PolyCE

Post-Consumer High-tech Recycled Polymers for a Circular Economy

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Summary

Plastics from WEEE typically include ABS, PC, ABS/PC blends, (filled) PP and HIPS. 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, we offer strategic tools that can facilitate the effective incorporation of recycled WEEE plastics into high quality new EEE products. These tools are offered in three parts, two of them are finally combined into an extended design guide box. An overview of the content and format of this design box can be seen on Figure 1. The first development is not used as a design guide but instead is aimed to increase awareness of high quality recycled materials amongst developers and converters in general. A small demo product, in the form of a business card holder gives a convincing first impression of the possibilities and quality of recycled materials available on the market. The goal of this product is to bring recycled materials in consideration for new and existing appliances and targets product developers, designers and converters.

However, many Original Equipment Manufacturers (OEMs) are reticent to use materials for which they have little 'feeling' for. A simple technical data sheet typically does not suffice to convince them. 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. 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. These are offered in two distinct forms. The first essential tool are the Design form/for Recycling guidelines. In these guidelines the developer is assisted during the design path of either a new or existing product, which requires two different design approaches.
The second tool is offered in the form of the dEEEterminator, a tactile hands-on design tools equipped with several materials evaluating and common EEE-product features. This tool is meant to bridge the gap between a dry and scientific technical date sheet and the actual "feel" of the material. Both these design tools are complimentary to each other; this made it a logical step to combine them in one single design experience box, called the dEEEterminator box.

In collaboration with WP8, design experiences based on the knowledge gained from the different demonstrator cases will be added to the design box in order to complete the entire experience with real life testimonies.

Figure 1: Design from Recycling guidelines and dEEEterminator in design box

Content

1 Task description

This deliverable reports the results obtained in task 4.2, which addresses Design from Recycling strategy. In contrast to Design for Recycling, which is a well-known strategy, Design From Recycling has started gaining an importance in the last years. Design for Recycling is a strategy in which new products are developed so that they can be recycled at their end-of-life. It entails easy separation of different materials and an all-round efficient material use. The strategy is part of a virgin material’s start-of-life. Design from Recycling is an altogether different approach, even though the two do not exclude one another. In Design from Recycling, the secondary raw material originating from the recycled polymer waste of a previous product’s end-of-life is the starting point of new product development. Design from Recycling involves identifying the recycled polymer’s strengths and weaknesses through extensive characterization. Therefore, the objective of this task is to come to a design process, which incorporates the design of parts and products made of recycled material. The goal is to come to a clear design process, which gives designers the possibility to make the choice for recycled material more easily. By doing so the goal is to get recycled material more integrated in the design strategy of companies. Therefore it is important to come to a material–driven design process, whereby the impact on all other design requirements is taken into account. It is known that the design of plastic parts is a balancing act between several items like design, material, mould and processing. Based on given material properties the design impact can be mentioned and related to design rules for designers and customers. The development of the design process will be based on available recycled material with its known properties resulting in possible material-product combinations. Furthermore, the extent to which the minimal requirements for PCR as defined in task 4.1 can be lowered and/or occasional dips below performance specification can be allowed by the proper implementation of these design from recycling rules will be investigated. Partners: UGent, Pezy, KU Leuven; months: 5-24

D4.2: Design from Recycling strategy for PCR polymers from WEEE, M25, UGent

1.1 Task approach

To present day, mechanical recycling remains the most ubiquitous pathway for the effective recycling of thermoplastics like these dominant WEEE polymers (Ragaert, Delva and Van Geem, 2017). 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’ for. A simple technical data sheet typically does not suffice to convince them (Veelaert, Du Bois and Ragaert, 2017). 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 (Ragaert *et al.*, 2016; Veelaert *et al.*, 2017), 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 (Rodrigo and Castells, 2003). Design for Recycling is, via the Ecodesign Directive (European Council, 2009), heavily promoted by the European Commission within the framework of the Circular Economy (European Commision, 2015). 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 (Veelaert *et al.*, 2017).

Previously, this strategy has already been successfully implemented to successfully realize a high-quality consumer product made from the manufacturer's own production waste (Ragaert *et al.*, 2016). 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 (Veelaert *et al.*, 2016). The presence of high quality PCR recycled plastics is often thought of as non-existent. In attempt to overcome this hurdle, product designers could be introduced to these materials by means of a small demo product. The business card holder is one possible demo product that can be used to aid with this hurdle. The high quality finish and functionality lend it perfectly for an convincing first impression.

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 intensive academic-industrial collaboration. These tools for Design from Recycling are worked out in the form of guidelines and a tactile design tool, the so called dEEEterminator. These tools work hand in hand and speak to product developers and designers alike. The complementarity of these tools makes it a logical choice to combine them as a whole. Combined in a design box they form an ideal starter kit to boost the use of PCR WEEE plastics being it in the EEE sector or other.

2 Business card holders

The presence of high quality PCR recycled plastics is often thought of as non-existent. In attempt to overcome this hurdle, product designers could be introduced to these materials by means of a small demo product. The business card holder is one possible demo product that can be used to aid with this hurdle. The high quality finish and functionality lend it perfectly for a convincing first impression.

The business card holder is made out of recycled WEEE sourced plastics and can be made in a wide variety of different recycled plastic materials. The product itself is small and lightweight making it possible to produce a lot of samples with little material. The major goal of this demo object is to show of some key material properties. It can be used to get an indicative understanding of the behaviour of the material during processing. Surface quality and colour can be evaluated because of the high gloss finish on one side and a matte finish on the other. Additionally, it is a thin walled product giving an idea about the possibilities in other product parts e.g. esthetical covers. The strength can also be physically evaluated by trying to deflect or break it. Above this the business card holder also has more complicated features like a two part integrated hinge, a clip system to lock the holder and a retaining lip to hold the cards in place if you open it. This product is meant to give a convincing first impression and step away from the image that recycled plastics are of lesser quality or ugly. It is not meant to be used as a design tool itself, but to put recycled plastics in consideration once material choices are made during product development. On Figure 2 and 3 a photograph of the business card holder can be found made from WEEE sourced recycled ABS.

Figure 2: Business card holder rABS

Figure 3 Business card holder closed with PolyCE logo

3 Guidelines

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

- A: New product to be developed
- 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.

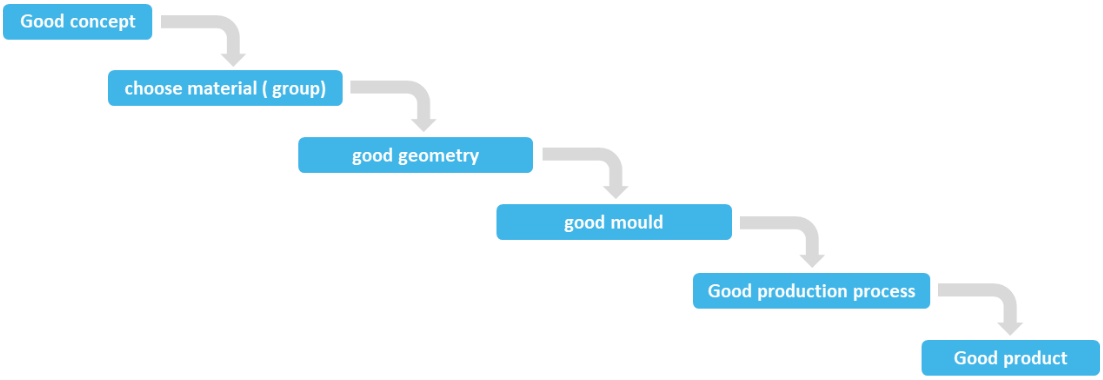

Figure 4: The product development waterfall

The characteristics of a plastic product part are the result of a combination of material, geometry, mould and production process. The correct and most effective order to make choices during development of a product part is also in that order. This is called the product development waterfall (Figure 4). 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 material (group) 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 creating the mould (e.g. shrinkage) and deviation in dimensions due to differential shrinkage (pressure, flow behaviour) will be corrected during release of the mould.

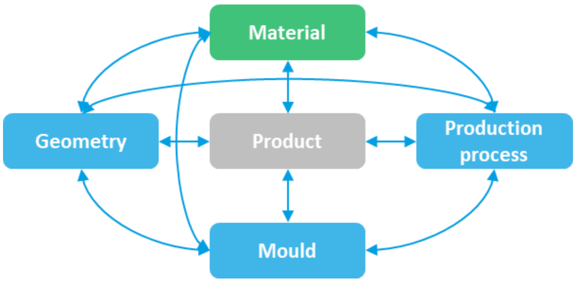

Figure 5: Changing material might have effect on other aspects

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. The other aspects of the product development waterfall might be affected (Figure 5). 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 behaviour. In the end, the total product will require a new product release.

4 dEEEterminator

A supporting tool, which was previously developed for the generic Design from Recycling strategy, was the so-called determinator (Veelaert *et al.*, 2017)**.** 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 6.

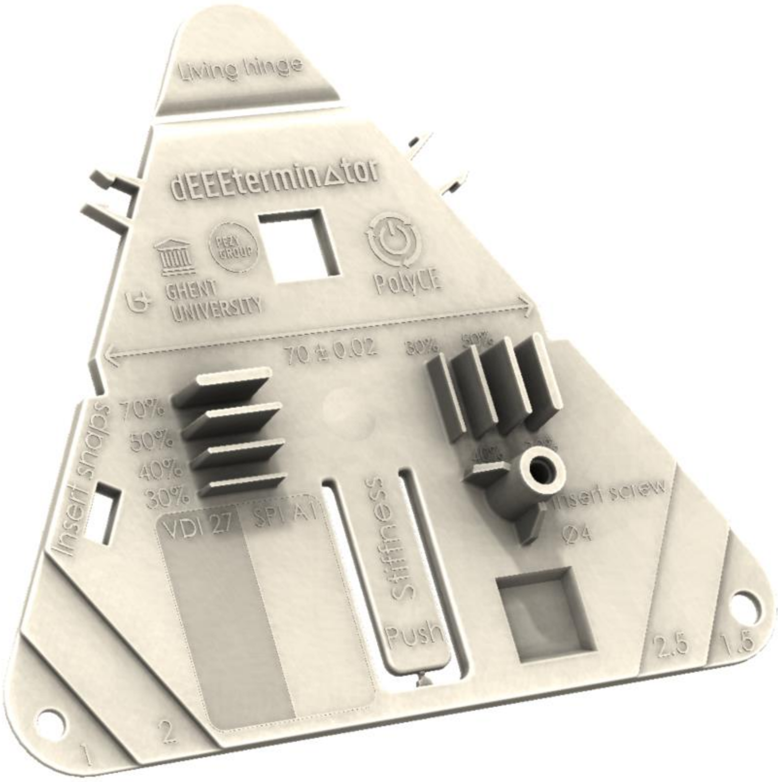

Figure 6: dEEEterminator tactile Design from/for Recycling tool

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 7.

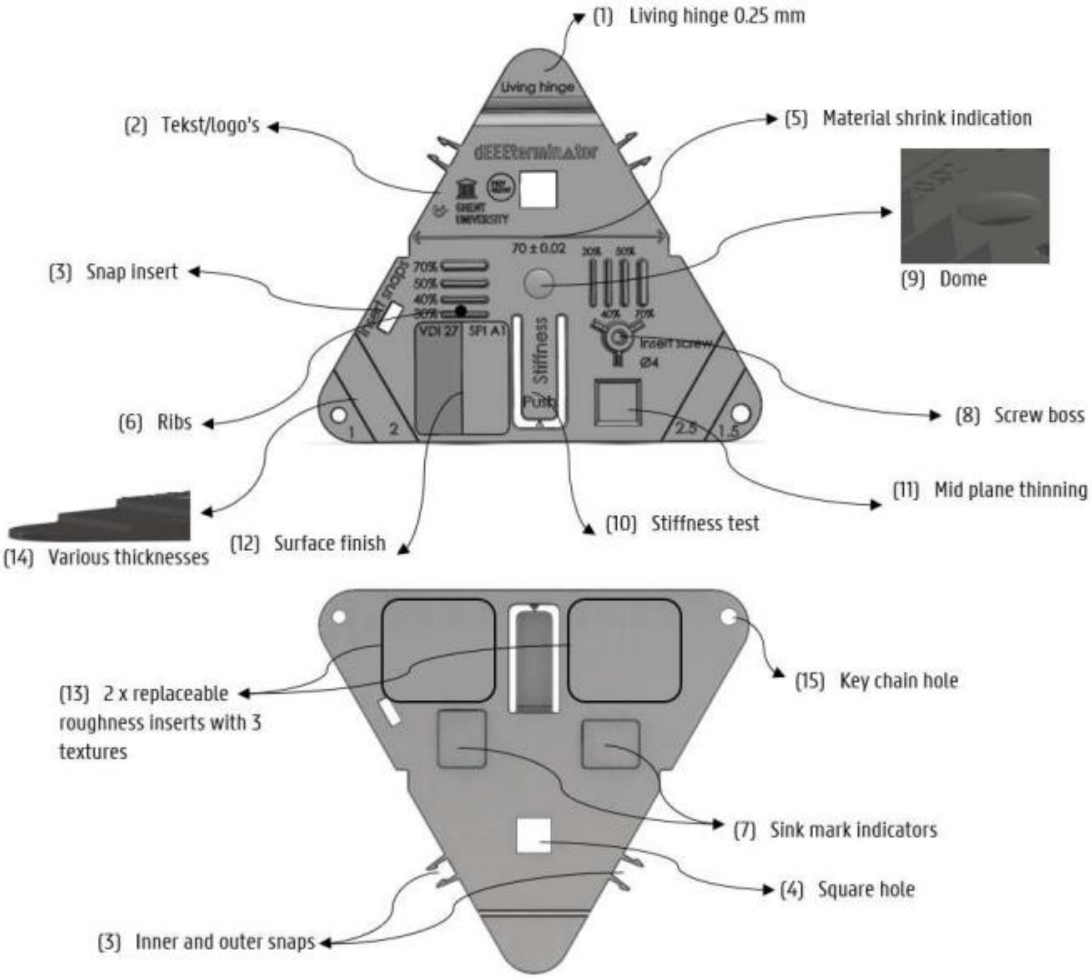

Figure 7: Features of dEEEterminator design tool

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 (Rothheiser, 1999). 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 canister. An esthetical advantage 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, for instance 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 (Rothheiser, 1999). 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 break under the force exerted by the screw and the force required pulling 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 right-hand 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 aesthetics 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.

On Figure 8 a photograph of two moulded dEEEterminators can be seen respectively moulded in black recycled ABS and white recycled HIPS.

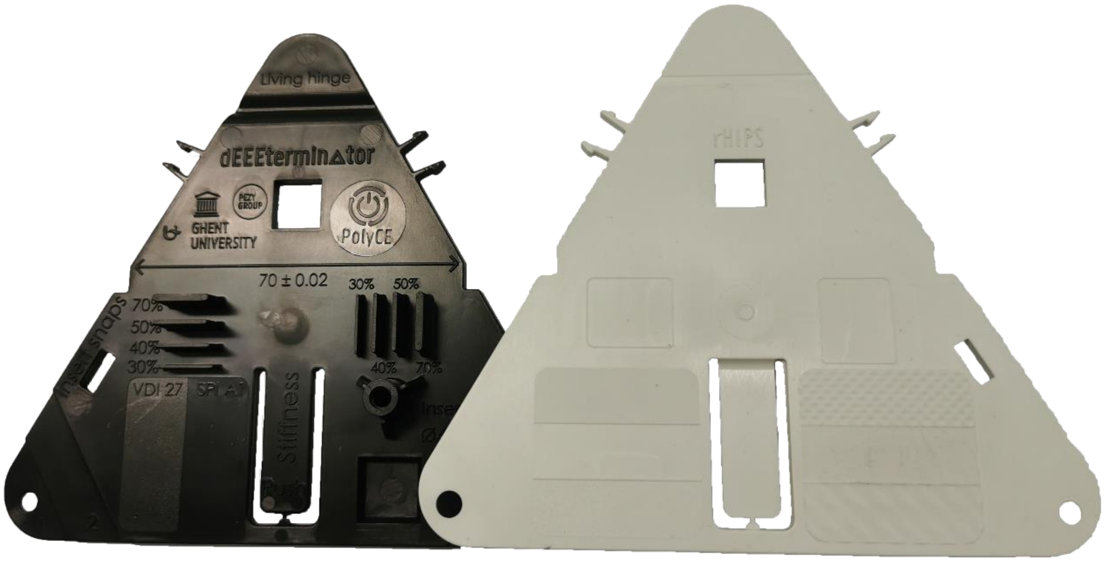

Figure 8 Moulded examples of the dEEEterminator in rABS and rHIPS

5 dEEEterminator box

The complementarity of the design guidelines and the dEEEterminator makes it a logical choice to combine them as a whole. Combined in a design box they form an ideal starter kit to boost the use of PCR WEEE plastics being it in the EEE sector or other.
The dEEEterminator box is used as a carrier for sixteen different dEEEterminator tactile design tools and the Design from Recycling guidelines. The possibility to add many different materials gives great advantages towards the product designer. It gives to possibility to make a decision from a wide selection of recycled materials, not to restrict any decisions made. Above this, it also makes it very easy to compare materials for less experienced developers. In order to complete the practicality of the box, technical datasheet cards are included. With this total experience Design from Recycling tool it is possible to lower the bar for implementation for high-end recycled WEEE plastics in industry. Additionally, from the experience gained from the various demonstrator cases, it is possible to add real life experiences. These design experiences will be part of WP8 and will, after completion, be added to the dEEEterminator Box. The box targets product developers and designers alike, and gives them all the tools and knowledge needed to implement the use of recycled materials in EEE-products of tomorrow. The content of the dEEEterminator box is visually represented in Figure 9.

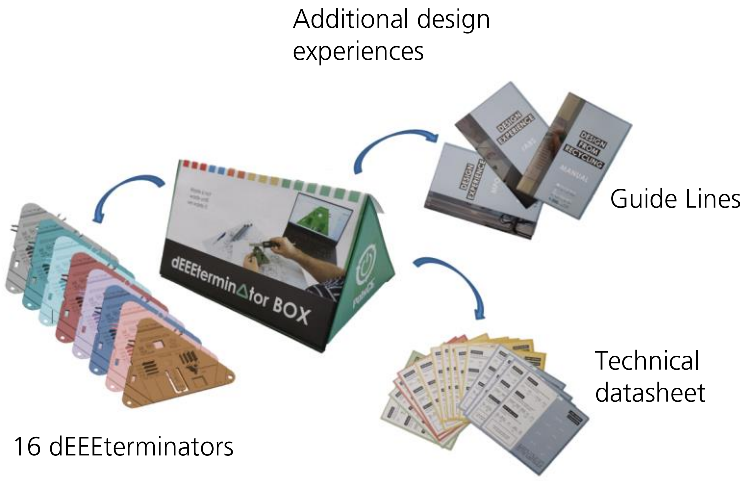

Figure 9: dEEEterminator box content

On Figure 10 it is possible to see all the information that is represented on the outside of the box. Next to the obligatory logos of the PolyCE project and the Ghent University, an introduction of the PolyCE project is given together with all the partner logos to give the user a general idea of the project and its goals. On a separate location a link to the website of the project is added making it easy for the user to get more detailed information. Key features of the dEEEterminators are given at a moment's notice when opening the box. A colour coded index on the closing lip makes it easy to find the required material and gives an overview of the materials present in the box.

Figure 10: Visual information of the dEEEterminator box

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