent clarity and gloss ▸ Controlled easy tear properties
Material:	TOPAS 8007F-04 and 8007F-400
Customer:	New England Extrusion (NEX)

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FORMING WEB

Description:	Formable bottom web for meat packaging using a blend with LLDPE in a multilayer film having an oxygen barrier
Advantages:	▸ Excellent thermoformability ▸ Improved toughness ▸ Puncture resistance ▸ Potential for downgauging
Material:	TOPAS 8007F-04, 8007F-400 and 9506F-04
Customer:	Not disclosed

6.2 Healthcare

Packaging for medicines and devices must meet such demanding criteria as biocompatibility, protection against external influences, optimum shelf life, clear identification, and easy handling and dispensing. For medicines in tablet form, blister packs have become increasingly desirable because they easy and safe for patient use, and help patients comply with dosage recommendations. Modern medical devices often require protection from moisture, while clarity is desired for ease of identification and quality control.

TOPAS blister films provide high moisture barrier, are crystal clear, physiologically inert, and can be produced and disposed of in an environmentally friendly way. TOPAS films used in pharmaceutical blister packs usually have thin PP or HDPE outer layers and an interior layer of pure TOPAS or TOPAS blended with PE. For medical trays, TOPAS is combined with outer layers of PETG or SBC for clear deep draw packaging with outstanding moisture barrier.

TOPAS significantly improves thermoforming uniformity and film stiffness when used in blends or discrete layers. This provides improved barrier performance due to decreased corner thinning and opportunities for downgauging while maintaining tactile stiffness in many formed packages. Clarity and high gloss enticingly display health, beauty, and medical products in many types of formed packages, including forming webs.

PHARMACEUTICAL BLISTER

Description:	TOPAS as moisture barrier in multilayer coextruded or laminated films
Advantages:	▸ Excellent moisture barrier ▸ Good thermoformability ▸ High purity ▸ Halogen free ▸ High clarity
Material:	TOPAS 8007F-04
Customer:	Alcan Pharmaceutical Packaging, Klöckner Pentaplast, Tekni-Plex

STERILIZABLE BLISTER

Description:	Steam sterilizable thermoformed blister packs
Advantages:	▸ No shrinkage or distortion of blister film during steam sterilization (121°C/20 min) ▸ High moisture barrier ▸ Excellent forming ▸ Polyolefin solution ▸ Contact clarity
Material:	TOPAS 6013F-04
Customer:	Not disclosed

MEDICAL FORMING WEB

Description:	Forming webs for medical device packaging made from TOPAS/PE blends
Advantages:	▸ Good forming properties ▸ Limited shrink back ▸ Excellent stiffness ▸ Downgauging ▸ Easy tear
Material:	TOPAS 8007F-04, 8007F-400
Customer:	Not disclosed

MEDICAL TRAY

Description:	Clear thermoformable barrier film with deep draw capability
Advantages:	▸ Excellent clarity ▸ High moisture barrier ▸ Retains barrier and optics in deep draw ▸ Good formability
Material:	TOPAS 8007F-04
Customer:	Tekni-Plex

6.3 Consumer

TOPAS delivers solutions over a wide range of packaging needs beyond food, healthcare and personal care. In the fast-growing area of shrink film and shrink labels, TOPAS allows the combination of excellent shrink characteristics and good aesthetics in a halogen-free, easily recyclable film. Stiffness and high temperature capability are being utilized in applications as disparate as foam containers suitable for high temperature (> 100°C) microwaving, to improved quality plastic zippers. TOPAS is a valuable new tool in the packaging engineer's toolbox, providing more versatility than ever in the design of functional, environmentally friendly packaging.

SOFT SHRINK

Description:	High performance multilayer polyolefin shrink film
Advantages:	▸ High shrinkage ▸ Low shrink force ▸ Low shrink temperature ▸ Tough and stiff ▸ Clarity
Material:	Not disclosed
Customer:	Cryovac

SHRINK SLEEVES & LABEL

Description:	Oriented polyolefin films for container labeling
Advantages:	▸ High shrinkage ▸ Low shrink force ▸ Low density for easy recycling ▸ Printability
Material:	TOPAS 9506F-04
Customer:	Not disclosed

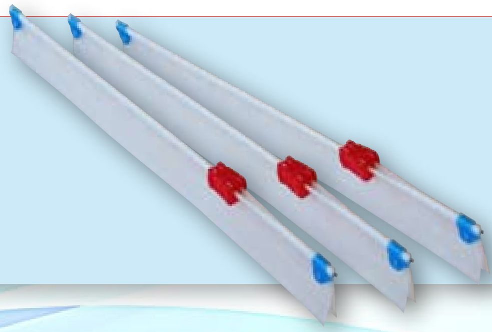
EASY TEAR

Description:	Linear tear pouch with TOPAS-enhanced sealant film
Advantages:	▸ Easy opening ▸ Controlled and linear tear ▸ Improved stiffness
Material:	TOPAS 8007F-04
Customer:	Wipf

COATED PAPER

Description:	Paperboard extrusion coated with TOPAS for barrier applications
Advantages:	▸ Moisture barrier 5x better than LDPE ▸ Less curl ▸ Lower disposal fee (DSD recycling)
Material:	TOPAS 8007F-04, 8007F-400
Customer:	VG Nicolaus

ZIPPER



Description:	Zippers for food and consumer goods
Advantages:	▸ Shrinkage control (reduced camber) ▸ High strength for heavy bags ▸ Mechanical strength and stiffness
Material:	TOPAS 6013F-04
Customer:	Pactiv

FOAM

Description:	Heat resistant foam containers and trays
Advantages:	▸ Improved heat resistance ▸ Strength and stiffness ▸ Low density (ca. 0.1 g/cm³) ▸ Good thermoforming
Material:	TOPAS 6013F-04
Customer:	Not disclosed

7. Subject index

8. Figure and table index

9. Conversion table

Unit conversion factors

		← Multiply by / Divide by →	
Length	Meter (m)	0.0254	Inch (in)
		0.3048	Foot (ft)
Area	Square meter (m^2)	6.45×10^{-4}	Square inch (in^2)
		0.0929	Square feet (ft^2)
Volume	Cubic meter (m^3)	1.64×10^{-5}	Cubic inch (in^3)
		0.0283	Cubic feet (ft^3)
Mass	Kilogram (kg)	0.4535	Pound (lb)
Force	Newton (N)	4.448	Pound force (lb)
		9.807	Kilogram force (kg)
Pressure	Pascal (Pa)	=	Newton/meter^2 (N/m^2)
		9.81×10^4	kg_f/cm^2
		10^5	Bar
		$6{,}897 \times 10^3$	lb_f/in^2 (psi)
	Megapascal (MPa)	$6{,}897 \times 10^{-3}$	lb_f/in^2 (psi)
Viscosity	Pascal second (Pa s)	0.1	Poise
Energy	Joule (J)	4.187×10^3	Calorie (cal)
	Kilojoule/kilogram (kJ/kg)	4.187×10^3	Calories/gram (cal/g)
	Joule/kilogram (J/kg)	2.33×10^3	btu/lb

Tensile or flexual property conversion

Strength										
MPa	75	100	125	150	175	200	225	250	275	300
psi	10,900	14,500	18,100	21,800	25,400	29,000	32,600	36,300	39,900	43,500
Modulus										
MPa	6,000	8,000	10,000	12,000	14,000	16,000	18,000	20,000	22,000	24,000
psi x 10^6	0.87	1.16	1.45	1.74	2.03	2.32	2.61	2.90	3.19	3.48

Length conversion

inches	mils	cm	mm
1 (1)	1000	2.54	25.4
1/2 (0.5)	500	1.27	12.7
1/4 (0.25)	250	0.64	6.4
1/8 (0.125)	125	0.32	3.2
1/16 (0.0625)	62.5	0.16	1.6
1/32 (0.0313)	31.3	0.08	0.8
1/64 (0.0156)	15.6	0.04	0.4

Temperature conversion

Conversion factor: °F = 1.8 (°C) + 32

Degrees Centigrade (°C)	0	10	20	50	75	100	125	150	175	200
Degrees Fahrenheit (°F)	32	50	68	122	167	212	257	302	347	392

Notes

Other TOPAS literature is available.
Please refer to our website for an electronic version or contact your TOPAS representative.

TOPAS
Product brochure

TOPAS
Medical brochure

TOPAS
Diagnostic brochure

TOPAS
Optical brochure

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Starch-based completely biodegradable polymer materials

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Abstract. Starch is a natural polymer which possesses many unique properties and some shortcoming simultaneously. Some synthetic polymers are biodegradable and can be tailor-made easily. Therefore, by combining the individual advantages of starch and synthetic polymers, starch-based completely biodegradable polymers (SCBP) are potential for applications in biomedical and environmental fields. Therefore it received great attention and was extensively investigated. In this paper, the structure and characteristics of starch and some synthetic degradable polymers are briefly introduced. Then, the recent progress about the preparation of SCBP via physical blending and chemical modification is reviewed and discussed. At last, some examples have been presented to elucidate that SCBP are promising materials for various applications and their development is a good solution for reducing the consumption of petroleum resources and environmental problem.

Keyword: *biodegradable polymers, starch, biopolymer, preparation, application*

1. Introduction

As well known, synthetic polymer materials have been widely used in every field of human activity [1] during last decades, i.e. post-Staudinger times. These artificial macromolecular substances are usually originating from petroleum and most of the conventional ones are regarded as non-degradable. However, the petroleum resources are limited and the blooming use of non-biodegradable polymers has caused serious environmental problems. In addition, the non-biodegradable polymers are not suitable for temporary use such as sutures. Thus, the polymer materials which are degradable and/or biodegradable have being paid more and more attention since 1970s.

Both synthetic polymers and natural polymers that contain hydrolytically or enzymatically labile bonds or groups are degradable. The advantages of synthetic polymers are obvious, including predictable properties, batch-to-batch uniformity and can be tailored easily [2]. In spite of this, they are quite expensive. This reminds us to focus on natural polymers, which are inherently biodegradable [3] and can be promising candidates to meet different requirements.

Among the natural polymers, starch is of interest. It is regenerated from carbon dioxide and water by photosynthesis in plants [4]. Owing to its complete biodegradability [5], low cost and renewability [6], starch is considered as a promising candidate for developing sustainable materials. In view of this, starch has been receiving growing attention since 1970s [7, 8]. Many efforts have been exerted to develop starch-based polymers for conserving the petrochemical resources, reducing environmental impact and searching more applications [9–11]. In this paper, the status of preparation and applications of starch-based completely biodegradable (SCBP) polymers is reviewed and presented.

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2. Structure and properties of starch

Starch is mainly composed of two homopolymers of D-glucose [8]: amylase, a mostly linear α-D(1, 4')-glucan and branched amylopectin, having the same backbone structure as amylose but with many α-1, 6'-linked branch points (Figure 1). There are a lot of hydroxyl groups on starch chains, two secondary hydroxyl groups at C-2 and C-3 of each glucose residue, as well as one primary hydroxyl group at C-6 when it is not linked. Evidently, starch is hydrophilic. The available hydroxyl groups on the starch chains potentially exhibit reactivity specific for alcohols. In other words, they can be oxidized and reduced, and may participate in the formation of hydrogen bonds, ethers and esters [12].

Starch has different proportions of amylose and amylopectin ranging from about 10–20% amylose and 80–90% amylopectin depending on the source [13]. Amylose is soluble in water and forms a helical structure [14]. Starch occurs naturally as discrete granules since the short branched amylopectin chains are able to form helical structures which crystallize. Starch granules exhibit hydrophilic properties and strong inter-molecular association via hydrogen bonding formed by the hydroxyl groups on the granule surface.

Owing to its hydrophilicity, the internal interaction and morphology of starch will be readily changed by water molecules, and thereby its glass transition temperature (T_g), the dimension and mechanical properties depend on the water content. T_g of native starch can be as low as 60 to 80°C when the weight fraction of water is in the range 0.12 to 0.14, which allows starch to be successfully injection moulded to obtain thermoplastic starch polymers in the presence of water [15]. On the other hand, the hydrophilicity of starch can be used to improve the degradation rate of some degradable hydrophobic polymers, which will be shown in 3.1.1.

Starch is totally biodegradable in a wide variety of environments. It can be hydrolyzed into glucose by microorganism or enzymes, and then metabolized into carbon dioxide and water [16]. It is worth noting that carbon dioxide will recycle into starch again by plants and sunshine. Starch itself is poor in processability, also poor in the dimensional stability and mechanical properties for its end products [17]. Therefore, native starch is not used directly.

3. Preparation of starch-based biodegradable polymers

To improve the properties of starch, various physical or chemical modifications of starch such as blending, derivation and graft copolymerization have been investigated.

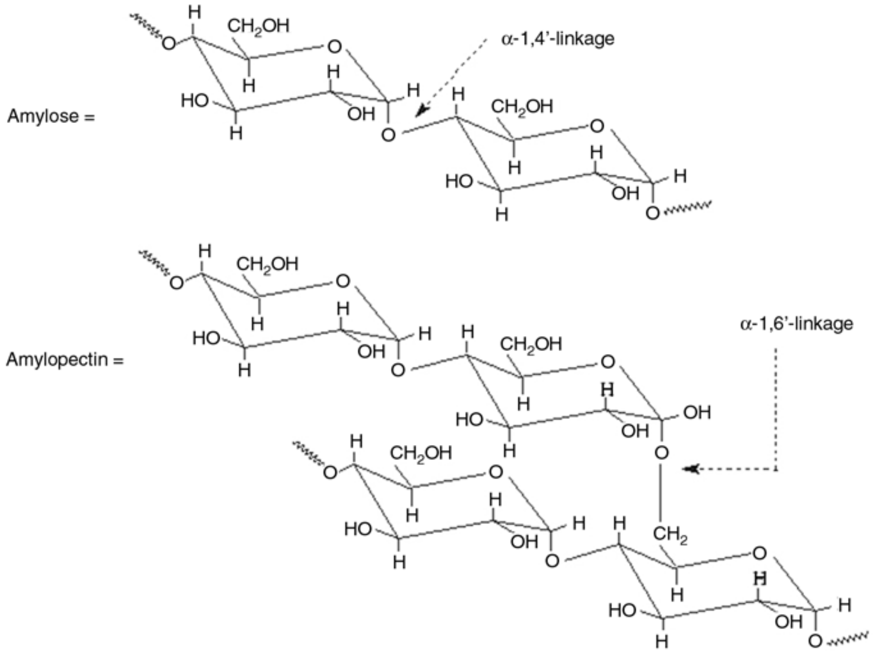

Figure 1. Molecular structure of starch

3.1. Physical blends

3.1.1. Blend with synthetic degradable polymers

At first, starch was adopted as a filler of polyolefin by Griffin [18] and its concentrations is as low as 6–15%. Attempts to enhance the biodegradability of the vinyl polymers have been investigated by incorporating starch to a carbon-carbon backbone matrix [19]. In all these cases starch granules were used to increase the surface area available for attack by microorganisms. However, such a system is partially biodegradable and not acceptable from an ecological point of view. Thus, the blends of starch and polyolefin will not be mentioned any more in this article.

To prepare completely biodegradable starch-based composites by this strategy, biodegradable polymers are assumed. Usually, the components to blend with starch are aliphatic polyesters, polyvinyl alcohol (PVA) and biopolymers. The commonly used polyesters are poly(β-hydroxyalkanoates) (PHA), obtained by microbial synthesis, and polylactide (PLA) or poly(ε-caprolactone) (PCL), derived from chemical polymerization. The goal of blending completely degradable polyester with low cost starch is to improve its cost competitiveness whilst maintaining other properties at an acceptable level [20, 21].

PLA is one of the most important biodegradable polyesters with many excellent properties and has been widely applied in many fields, especially for biomedical one. PLA possesses good biocompatibility and processability, as well as high strength and modulus. However, PLA is very brittle under tension and bend loads and develops serious physical aging during application. Moreover, PLA is a much more expensive material than the common industrial polymers [22].

Many efforts have been made to develop PLA/starch blends to reduce total raw materials cost and enhance their degradability. The major problem of this blend system is the poor interfacial interaction between hydrophilic starch granules and hydrophobic PLA. Mechanical properties of blends of PLA and starch using conventional processes are very poor because of incompatibility [23]. In order to improve the compatibility between hydrophilic starch granules and hydrophobic PLA, glycerol, formamide, and water are used alone or combined as plasticizers to enhance the dispersion and the interfacial affinity in thermoplastic starch (TPS)/PLA blends. In the presence of water and other plasticizers including glycerol, sorbitol, urea, and formamide [24], the strong intermolecular and intramolecular hydrogen bonds in starch can be weakened.

To improve the compatibility between PLA and starch, suitable compatibilizer should be added. Besides, gelatinization of starch is also a good method to enhance the interfacial affinity. Starch is gelatinized to disintegrate granules and overcome the strong interaction of starch molecules in the presence of water and other plasticizers, which leads to well dispersion [25, 26]. The glass transition temperature and mechanical properties of TPS/PLA blend depend on its composition and the content of plasticizer as well (Table 1), indicating the compatibility between PLA and TPS is low but some degree of interaction is formed [26].

PCL is another important member of synthetic biodegradable polymer family. It is linear, hydrophobic, partially crystalline polyester, and can be slowly degraded by microbes [27–29]. Blends between starch and PCL have been well documented in the literatures [30–35]. The weakness of pure starch materials including low resilience, high moisture sensitivity and high shrinkage has been overcome by adding PCL to starch matrix even at low PCL concentration. Blending with PCL, the

Table 1. Thermal and mechanical properties of thermoplastic starch/polylactide (TPS/PLA) blends

Content of TPS [wt%]	T_g [°C]		Tensile Strength [MPa]	Elongation at Break [%]
	PLA	TPS		
100 (TPS1)[a]	–	10	3.4	152.0
90 (TPS1)	47	NF[b]	2.9	48.8
75 (TPS1)	53	NF	4.8	5.7
100 (TPS2)[a]	–	43	19.5	2.8
90 (TPS2)	NF	NF	14.1	1.3
75 (TPS2)	NF	NF	12.0	0.9
0	58	–	68.4	9.4

[a]the content of glycerol and water in TPS1 and TPS2 are 18 and 12, 10 and 16 wt% respectively
[b]T_g value is not found in the literature

Table 2. Thermal and mechanical properties of thermoplastic starch/polycaprolactone (TPS/PCL) blends

Content of TPS [wt%]	T_g [°C]		Tensile Strength [MPa]	Elongation at Break [%]
	PCL	TPS		
100 (TPS1)[a]	–	8.4	3.3	126.0
75 (TPS1)	31.0		5.9	62.6
100 (TPS2)[a]	–	43.4	21.4	3.8
75 (TPS2)	41		10.5	2.0
60 (TPS2)	NF[b]		9.0	2.4
0	–61.5	–	14.2	>550.0

[a]the content of glycerol and water in TPS1 and TPS2 are 18 and 12, 10 and 16 wt% respectively
[b]T_g value is not found in the literature

impact resistance and the dimensional stability of native starch is improved significantly. The glass transition temperature and mechanical properties of TPS/PCL blend are varied with its composition and the content of plasticizer (Table 2) [32]. As can be seen, TPS/PCL blend is similar to TPS/PLA blend in both the compatibility and the role of components.

PCL/starch blends can be further reinforced with fiber and nano-clay respectively. Moreover, the other properties of the blends such as hydrolytic stability, degradation rate, and compatibilization between PCL and starch are also improved [34, 35].

PVA is a synthetic water-soluble and biodegradable polymer [36]. PVA has excellent mechanical properties and compatibility with starch. PVA/starch blend is assumed to be biodegradable since both components are biodegradable in various microbial environments. The biodegradability of blends consisting of starch, PVA, glycerol and urea is performed by bacteria and fungi isolated from the activated sludge of a municipal sewage plant and landfill, which indicate that microorganisms consumed starch and the amorphous region of PVA as well as the plasticizers [37]. Meanwhile, the blend is expected to exhibit good mechanical and process properties [38, 39]. Owing to the strong interaction among hydroxyl groups on PVA and starch chains, all the T_g of the starch/PVA blends of different compositions are lower than that of PVA. The excellent compatibility of two components make the tensile strength of the blend increases with increasing PVA concentration, and the elongation at break of the blend is almost kept constant [37].

In addition, PVA can be used to enhance the compatibility of starch/PLA blends. Because both starch and PVA are polyols, starch will form continuous phase with PVA during blending. As a result, the mechanical properties of the starch/PLA blends are improved in the presence of PVA [40]. As for the blend system without PVA, starch acts as filler in the PLA continuous matrix. PLA acts as the main load-bearing phase because of the weak interaction between starch and PLA.

3.1.2. Blend with biopolymers

Natural polymers such as chitosan and cellulose and their derivatives are inherently biodegradable, and exhibit unique properties. A number of investigations have been devoted to study the blend of them with starch.

Starch and chitosan are abundant naturally occurring polysaccharide. Both of them are cheap, renewable, non-toxic, and biodegradable [41]. The starch/chitosan blend exhibits good film forming property, which is attributed to the inter- and intramolecular hydrogen bonding that formed between amino groups and hydroxyl groups on the backbone of two components. The mechanical properties, water barrier properties, and miscibility of biodegradable blend films are affected by the ratio of starch and chitosan [42].

Extrusion of the mixture of corn starch and microcrystalline cellulose in the presence or absence of plasticizers (polyols) is used to produce edible films [43]. By increasing the content of the cellulose component, the rupture strength is increased, whereas the elongation at break and the permeability of films for water vapor are decreased. Starch can form thermodynamically compatible blend films with water-soluble carboxymethylcellulose (CMC) when the starch content is below 25 mass% [44]. Such films are biodegradable in presence of microorganisms.

Starch-based nanocomposite film is obtained by casting the mixture of plasticized starch and flax cellulose nanocrystals. The mechanical properties and water resistance are greatly improved. The tensile strength of nanocomposite and unreinforced films are 498.2 and 11.9 MPa respectively [45].

3.2. Chemical derivatives

One problem for starch-based blends is that starch and many polymers are non-miscible, which leads to the mechanical properties of the starch/polymer blends generally become poor. Thus, chemical strategies are taken into consideration.

Chemical modifications of starch are generally carried out via the reaction with hydroxyl groups in the starch molecule [46]. The derivatives have physicochemical properties that differ significantly from the parent starch but the biodegradability is still maintained. Consequently, substituting the hydroxyl groups with some groups or chains is an effective means to prepare starch-based materials for various needs.

Graft copolymerization is an often used powerful means to modify the properties of starch. Moreover, starch-g-polymer can be used as an effective compatibilizer for starch-based blends [47–49].

PCL and PLA are chemically bonded onto starch and can be used directly as thermoplastics or compatibilizer. The graft-copolymers starch-g-PCL and starch-g-PLA can be completely biodegraded under natural conditions and exhibit improved mechanical performances. To introduce PCL or PLA segments onto starch, the ring opening graft polymerization of ε-caprolactone or L-lactide with starch is carried out [17, 31, 50, 51].

Starch-g-poly(vinyl alcohol) can be prepared via the radical graft copolymerization of starch with vinyl acetate and then the saponification of the starch-g-poly(vinyl acetate). Starch-g-PVA behaves good properties of both components such as processability, hydrophilicity, biodegradability and gelation ability [52–56].

Starch can be easily transformed into an anionic polysaccharide via chemical functionalization [57]. For instance, a carboxylic derivative of starch, maleic starch half-ester acid (MSA), has been prepared via the esterification of starch with maleic anhydride in the presence of pyridine [58]. MSA is an anionic polyelectrolyte, consequently it can perform ionic self-assembly with chitosan in aqueous solution and forms a polysaccharide-based polyelectrolyte complex [59].

4. Applications of starch-based biodegradable polymers

4.1. In food industry

Food packaging and edible films are two major applications of the starch-based biodegradable polymers in food industry.

The requirements for food packaging include reducing the food losses, keeping food fresh, enhancing organoleptic characteristics of food such as appearance, odor, and flavor, and providing food safety [60]. Traditional food packaging materials such as LDPE have the problem of environmental pollution and disposal problems [61]. The starch-based biodegradable polymers can be a possible alternative for food packaging to overcome these disadvantages and keep the advantages of traditional packaging materials. However, the components in the conventional starch-based polymer packaging materials are not completely inert. The migration of substances into the food possibly happens, and the component that migrates into food may cause harm for the human body. In view of this, new starch-based packaging materials are being developed. For instance, a starch/clay nanocomposite food packaging material is developed, which can offer better mechanical property and lower migration of polymer and additives [62].

Starch-based edible films are odorless, tasteless, colorless, non-toxic, and biodegradable. They display very low permeability to oxygen at low relative humidity [63] and are proposed for food product protection to improve quality and shelf life without impairing consumer acceptability [64].

In addition, starch can be transformed into a foamed material by using water steam to replace the polystyrene foam as packaging material. It can be pressed into trays or disposable dishes, which are able to dissolve in water and leave a non-toxic solution, then can be consumed by microbic environment [65].

Evidently, the starch-based biodegradable polymers are attractive for food industry and will make great progress in the future.

4.2. In agriculture

Starch-based biodegradable polymers have found three major applications in agriculture: the covering of greenhouse, mulch film and fertilizers controlled release materials [66]. The consumption of agriculture films is abundant. Generally, the disposal methods of tradition films are landfill, recycling or burning. But they are time-consuming, not economic and lead to environmental pollution [67]. On the other hand, the utilization efficiency of fertilizers is the key element of the development of agricultural productions. However, due to surface runoff, leaching and vaporization, the fertilizers escape to environment to cause diseconomy and environmental problems [68, 69].

The development of starch-based biodegradable polymers offers a possibility to overcome the mentioned problems. They can be used as the fertilizers controlled release matrices to release the fertilizers slowly or in controlled way. As a result, the loss of fertilizers and environment pollution can be avoided or reduced [50, 70].

After using, starch-based films can be ploughed into soil and disposed directly. Moreover, no toxic residues formed after the degradation of starch-based biodegradable polymers [71, 72]. Thus, the development of starch-based materials for agriculture applications is being continued. For example, to enhance the mechanical properties and solvent or gas resistance, starch-based biodegradable materials are mixed with some nano-grade additives such as TiO_2, layered silicate and MMT to form bio-nanocomposites [73–75].

4.3. In medical field

Starch-based biodegradeable polymers have some advantages to be medical polymer materials [76–81]:

a) good biocompatibility
b) biodegradable and its degradation products are non-toxic
c) proper mechanical properties
d) degradation as requirement

Starch-based biodegradeable polymers have been widely investigated in bone tissue engineering. Starch-based biodegradable bone cements can provide immediate structural support and degrade from the site of application. Moreover, they can be combined with bioactive particles, which allow new bone growth to be induced in both the interface of cement-bone and the volume left by polymer degradation [82]. In addition, starch-based biodegradeable polymer can also be used as bone tissue engineering scaffold [83].

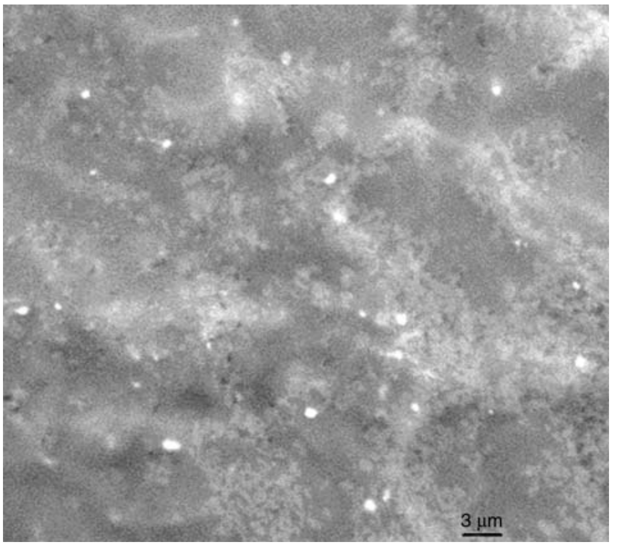

Figure 2. SEM photograph of strach-g-PVA/HA hydrogel (scale bar 3 µm)

Starch-based biodegradable polymers, in the form of microsphere or hydrogel, are suitable for drug delivery [84, 85]. There is no need for surgical removal of the device after drug depletion.

The unique properties, such as hydrophilicity, permeability, biocompatibility, and to some extent similar to soft biological systems, of starch-based hydrogels make them useful for various biomedical applications [86]. The 3D structure of starch-based hydrogels enable them absorb and reserve a plenty of water and keep good enough mechanical property at the same time. Starch-based hydrogels have received growing interest for biomedical applications. In our lab, physically cross-linked starch-g-PVA and starch-g-PVA/hydroxyapatite hydrogel are obtained via repeated freezing/thawing circles, and hydroxyapatite (HA) can be well dispersed in such a matrix (Figure 2) [55, 87]. The water content in the fresh starch-g-PVA/HA hydrogel is comparable to that of PVA/HA hydrogel, and the dried starch-g-PVA/HA films can re-adsorb water soon and reach swelling equilibrium within 12 minutes.

5. Conclusions

Starch is renewable from carbon dioxide, water and sunshine. It is biodegradable, cheap and to be physical or chemical modified easily. This means someday it is unnecessary to rely on petroleum to prepare polymers, people may 'plant' polymers of suitable performances from the earth, and the environmental problems will be no longer as severe as today. At present and in the near future, different physical and chemical approaches are effective strategies to develop starch-based completely biodegradable polymers of appropriate biocompatibility, degradation rate and physical properties for various applications.

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Plant-Based Bottles by PepsiCo and Coke are Plastic

JUNE 20, 2011 / 1 COMMENT

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Extremely sorry to let you know that we can't rely on plant-based PET bottles to solve our plastic woes any more.

Some recent reports indicate that Coca-Cola and PepsiCo's plant-based bottles are just the very same plastic. The companies have merely replaced the fossil fuels (petroleum and natural gas) traditionally used to make their plastic bottles with ethanol from renewable sources (plant waste in Pepsi's case and Brazilian sugar cane in Coke's).

Though these initial inputs come from renewable, lower-carbon sources, the resulting plastics are chemically identical to the polyethylene terepthalate, or PET,and high-density polyethylene, or HDPE, that regular plastic bottles are made of. No doubt, these are as harmful as their petroleum-based predecessors.

The study highlights that Pepsi and Coke are using plants to make the same polymers we find in other plastics and it has zero effect on plastic pollution. Besides, the bottles made from ethanol contain phthalates and bisphenol A,

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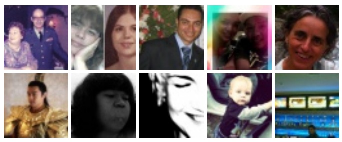
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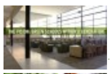
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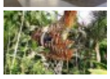
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which can be associated with obesity, autism, and various types of cancer. Bio-resins may be recyclable, but new Pepsi and Coke bottles are neither biodegradable nor recycled.

It needs to be noted that companies like Naked Juice, Naya Water, and Eldorado Water have been already on the path of green by using bottles made from 100% recycled materials. Unfortunately, PepsiCo's and Coke's green bottles turned out to be a mere hollow green façade!

(via Slate)

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ONE RESPONSE

GREG MCMILLAN / JUNE 21, 2011 AT 2:42 PM

Hate plastics if you like; but get your facts straight. PET resin used for small water or soda bottles does NOT contain BPA or phthalates! Does not now and never has! A diffent plastic, Polycarbonate is made using BPA and is not used for soda bottles. Coke and Pepsi soda bottles are recycled every day. Yes the PET made from these new "renewable technoligies" make the same PET and that is a good thing because they can be recycled in the existing recycling stream already reclaimin nearly a billion pounds per year.

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Here on GreenPacks we're passionate about everything that involves a cleaner life on Earth. It's true that our lives depend on a greener future, but the change should come from within. We first need to be good stewards to ourselves and then to Mother Nature, not the other way around. More here

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