Design from Recycling for post-consumer WEEE plastics

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ABSTRACT: Waste from electronic and electrical equipment (WEEE) is an increasingly growing source for post-consumer plastics [1]. Reasons for this include the rapid development of new electronic and electrical equipment (EEE), combined with the ever-reducing lifetime of consumer products, as well as European legislation. Plastics from WEEE typically include ABS, PC, ABS/PC blends, (filled) PP and HIPS as majority fractions. These thermoplastics are – at least theoretically – very suitable for mechanical recycling. However, plastics converters are still somewhat reticent to use these secondary raw materials in their products, either because they have little faith in the (reproducible) quality of recycled feedstock or because they lack product development tools for the use of these recycled polymers. With Design from Recycling, strategic tools are offered that can facilitate the effective incorporation of recycled WEEE plastics into high-quality new EEE products.

KEYWORDS: plastics recycling, post-consumer, mechanical recycling, design from recycling, WEEE

1 INTRODUCTION

The production of electrical and electronical equipment (EEE) keeps growing with an increasing pace due to a rapid economic growth. These increasing quantities of products are accompanied with a substantial growth in waste from electrical and electronical equipment (WEEE). The waste is mainly generated in Organisation for Economic Cooperation and Development (OECD) countries where the market is saturated with huge quantities of electrical and electronical goods [2]. But even so, WEEE tonnages in the EU are not to be underestimated, given the rapid development of new EEE products and the ever-reducing lifetime of these consumer products [3].
European legislation is in place to promote the recovery and re-use of WEEE materials, such as the European Directive (2000/53/EC) and the WEEE directive (2002/96/EC), which state that at least 70-80% of materials of end-of-life vehicles and WEEE have to be recovered in the form of energy and/or materials. It is estimated that globally, 20-50 million tonnes of WEEE is generated annually and makes up five percent of all municipal solid waste [4]. WEEE consists of a large variety of materials (mostly ferrous and non-ferrous metals, glass and plastics). A typical WEEE fraction contains 20-30 wt% plastics [3], which is even more in volume percentages as plastics typically have much lower densities than metals. The general composition of the plastic fraction itself is depicted in Figure 1: the main polymers present are acrylonitril-butadieen-styreen (ABS), high-impact polystyrene (HIPS), polycarbonate (PC), PC/ABS blends and polypropylene (PP) Theoretically, all of these polymers can be separated into monostreams of relatively high purity and then

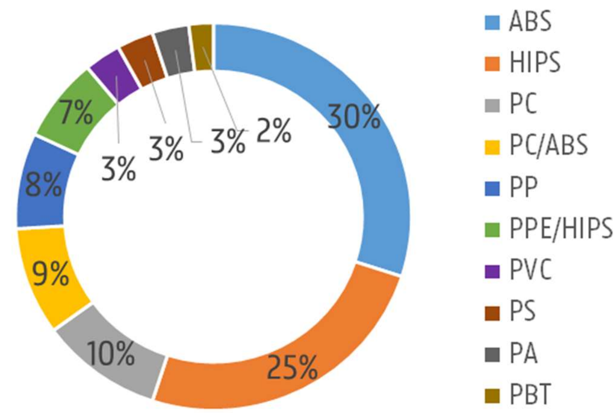

Figure 1: Typical compostion of WEEE . [5]

be reused in new product applications. However, some practical hurdles remain. One of the main challenges is the variability in the material composition between batches, due to the presence of polymer mixtures, additives or contaminations. Moreover, it is well known that polymers are subject to degradation, occurring both during their lifetime and during the reprocessing of the materials [4]. These will inevitably lead to a loss of quality, as will the presence of impurities of any kind.

2 DESIGN FROM RECYCLING

To present day, mechanical recycling remains the most ubiquitous pathway for the effective recycling of thermoplastics like these dominant WEEE polymers [6]. In mechanical recycling, plastics are sorted, separated, cleaned if necessary, reduced in size by grinding and/or shredding and then reprocessed into a granulate fit for conversion. In many cases for WEEE plastics, the final reprocessing step includes the compounding of new additives and/or virgin materials in order to increase mechanical, lifetime or esthetical properties. Subsequently, the polymers need to be repurposed towards new products, be it in a closed-loop or open-loop application. However, unknown is often unloved and many Original Equipment Manufacturers (OEMs) are reticent to use materials for which they have little 'feeling'. A simple technical data sheet typically does not suffice to convince them [7] Hence, in order to valorise as much of these recycled polymers as possible, in an as high-level application as possible, adapted product development tools are required.

Design from Recycling is such a product development strategy [8][9], strongly complimentary to the better-known Design for Recycling, which focuses on product recyclability at end-of-life (EoL) by promoting easy separation of different materials and an all-round efficient material use [10]. Design for Recycling is, via the Ecodesign Directive [11], heavily promoted by the European Commission within the framework of the Circular Economy [12].

In Design from Recycling, the secondary raw material originating from the recycled polymer waste of a previous product's EoL is the starting point of a new product development. Key aspects of the strategy include a thorough characterization of the recycled polymer, adapted product (and mould) design to the recycled polymer's properties and identifying acceptable (cost-effective) strategies for the upgrading of the material quality (to product requirements) where necessary [9] Previously, this strategy has already been successfully implemented to successfully realize a high-quality consumer product made from the manufacturer's own production waste [8].

In developing new EEE appliances with recycled plastics, as in all product design, it often remains challenging for product developers to gain a good understanding of the quality and possibilities of available recycled materials [13]. Additionally, it is tempting to fall back on previous knowledge and choose within a set of standard used materials. This is a major hurdle for the increased use of post-consumer WEEE plastics in new products, be they EEE appliances or other. To further facilitate the effective implementation of Design from Recycling specifically for with WEEE plastics, sector-specific tools have been developed in an intensive academic-industrial collaboration. Tools for Design from Recyling

2.1 *Product development guidelines*

The products (parts) that are to be made from WEEE plastics are differentiated into two categories:

- A: New to be developed product
- B: Existing product, existing production tool

This differentiation is essential for which strategy to follow with respect to the materials.
Category A, a new to be developed product, we consider as 'designing as usual'. The steps we take during the development process are no different than conventional product development. By using the typical product development waterfall shown in Figure 2, the first important step after concept choice is to define the production process and the material group. This is typically based on product requirements and previous

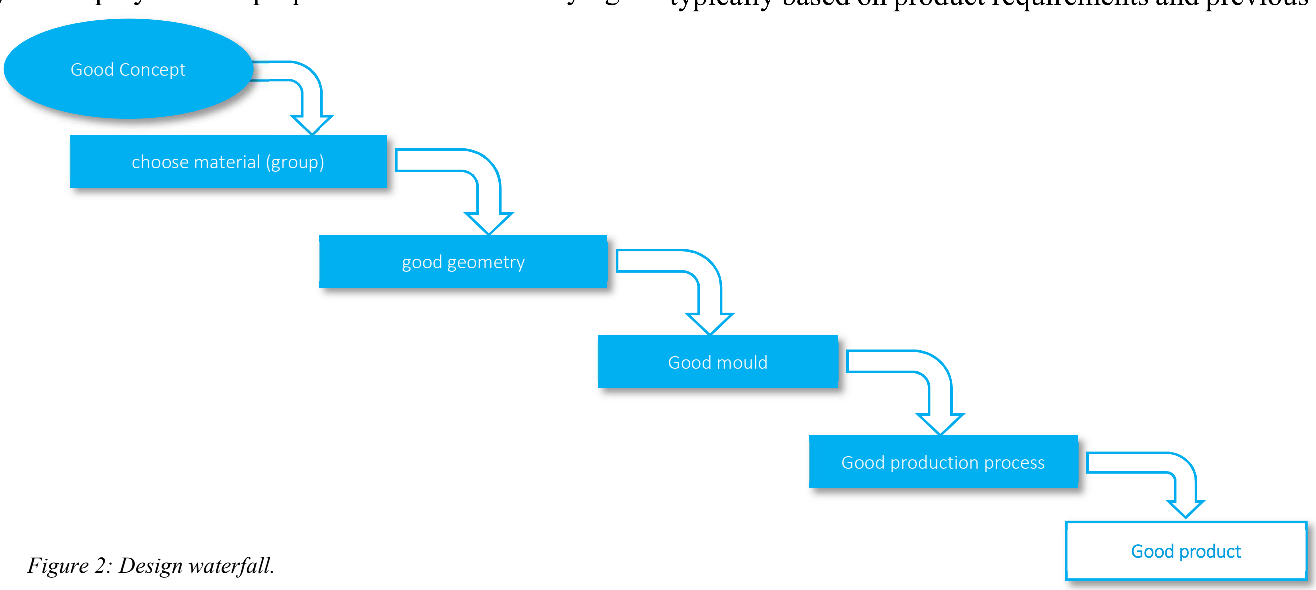

Figure 2: Design waterfall.

experience. After that, determining the geometry of that part and a suitable mould and production process can be developed, keeping the specifics of the chosen material (group) in mind. Based on the use of recycled material we anticipate making a guarantee for the overall production stability of the recycled material by making the design more robust. A main exception we make is to think from the start in user scenarios, so as to be able to foresee where a product or parts of a product will end up after the use phase. This is the fundament to make choices on concept level. At this stage, choice of materials is also initiated. Initially on a high level: does it have to be recyclable or biodegradable? What material group (PE, PC/ABS, etc.) will be used? This also means that at this stage, the long-term availability of the materials must be known. The requirements given from the product must be translated to material requirements, which can be tuned within given boundaries. The typical behaviour of the chosen material will be investigated before ordering the mould (e.g. shrinkage) and deviation in dimensions due to differential shrinkage (pressure, flow behavior) will be corrected during release of the mould.

Based on category B (existing product), there is an existing tool and all steps of the development waterfall are already taken. This means that the only thing that changes is the virgin plastic that was used initially is replaced by a recycled plastic and is produced in the same geometry with the same mould. Therefore no development costs for designing the product will be necessary. Although this sounds easy, in reality changing the material in a given production environment has more impact than normally expected. Based on the given mould, the production process must be stable and the part geometry must be within specifications. This means that not only the mechanical properties of the virgin and the recycled plastic are virtually similar or the properties of the part that is made by recycled material is still within the part specifications, but for the converter also the material should behave the same as a virgin material. Especially the lot-to-lot stability is important. This can only be proven with a long term testing on production level. Test and verification on material and part level will be necessary to prove the new material can be released for production. Due to small variation in dimensions small changes in the tool could be implemented to solve these issues. The way of working is often that beforehand, the most essential mechanical properties of the material are determined, then a small test is done on a small scale for first material test and then a large test in a production environment is done. Afterwards the parts are checked and tested, not only on short-term properties, but also on long-term behavior. In the end, the total product will require a new product release.

2.2 *The dEEEterminator tool*

A supporting tool, which was previously developed for the generic Design from Recycling strategy, was the so-called Determinator [9]. This is an injection moulding product, complimentary to the technical data sheet, which serves as a tactile tool for the product developer to evaluate the material hands-on and first-hand. As the existing Determinator is very generic in nature and because the EEE industry has some very specific feature requests, the initial design was adapted to suit this needs. As a result of this collaboration, the dEEEterminator was developed, as seen in figure 3.

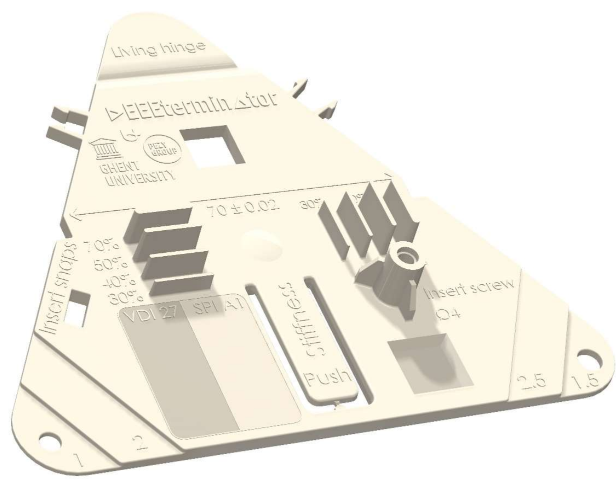

Figure 3: dEEEterminator design tool.

The dEEEterminator offers a wide variety of features, all with their own use in EEE products and possibility to show material properties. Some features also have a double purpose, not only giving an indication about the mechanical properties but also about the effects of contaminations and rheological properties. The dEEEterminator tool focusses on visualization of recycled thermoplastic resins, but for comparing purposes the tool can also be made out of the virgin counterpart.

The great variety of features in the dEEEterminator tool is detailed in Figure 4.

A common feature in plastic parts is the (1) living hinge. This is a thin, flexible section of plastic that connects two halves which need to be able to move in an open-closed like relation to one another, like in shampoo bottle caps. Cable tie-down points are a possible use in an EEE part. Living hinges are commonly used in parts that need to be opened and closed multiple times, but it is also possible to use living hinges in parts that only need to be closed once. The advantage in using living hinges in plastic products is the reduction of number of parts. This results in a lower moulding and assembly cost. The type of hinge used in this tool is the most simple and common type, namely the one-piece integral hinge and is used in parts made out of semi-crystalline resins such as polypropylene [14]. With this feature, not only the properties of the living hinge can be visually determined (e.g. durability and flexibility), but also some material related properties could be assessed, such as whether it is even possible to form a living hinge by injection moulding in a conventional mould. This will give an indication on the rheological properties and speed of solidification. It is also possible that due to contaminations in the recycled polymer with a diameter greater than 0.25 mm it is impossible to form the living hinge. When the living hinge is formed, the material can be evaluated on its suitability to be used for this purpose but also on how easy it is to break or tear the hinge, giving a first impression about the strength, stiffness and brittleness of the material.

Text (2) is used on the dEEEterminator to indicate and give more information about certain features. The logos of the main design partners are also added on the part. These texts and logos can also tell us more about the material. Text and logos in plastic parts are often used to indicate production information. This information must be clearly seen. If the material does not allow for the text/logos to be clearly formed this can give an indication about certain impurities in the material.

Another widely used feature in EEE are snap fits (3), used for the connection of circuit boards to the product. Snap fits come in a wide variety of shapes and sizes, tailored to their purpose. Snap fits can be designed to be easily, hard or impossible to reopen without damage to the part. In general snap fits allow for a cost reduction in assembly and disassembly for recycling cost. By using snap fits, no additional materials (like glue or screws) are used for assembly, thereby increasing the recyclability and decreasing the cost. Snap fits also allow for different kind of materials to be easily connected e.g. a plastic lid that snaps on a metal cannister. An esthetical advantage

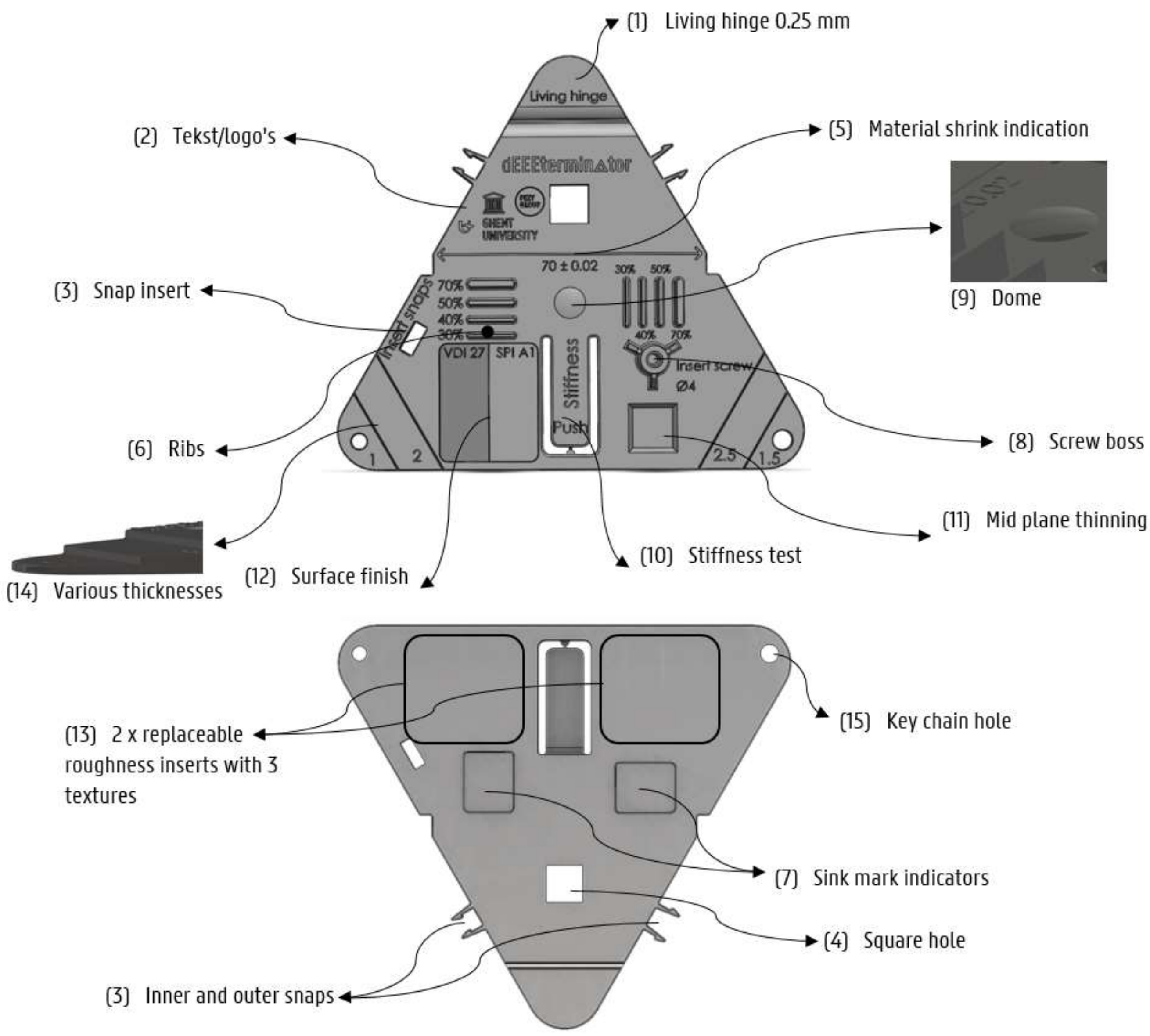

Figure 4: Features of the dEEEterminator.

can be achieved with snap by using inner snaps without access from the outside. Contributing to the low assembly cost is the energy needed for assembly, compared to other methods snap fits are the most energy efficient way to assemble a product. There is no necessity to use solvents or adhesives, this mean no health hazards and instantaneous bonding reducing waiting times. However there are limitations on the use. The mould can limit the use of snap fits as does the process e.g. internal strippable undercuts. Some types of snap fits are vulnerable to failure due to improper design, fatigue and acceding stresses. Because snap fits are impossible to repair, failure can lead to a complete failure of the assembly unless enough redundancy has bene foreseen. Snap fits require specific material properties to be successful, only the more ductile materials are suited. Thermal expansion can also result in loosening of the connection[14]. With this feature, the suitability of the material for snap fits can be evaluated.

A less common feature is the square hole (4). This feature has a very specific purpose. Since square holes disrupt the flow of the molten polymer, pigment concentrations can be found around this feature. Another effect that can be evaluated is the weld line that might form, after the square hole in relation to the injection point. This can give an indication about the rheological properties of the material.

Polymer materials are susceptible to mould shrinkage (5). Therefore, moulds are usually designed to be bigger than the eventual part, and so counteracting the shrinkage of the material. Since this is a property that is mostly not given in the technical datasheet a shrink indication feature was added to the part. This feature allows for the user to measure a fixed mould distance (70 ± 0.02 mm) and then calculate the mould shrinkage from the difference with the part distance.

A feature used in almost every plastic part/product is the (supporting or connecting) rib. Ribs (6) come in all shapes and sizes; in this tool the selection was made for ribs with a width of 30 %, 40% 50% and 70 % of the original thickness (3 mm). With this feature, it becomes possible to evaluate sink marks caused by the ribs, this can be done in combination with the sink mark indications (7) on the back of the tool. The ability to fill both ribs in line with and perpendicular to the flow will give an indication about the rheological properties. Possible contaminations can also disrupt the filling of these ribs, which also gives an indication about the purity of the resin.

The screw boss (8) feature has many uses in the typical EEE product, as well as in other products. Examples of this are corded and cordless drills; in this product, screws connect the two clamshell parts to each other. Here the screw taps its own threads in the screw boss and secures the two parts together. Advantages are the possibility to reopen the part for maintenance, fixing or replacing inner parts, as well as the strength of the connection, which exceeds that of snap fits. However, this way of assembling is more labour intensive and requires extra materials (screws). The screw boss was added to make it possible to test the suitability of the material for this purpose by screwing in a screw and evaluating the force it requires to drive in the screw, checking if the materials breaks under the force exerted by the screw and the force required to pull the screw out of the boss.

To reduce shear stresses during injection moulding, it is common to add a small dome (9) on the opposite side of the injection point. This makes it possible to inject the materials with higher speeds and so increase the production rate. This can also be added to avoid high shear stresses in sensitive materials. This feature was added on the part because of the wide variety of materials that will be used to make this tool. This allows for the best possibly chance to produce a successful product.
A feature that is solely used for the evaluation of mechanical properties of the material is the stiffness test (10). The stiffness test is a bar (thickness of 1.5mm) that can be pushed down with a finger to evaluate stiffness. The first time this is done, a break loose connection must be broken which can give an indication about the strength and brittleness of the material. By holding the stiffness feature down for a certain amount of time and then releasing, the stress relaxation can be evaluated, based on the degree to which the bar returns to its original position.

On the righthand side of the stiffness test, a mid-plane thinning (11) feature was added. This features has is use in EEE products were partial transparency is required e.g. were led lighting needs to shine through the part. This will not influence the esthetics of the parts when not in use and will have minimal effect on the structural properties of the part. With this material the rheological and speed of solidification can be evaluated, since the surroundings of this feature will most likely fill up first before closing the feature itself. This could also result in weld lines or a diesel effect.

Surface texture is a very important aspect of the aesthetics of a product, which in turn is of great importance for the marketing of EEE products. In the front of the tool, two fixed surface finishes (12) are added: one with lens quality (SPI A1) and the other with a matte surface texture (VDI 27). This allows for evaluation of colour and impurities. In the back part, two removable inserts (13) make it possible to have six additional surface textures according to the request of the client. These surface textures each have a surface area of 10 x 30 mm².

The dEEEterminator also contains five different thicknesses (14) throughout the tool from 1 to 3 mm with 0.5 mm increments. On the two smallest thicknesses two holes (15) were added to evaluate weld lines and make it possible to connect several dEEEterminators via a keychain.

3 CONCLUSIONS AND OUTLOOK

Within this paper, we have presented two practical tools for the improved product development with recycled WEEE plastics, namely design guidelines and the dEEEterminator, which is a tactile product showing of strength and weaknesses of a polymer within an effective product. With the use of these tools, it will be within the future work of this project to develop large-scale demonstrator EEE products containing WEEE recycled content.

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