PolyCE

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

Project Duration:	**01/06/2017 - 31/05/2021**
Deliverable No.:	**4.1**
Deliverable Title:	**Report on minimum material requirements for the trails**
Version Number:	V180109v1
Due Date for Deliverable:	31/01/2018
Actual Submission date:	**27/02/2018**
Lead Beneficiary:	**KU Leuven- University of Leuven**
Lead Author:	Dr. Jef Peeters Florian Wagner Alexander Boudewijn Hans Ramon Dr. Jozefien De Keyzer Prof. Dr. Wim Dewulf Prof. Dr. Joost Duflou Dipl.-Ing. Arthur Schwesig

Deliverable Type: R
Dissemination Level: PU

Lead Author Contact: Dr. Jef Peeters
KU Leuven – University of Leuven
phone +32 16 32 25 59
e-mail: jef.peeters@kuleuven.be

Contributing Partners

UL, MGG Polymers, Sitraplas, Pezy group, UGent, ONA, Circular Devices; Whirlpool, Philips

Disclaimer

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730308

Summary

An overview is provided in this report on the minimum requirements for distinct plastic grades of the different post-consumer recyclate (PCR) types targeted in the PolyCE project for different stages in the value chain.

The requirements are defined for the following two stages of the value chain: 1.mixed plastic flakes from WEEE, which are the plastics separated from WEEE by pre-processors, 2. post-consumer recyclates compounds, which are the compounds supplied to the original equipment manufacturers that are produced from sorted and cleaned mixed plastic flakes

Performed analyses have demonstrated that the requirements strongly depend on the targeted application and that distinct requirements, such as size distribution, humidity, mechanical, aesthetic, flame retardant, bromine concentration, metal content, etc., are considered depending on the stage of the plastic material value chain. To define the minimum requirements, input was gathered from all project partners with knowledge on plastic sorting, compounding and the production of plastic components and is translated in a shortlist of uniform requirements to which PCR grades should minimally comply to be applied in the applications considered by the original equipment manufacturers of the PolyCE project.

Content

1 Introduction: Why minimum requirements for PCRs?

As there are no standard quality criteria for PCR plastics, the required material performances are today mostly agreed on a case-by-case basis between the WEEE pre-processor, the mixed plastic flakes sorter, the compounder producing PCR compounds and the original equipment manufacturer (OEM) using the PCR in production of new or existing equipment. Aiming to improve the industrial cooperation among all actors of the value chain and increase the use of PCR in Europe, the PolyCE project objective is to develop a uniform grade system for PCR plastics, which can be used to classify PCRs according to their applicability for a final use. It has also been recognized by the European plastic industries represented by Plastics Europe that: "EU-wide quality standards for plastic waste and its treatment should be developed, including specifications for sorted waste, harmonization of test methods for recycled plastic materials and certification of plastic recycling operations (Plasics Europe, 2017)."
To achieve this objective it is first of all important to obtain a good understanding of existing standards to evaluate the quality of PCRs at different stages of the value chain. Therefore, this report first describes the scope of the presented research by defining for which type of companies and organizations existing standards have been investigated and for which plastic materials considering the entire value chain from minimum requirements of mixed plastic flakes to minimum requirements of final recyclate compounds. Thereafter, the method is explained which was used to, on the one hand, determine a shortlist of plastic recyclate properties that should be tested and according to which standards these properties should be tested, and, on the other hand, to specify minimum requirements for plastic recyclates for the envisaged applications of the OEMs that are partners of the PolyCE project.
The short list of PCR properties to be tested and standards to be adopted to facilitate international communication between recyclers and OEMs and ease the identification of PCR for a broad variety of injection moulding and extrusion applications, will be used as a starting point for task 4.3.: "Development of standard and systematic testing procedures for the different types of PCR to determine the PCR grade and to control quality consistency across the material value chain." The defined minimum requirements will be used to start up the discussion within later Work Package 5: "Create eco-innovative and sustainable polymer compounds for the electronics industry", and Work Package 7: "Circular economy solutions for the environmentally sustainable reuse of PCR plastics - large scale demonstration prototypes" to identify which recyclates could be used for which applications and/or to which extend the material should be improved or modified.

2 Standards and requirements for PCR for whom?

Companies and organizations can be categorized in many different ways, but one of the most commonly adopted categorizations is by type of activities they perform. In case of recycling companies, the categorization in terms of the activities performed by recycling companies is in many cases difficult due to the vertical integration of many recycling companies, which today perform a broad variety of activities. Nonetheless, most recycling companies or their business units can still be assigned to one of the three categories shown in Figure 1.

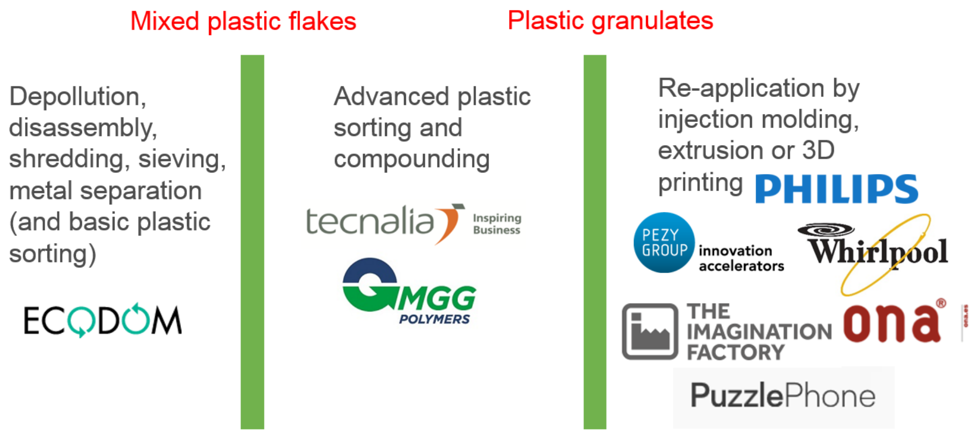

Figure 1 The stage for mixed plastic flakes and compounded granulates with respect to the activities of the industrial PolyCE project partners

To improve the communication among these different companies and business units related to plastic recycling, two distinct stages in the value chain should be considered. The first stage involves the pre-processors and compounders. The pre-processor receives complete products from collection centres and separates different types of metals from a mixed plastic fraction. Several pre-processors will not only separate the metals from the plastics, but also separate different plastic grades and/or qualities from the waste products. The compounder will perform an extrusion process in which the plastic flaxes received from the pre-processor will be homogenized, mixed with additives or other materials and granulated. In many cases the compounder will also perform a sorting step to improve the purity of the input to the compounding process. The second stage includes the compounder and the original equipment manufacturer, of which the latter uses a compound in the form of granulates to produce components for new products.
The main difference between these two stages is that at the first stage the material can be best described as mixed plastic flakes which are heterogeneous both in terms of material and size, whereas the material in the second stage can be best described as homogenous both in terms of material and size. In prior research it has been demonstrated that a compounding step is not always required, which offers the advantages of a lower processing cost and less material downgrading due to the avoided heat cycle (Wagner et al., 2016). However, direct injection moulding of PCR without intermediate melt filtration step is rarely performed due to the risk of remaining (metal) impurities in the PCR which could damage the mould. Therefore, compounding with melt filtration for the removal of impurities and the addition of additives is state of the art in the recycling industry.

Because of the prior mentioned reasons and the substantial differences in shape and homogeneity of the materials in these two stages, minimum requirements and testing procedures are being developed for the material at the stage of mixed plastics and compounded plastic granulates.

3 Standards and requirements for which PCR?

Every thermoplastic can be mechanically recycled and even thermosets can be used as fillers in the production of new thermosets. Accordingly, minimum requirements are relevant for every type of plastic. However, the PolyCE project only focusses on closing plastic material loops for (W)EEE. Therefore, the scope of the presented research is limited to those plastics commonly used in EEE. Since the partners of the PolyCE project partners predominantly use injection moulding and extrusion techniques for plastics, and not or only to a limited extend other production techniques, the scope is also limited to defining minimum requirements for plastics commonly adopted in EEE injection moulding and extrusion applications. The considered plastics can be grouped as follows and can in specific cases contain brominated (Br) or phosphor (P) based flame retardant (FR) additives, glass fibre (GF) and/or talc.

Table 1 Overview of the presence of plastic types and additives in the scope of the presented study

Full plastic name	Abbreviation	ISO	Br FR	P FR	GF	Talc
(High) (Impact resistant) Polystyrene	(HI)PS	19063	possible	exceptional	infrequent	exceptional
Acrylonitrile-Butadiene Styrene	ABS	19062/ 2580	possible	exceptional	infrequent	exceptional
	PC/ABS		exceptional	possible	possible	exceptional
Polypropylene	PP	19069	exceptional	exceptional	frequent	possible
Polycarbonate	PC	7391	exceptional	exceptional	possible	exceptional

4 Existing standards to evaluate virgin plastics and PCR

This section provides an overview of existing standards that can be used to compare mixed plastic flakes and granulated plastic compounds and to evaluate their applicability for injection moulding or extrusion for application in EEE. It was compiled based on information provided by the partners of the PolyCE project partners.

4.1 Existing standards for specimen preparation

Plastic specimens are today commonly produced by means of different production techniques and in different shapes. Commonly used production techniques for plastic specimens are: injection moulding, compression moulding or extrusion and cutting out of a plate, as described in the standards listed in Appendix 8.1. While the preparation procedures are standardized they provide a certain degree of freedom regarding the process parameter, which is required to allow material specific processing and specimen production. Since the adopted production technique strongly influences the internal structure of the plastic specimen, also the properties of the plastic material can be strongly influenced by the adopted specimen preparation technique. In addition, the shape can also influence the aesthetic and mechanical performances, for example difference in aesthetic properties due to surface roughness and difference in mechanical properties due to notch effect (with unnotched testing). Therefore, more transparency is required in the display of applied production techniques and process parameters to allow comparative and reproducible properties, regardless if the tested plastic is recycled or virgin.

Therefore, to facilitate communication and allow correct comparison between different types of PCRs in the project, it is crucial that the same specimen preparation technique is adopted with the same processing parameters or that the adopted specimen preparation technique and processing parameters are communicated along with other material testing results to indicate when specific properties cannot be compared (e.g. recommended processing parameters on datasheets).

4.2 Existing material processing standards

The material standards named “Plastics – Polymername (Abbreviation) moulding and extrusion materials” consist of “Part 1: Designation system and basis for specification” and “Part 2: Preparation of test specimens and determination of properties”.
In Part 2 processing conditions for injection moulding and extrusion are defined based on classifications made in Part 1. For instance in ISO 2897 the types of polystyrenes are differentiated based on their impact resistance by a classification system, which is based on appropriate levels of the designated properties: a) Vicat softening temperature, b) melt flow rate, c) Izod impact strength, d) flexural modulus and on information about the intended application and/or method of processing, important properties, additives and colourants. In Part 2 the methods of preparation of test specimens and test methods to be used in determining the material properties, such as, for instance, injection moulding parameters (melt temperature, mould temperature, injection velocity), conditioning of the test specimens, as well as appropriate testing methods and test conditions for this material (selected from ISO 10350 single data point) are defined.
Hence, the material standards contain crucial data to achieve comparable properties from the testing with standardized testing methods as the defined processing and testing conditions may strongly influence the measured properties. The list of material standards shows that not all plastics are covered. For example, no material standards are available for PC/ABS, whereas this is a blend of a polymer and a copolymer that is often applied

in electronic products. A material standard for PC is available as well as a material standard for ABS. However, both standards contain different parameters and no specification for the blends is available.
Therefore, it is, on the one hand, important that the processing parameters are adopted as described in existing standards and, on the other hand, that material standards are available for all materials, which will require the development of a material standard for PC/ABS in the next 5 years, as the amount of this plastic in electronics is expected to increase.

4.3 Existing testing standards for mixed plastic flakes

Only a limited number of standards were retrieved, as shown in Appendix, to assess mixed plastic flakes and most of the retrieved standards adopt a rather qualitative assessment of the quality or list the properties to be assessed without describing a method how these properties should be assessed in a quantitative manner.

4.4 Existing testing standards for compounded plastic granulates

As listed in the Appendix, a large number of testing standards exists to quantify the quality of compounded plastics granulates. To determine the minimum requirements for compounded plastic granulates, a comprehensive list of available testing procedures was compiled from the documents shared by the partners of the PolyCE project through the PolyCE file share server. Additionally, standards and testing techniques mentioned in the datasheets of Sitraplas and MGG Polymers were included in the overview. Furthermore, testing procedures considered potentially relevant by KU Leuven were added. The list was sent out to Whirlpool, PuzzlePhone, ONA and Philips with the request to mark the standards considered relevant and extend the list with new tests/standards/properties if considered relevant.

Based on the gathered list of existing standards it could be concluded that already many testing methods exist at the stage of plastic compounds. As these techniques apply to both virgin and recycled plastic no need for differentiation between recylclates and virgin plastics is seen and further developments of testing techniques at the stage of compounded plastic recyclates is not required. However, in contrast to virgin materials for which all retrieved testing standards were developed, it should be considered that recycled plastics may have suffered degradation during their lifetime and the reprocessing. To capture possible property flaws due to degradation, it can be considered to include the testing of the oxidation index, yellowing and rheological testing. As based on experience of MGG Polymers in most cases the degradation is not cause of large quality losses and the source is more relevant, these testing techniques are not considered relevant for the evaluation of minimum requirements at the stage of compounded plastics.

4.5 Method for minimum requirements for PCR mixed plastic flakes

In theory every fraction of mixed plastic flakes can be sorted out to be recycled, whereas the overall yield and final purity of the fraction will strongly depend on both the input material composition and the adopted separation processes, as well as the (melt filtration) compounding processes. Accordingly, it is important to understand how plastic separation processes work to understand which properties of a fraction of mixed plastic flakes influences the separation efficiency and to understand which impurities influence the quality of the final compound and to which extend they influence the final quality.

While considering this already high complexity, it should also be taken into account that some deficiencies of the separation process can also be countered or compensated in the compounding process, for example by mixing PCR with virgin plastic material. As a result, the minimum requirements for mixed plastic flakes depend on too many technical and economic factors to determine these requirement in a non-subjective manner. For this reason, the properties of mixed plastic flakes that are considered to have a significant influence on the separation efficiency, final purity and applicability of the compound produced from it, as well as the minimum requirements for these properties, are defined based on expert interviews.

4.6 Method for minimum requirements for PCR compounds

The material selection process can be summarized in four steps, which are shown in Figure 2. In the translation step the company summarizes design requirements and translates them into material property values that are necessary to fit the minimum requirements of a certain component to be produced. The properties and corresponding values are then used to do a first screening of materials available on the market to identify potentially applicable materials, which are then ranked based on internal priorities. The resulting top ranked materials are then tested in order to evaluate the properties in the application and make a final decision. This last step of the final application and internal testing is crucial as the final properties of a plastic are a result of the material itself and its processing into a component. It is therefore not possible to fully reflect the properties based on standard testing procedures. Additionally, not all the necessary properties required by internal quality schemes of companies, are tested by the material providers, as these tests can be very application specific and costly.

1.Translation: Express design requirements

2.Screening: Elimination of materials by minimum requirements

3.Ranking: Selection of most suitable materials

4.Final evaluation: Final testing

Figure 2. Process of material selection.

In the context of the PolyCE project the goal is to determine minimum requirements for recycled plastics in order to ease the communication between the material supplier and the OEMs and evaluate the applicability of different recycled plastics in electrical and electronic applications. The determination of minimum requirements was defined to be best suited at the state of a screening process in the material selection. A comprehensive list of properties and standards was compiled based on commonly tested properties, requirements of OEMs and additional standards designed for recycled plastics, as well as knowledge from previous projects. Since this list of possible standards is long and performing all these analyses would be too costly a method to determine the minimum requirements at this stage was developed in the form of a shortlist. This defined list of properties is used as a starting point to develop a testing procedure for PCR. Afterwards, the properties of the commercially available PCRs, that have been supplied by MGG Polymers and Sitraplas, are compared with the ranges and minimum requirements defined by the developed shortlist in order to find material matches or discrepancies for the applications envisaged in the PolyCE project.

5 Proposed minimum requirements for PCRs

5.1 Proposed standards to be adopted to determine the minimum requirements for PCR mixed plastic flakes

Limited number of standards are identified that describe an unambiguous procedure to assess the quality or value of mixed plastic flakes in a quantitative manner. One of the most important factors influencing the quality is the purity and type of impurities, in other words the composition of the fraction. Either the purity or a maximum threshold for specific impurities are sometimes provided. For example, in the recycled standards series from the EN 15347, EN 15342, EN 15344, EN 15345, EN 15346, EN 15348 tests are mentioned with regard to the purity of recycled plastics. However, different standards apply for different materials and the impurities are displayed differently depending on the material. For instance, the assessment and display of the *PVC content, Polyolefin content, Other residual content* is requested in EN 15348 for recycled PET, while the standard for recycled PVC (EN 15346) requires the determination of *Impurities* and the standard EN 15345 for recycled PP declares the assessment of *Extraneous polymers* as optional. In addition, these standards do not include a description of unambiguous testing or analysis methods that should be adopted to determine the purity in a quantitative manner.

One of the testing methods that could be used is the near infrared spectrometer produced by IOSYS (Seidel, 2017), which is mounted on a XY table and can be used to randomly sample a mixed plastic fraction, as shown in Figure 3. However, due to the high absorption rate of NIR of dark plastics this technology cannot be used for analysing mixed plastic flakes that contain non-dark plastics, whereas in every WEEE category except fridges also dark plastics are frequently encountered. Therefore, there is a need for the development of techniques to determine the material composition of dark mixed dark plastic flakes in a quantitative unambiguous manner. In addition, the development of techniques to determine the degree of degradation of the polymer itself is considered of high value, specifically when considering that increased degradation could be the result of a circular economy with multi-stage recycling of plastics, even if the possible number of cycles and the amount of virgin material needed to compensate losses, still needs to be determined for a realistic scenario.

Figure 3 Near infrared spectrometer to analyze non-dark mixed plastic flakes to determine the composition

Next to the material composition also the size of the flakes has a substantial influence on the sorting efficiency and the yield of the plastic sorting process. Mainly for optical sorting processes in which plastic flakes are spread on a moving belt, optically analysed and afterwards blown out selectively, the size strongly influences the sorting efficiency, as the samples should ideally be about 50mm in diameter to improve the capacity which is generally limited by the analysis speed. For other processes, such as sink-float and electrostatic separation, a homogenous size of about 10mm diameter results in the highest separation efficiency, whereas a too high dust content should be avoided to allow proper functioning. In industry sieving is commonly used to determine the percentage of dust material. However, no standards were encountered that allow a good quantitative assessment of the size distribution, which again did not allow to specify minimum requirements for mixed plastic flakes. Therefore, there is a need for the development of techniques to determine the size distribution of mixed plastic flakes.

5.2 Proposed standards to be adopted to determine minimum requirements for and evaluate the applicability of compounded plastic granulates

A shortlist of standards and tests is created in order to identify the minimum requirements for plastic recyclates that can serve as a basis for communication between OEMs and recyclers to specify the requested and available material properties in a transparent, unambiguous and reproducible manner.

Information available on the PolyCE server from datasheets of the recycled and virgin plastics in the project, together with standards for recycled plastics from the British Standards series (EN 15342, EN 15343 EN 15344, EN 15345, EN 15346, EN 15347 and EN 15348) and Bales Characterization Guidelines from the Plastics Recyclers Europe, were compiled to a list. Additionally, properties and standards that were considered relevant by research partners as well as by the OEMs Philips, Whirlpool, ONA and PuzzlePhone were added to the list. A conceptual display of the method to create a list of minimum requirements for recycled plastics can be seen in Figure 4.

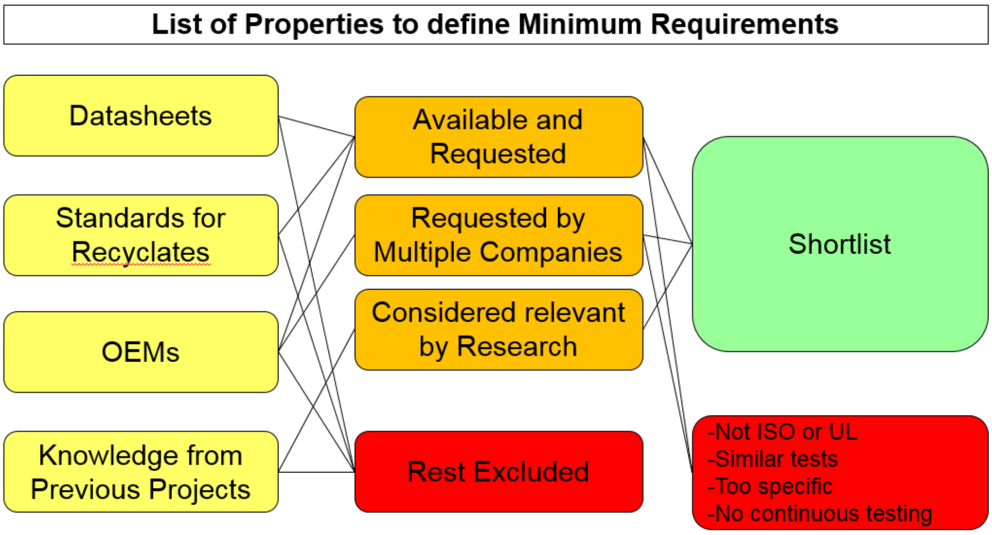

Figure 4. Method to create a shortlist for the determination of minimum requirements for recycled plastics.

In a first step the compiled list was minimized by only considering properties and standards relevant that:

- are both available in material datasheets and requested by multiple OEMs from the consortium of the PolyCE project (Pezy group, ONA, Circular Devices; Whirlpool, Philips)
- are considered relevant by multiple OEMs or recyclers (MGG Polymers, Sitraplas)
- are considered relevant by the involved researchers.

In a second step, standards and tests that could not be implemented in a continuous quality testing scheme by recycling companies, due to the relatively high testing costs and/or the limited availability of required testing equipment were removed. The standard testing methods that were excluded from the shortlist are:

- the drop test (PuzzlePhone and Philips internal testing techniques) with the recommendation to translate the drop test result into available impact testing values from Charpy testing ISO 179.
- the transport test (Whirlpool and ONA internal testing techniques) and the weldability test (Whirlpool and PuzzlePhone internal testing techniques) were considered too application specific.
- whereas the purity significantly influences the quality of the recycled content, no standards to inform on the purity of the compounded plastic granulates are included in the short list. This is excluded because information on the purity does not provide direct insights in the applicability of compounded plastic granulates and because the effect of impurities is already reflected in all other standards that are included in the short list of standards.
- the environmental stress cracking and Chemical Resistance were removed as they referred to company internal standards and it was not clear whether the same tests/testing conditions apply. As this test is known to be relevant it should be evaluated whether it could be included in the shortlist with referral to ISO standards.
- The RTI temperature was excluded as the testing procedure is too expensive to be included for minimum requirements

Additionally, the filler content is considered to be demanding to test and might therefore not be possible to be conducted batchwise (which is roughly defined tom be one truckload of approximately 22-25 tones). This also applies to the UL registered requirement. Additional harmonization was conducted by removing standards that deliver very comparable information, such as Izod notched ISO 180/Charpy notched ISO 179 and the Vicat softening point ISO 306 and the Heat Deflection Temperature ISO 75.Furthermore, if properties were tested with different standards, harmonization was conducted, where official ISO and UL standards were preferred over internal company or national standards, to guarantee comparable results and the feasibility of international adoption of the developed shortlist of standards. The RoHS and REACH compliance are also included in the shortlist as the recycled material needs to comply with these standards and mentioning them would improve communication and reduce a possible hesitation to choose recycled plastics. The flammability rating UL 94 was required by multiple companies and can be delivered by recyclers and therefore is included in the shortlist. However, it is considered an application specific property that could be excluded if a more general shortlist should be defined.
The properties considered relevant by research partners were:

- The declaration of the recycled content (e.g. EN 1534) to avoid confusion between post-consumer recyclates, industrial recyclates and blends of post-consumer and/or industrial recyclates and virgin plastics (e.g. EUCertPlast compliance).
- The transparency regarding the production parameters of the specimens that should be mentioned on the datasheets (ISO 19069, ISO 19062, ISO 2580, ISO

19063, ISO 7391, ISO 293, ISO 20753, ISO 294) so that the type of specimen, the specimen production (e.g. nozzle temperature/melt temperature, mould temperature) can be reproduced

Table 2. Proposed shortlist of standards to assess the quality of compounded plastic granulates

Available and requested		
Colour	Aesthetical	ISO 11664
Tensile stress at Break	Mechanical	ISO 527-2/50
Tensile Strain at Yield	Mechanical	ISO 527-2/50
Tensile Strain at Break	Mechanical	ISO 527-2/50
Flexural Modulus (23°C)	Mechanical	ISO 178
Tensile Modulus (23°C)	Mechanical	ISO 527-2/1
Tensile Strength (23°C)	Mechanical	ISO 527-2/50
Charpy Unnotched (23°C)	Mechanical	ISO 179-1eU
Charpy Notched (23°C)	Mechanical	ISO 179-1eA
Density	Physical	ISO 1183
Melt Flow Rate	Rheological	ISO 1133
Vicat Softening Point	Thermal	ISO 306/A50
Heat Deflection Temperature	Thermal	ISO 75
Shrinkage at Production	Dimensional stability	ISO 294-4
Flammability Rating	Flammability	UL94HB
RoHS Compliant	Safety	201165EU
REACH Compliance	Safety	
Requested by multiple companies		
Gloss	Aesthetical	ISO 2813,
Tensile stress at yield	Mechanical	ISO 527-2
UL registered	Others	
Filler content	Purity and chemical properties	ISO 3541-4
Food contact approval	Safety	EC10/2011
Considered relevant by research		
Recycled Content	History	EN 15343
Transparency in preparation and testing	Specimen preparation	ISO 19069, ISO 19062, ISO 2580, ISO 19063, ISO 7391, ISO 293, ISO 20753, ISO 294

The defined shortlist was created based on data and knowledge provided by UL, MGG Polymers, Sitraplas, Pezy group, UGent, ONA, Circular Devices; Whirlpool, Philips and KU Leuven and serves as an input for task 4.3 and WPs 5 and 7 in the PolyCE project. However, the list was defined at an early stage of the project and further development during the project is possible as it is planned to include experiences from the demonstrator trials in task 4.3 at a later stage of the project.

5.3 Proposed minimum requirements for the applicability of compounded plastic granulates for the OEMs of the PolyCE project consortium

The shortlist of minimum requirements identified in chapter 5.2 was applied to the requirements set by the OEMs in the project and compared to the properties provided by the material suppliers in order to identify properties that limit the application of the recycled plastics. The OEMs were asked to fill in property values with a colour code, by marking the values in red or blue, to define which values are required and which are optional. For every desired plastic and application of the OEMs, the best fit in recycled plastic was identified and property restrictions were analysed

The main issues limiting the applicability based on the shortlist are:

- Colour
- Charpy impact strength
- Tensile Modulus
- Density

Polystyrene (PS) – The main constraint is the colour requirement, which is currently under development to be achieved. Colour or gloss, are key properties for the production of visible plastic components that often determine whether a recycled plastic can be considered for a certain application. The colour requirements can often not be fulfilled as recycled plastics from WEEE are most commonly black and only a limited amount of PS from electronics is white (e.g. Polystyrene from fridges). Further communication between OEMs and the recyclers will be necessary to determine whether the required shade of white can be achieved or colour requirements from the OEM side can be adapted.

Polypropylene (PP) talc filled – the available recycled PP with talc currently does not fulfil the desired tensile modulus. Developments to achieve a higher Young's modulus of 3000-4000 MPa are currently running.

Polypropylene (PP) unfilled – the minimum notched Charpy impact strength mentioned on the datasheet of the recycled polypropylene did not reach the required of 7,5 kJ/m². An improvement of the minimum value is not expected to be a large hurdle and is currently under development.

Acrylonitrile Butadiene Styrene-(ABS) the notched Charpy impact strength was identified to be 2 kJ/m² lower than required. A more narrow standard deviation of the impact values to increase the minimum value mentioned on the datasheet is currently under development.

Beside the identified properties that limit the application for the OEMs, missing information did not allow to further define mismatches in properties. The main properties that were considered relevant by the OEMs, but not mentioned in all datasheets were:

- Gloss
- Shrinkage at production
- Flammability
- Flexual modulus
- Strain at Yield
- Strain at break

- Filler content
- Melt flow rate
- Heat deflection temperature

Gloss, strain at yield and strain at break are properties that are measured regularly. They therefore could be provided on the datasheets without additional testing. The MFI is most commonly mentioned in datasheets, however, different testing temperatures and weights mentioned in the requirements did not allow matching of the values. This could be harmonized by applying the material standards mentioned in secti0n 4.2, which propose testing conditions for MFI.

The flammability, flexural modulus, filler content, shrinkage at production and heat deflection temperature are occasionally measured by MGG Polymers and Sitraplas. However, not all materials and batches are tested with these methods. Providing this data might therefore include additional testing.

5.4 Proposed quality assurance for PCR

In the datasheets of plastic recyclates mostly the average value is reported for tests performed according to a specific standard, without reporting on the possible variation of these properties (e.g. colour). It can be expected that OEMs would also like to have information on the variation on specific values to anticipate/avoid production errors. The following possibilities were identified to enable recyclers to assure a certain quality:

- report the average together with the measured variation and perform regular analysis to confirm that the variation is less than reported in the datasheets
- report a minimum and maximum for every value and perform regular analysis to confirm that the variation is less than reported
- report the average together with an assurance of a stable process by certification of the production

However, the communication of a variation or minimum and maximum is more difficult as disadvantages for recyclers need to be considered as this is also not common practice for virgin plastic datasheets. Since most recyclers have only variations in the type of input material and the number of samples and analyses to be performed at the stage of mixed plastic flakes and compounded plastic granulates is targeted to be rather limited, it is proposed to focus on the development of a method to assure that a stable process is adopted.

6 Conclusions and future work

The values of the properties provided by the project partners and defined in a shortlist are not set of specifications, as the details of the demonstrators will be discussed in WP7. The requested information will at this stage serve to obtain a good idea of the direction we should be heading for in this and later work packages.

Properties of plastics change as the materials are processed. Key to maintaining performance through the supply chain is establishing a minimum set of requirements and cost-efficient methods and processes to track changes in performance and verify the material content throughout the plastic value chain. One of the most difficult issues with recycled plastic materials is chemical content introduced purposely and accidently during recycling. The potential of substances of concern introduced during recycling can limit the use of recycled content material, where the biggest risk of contamination are not well defined input clusters. To the greatest extent possible a program of hierarchical testing using existing standards is envisioned which will help define the final grades of recycled content material. On the one hand, the applicability of methods for reliable sample taking and the applicability and reliability of a variety of industrially available techniques, such as laser induced breakdown spectrometry (LIBS), Fourier transform infrared spectroscopy (FTIR) and x-ray fluorescence, to identify impurities and material downgrading in a cost efficient manner for plastics from pre-processors will be investigated, as well as opportunities to improve these techniques and the commonly used libraries. On the other hand, the optimal combination of rheological and mechanical testing methods to evaluate the quality and applicability of compounded PCRs will be investigated, such as the PC-ABS from MGG Polymers which was tested to be RoHS and REACH compliance by SGS, V0 by UL, etc. The outcome will be a method for recyclers, compounders and designers to obtain the information needed to assess the appropriateness of a particular plastic grade for the envisioned application.

Figure 5 Simplified example of ambitioned future communication between OEM and suppliers of PCR

A survey has been developed together with Ecodom to identify the standards/methods used today by pre-processors (see WP3).

For the definition of minimum requirements of recycled plastics two main stages have been identified, the stage of mixed plastics and the stage of the final plastic compound. Both stages are relevant for the final evaluation and grading of a recycled plastic. At the stage of mixed plastics a lack of standardization and availability of sufficiently adapted testing procedures was observed which will further be defined and investigated in the project. Possibilities are seen at this point in a more standardized working procedure throughout the recycling chain and the development of new testing procedures for mixed plastic flakes. Additionally, it will be important to at all stages consider costs as well as opportunities to use information gathered at the stage of mixed plastics and possibly avoid testing at the stage fo the final compound. At the stage of a final compound, the most significant role of minimum requirements is seen to be for a pre-screening process in material selection (e.g. datahseets), where no significant differences in data required on datasheets of recycled plastics compared to virgin plastics were observed. However, possibilities for improvement are seen in terms of transparency in order to guarantee comparability of results as well as on a more harmonized display of properties as defined by a proposed shortlist. At the stage of the final plastic compound a shortlist of relevant material properties was created from compiled standards and tests that are performed and requested by OEMs, recyclers and research institutes. This shortlist is designed to consider both the needs of the recyclers as well as those of the OEMs. It could work as a basic communication tool for pre-screening of recycles plastics and should include main quality aspects of the recycled plastics that can be tested on a regular basis by the material suppliers. A defined shortlist could help OEMs to translate application specific requirements into standardized tests, as today different standards and testing parameters are applied to achieve the same results, which in many cases results in incomparable values. Additionally, a stronger transparency will be required regarding the preparation of specimens as well as testing parameters in order to guarantee comparability of the results and reproducibility by applying the standards ISO 19069, ISO 19062, ISO 2580, ISO 19063, ISO 7391, ISO 293, ISO 20753, ISO 294. In this report a first shortlist is provided in section 5.2 that should serve as a basis for discussion with all project partners.

For the definition of minimum requirements for recycled plastics based on this shortlist, it could already be shown that colour and aesthetical requirements of recycled plastics are considered very important by OEMs. In the definition of a shortlist for recycled plastics this is reflected in the colour and gloss properties, which were considered relevant by the OEMs. This confirms also previous experiences, where these requirements often determined whether a recycled plastic can be considered.

However, it could already be identified that many of the minimum requirements from the OEMs side are very application specific and are defined specifically for a material in a certain application. The definition of minimum requirements can provide a first screening of materials to identify potentially applicable recycled plastics. However, it is not possible to fully reflect all requirements of the final application in the pre-screening process. This needs to be considered for the formulation of what is defined as a minimum requirement. A more general definition of minimum requirements can be achieved by identifying key properties that allow a first pre-screening process. For this purpose it will be necessary to further translate application specific requirements into properties that are listed in a shortlist, which sufficiently covers main quality aspects for recycled plastics.

Further research in this field will be necessary to get more information from the OEMs in the project on which properties are key aspects in a pre-screening process. As the translation from the minimum requirements of the final application into minimum requirements that can be tested on a regular basis by the recycler is limited, it is important to establish key properties that can capture the majority of the requirements and give a good indication whether the recycled plastic could be applied or not, to allow a subsequent ranking and final testing in the application.

7 References

- Plastics Europe, 2017. Plastics value chain restates its commitment to Circular Economy Package.
- Seidel, T., sIRoGran – scanning NIR-Spectrometer for Granulates/Flakes, 2017, http://www.iosys-seidel.de/en/sirogran.html
- Wagner, F., Peeters, J., De Keyzer, J., Duflou, J., Dewulf, W., 2016. Evaluation of the quality of post-consumer recyclates obtained from distinct recycling strategies, Proceedings of the 7th Bi-Annual International Polymers & Moulds Innovations Conference, pp. 307-312.

8 Appendix

8.1 Standards for specimen preparation

ISO 293 *Specimens from compression moulding*

Plastics - Compression moulding of test specimens of thermoplastic materials (ISO 293:2004)

ISO 294 *Specimens from injection moulding*

Plastics - Injection moulding of test specimens of thermoplastic materials - Part 1: General principles, and moulding of multipurpose and bar test specimens (ISO 294-1:2017)

Plastics - Injection moulding of test specimens of thermoplastic materials - Part 2: Small tensile bars (ISO 294-2:1996)

Plastics - Injection moulding of test specimens of thermoplastic materials - Part 2: Small tensile bars (ISO 294-2:1996/Amd 1:2004)

Plastics - Injection moulding of test specimens of thermoplastic materials - Part 3: Small plates (ISO 294-3:2002)

Plastics - Injection moulding of test specimens of thermoplastic materials - Part 4: Determination of moulding shrinkage (ISO 294-4:2001)

ISO 2818 *Notching*

Plastics - Preparation of test specimens by machining (ISO 2818:1994)

ISO 3167 *Specimens*

Plastics - Multipurpose test specimens (ISO 3167:2014)

ISO 3002 *Basic quantities in cutting and grinding*

ISO 20753

Plastics – Test specimens

8.2 Standards for the materials in scope

ISO 2897 *HI-PS*

Plastics - Impact-resistant polystyrene (PS-I) moulding and extrusion materials - Part 1: Designation system and basis for specifications (ISO 2897-1:1997)

Plastics - Impact-resistant polystyrene (PS-I) moulding and extrusion materials - Part 2: Preparation of test specimens and determination of properties (ISO 2897-2:2003)

ISO 2580 *ABS*

Plastics - Acrylonitrile/butadiene/styrene (ABS) moulding and extrusion materials - Part 1: Designation system and basis for specifications (ISO 2580-1:2000)

Plastics - Acrylonitrile/butadiene/styrene (ABS) moulding and extrusion materials - Part 2: Preparation of test specimens and determination of properties (ISO 2580-2:1994)

8.3 Standards for testing plastics

ASTM E 313-05

Standard Practice for Calculating Yellowness and Whiteness Indices from Instrumentally Measured Color Coordinates

ISO 178 ***Flexure***

Plastics - Determination of flexural properties (ISO 178:2010)

ISO 179 ***Charpy***

Plastics - Determination of Charpy impact properties - Part 1: Non-instrumented impact test (ISO 179-1:2010)

Plastics - Determination of Charpy impact properties - Part 1: Non-instrumented impact test - Amendment 1 (ISO 179-1:2000/A1:2005)

Plastics - Determination of Charpy impact properties - Part 2: Instrumented impact test (ISO 179-2:1997)

Plastics - Determination of Charpy impact properties - Part 2: Instrumented impact test - Amendment 1: Precision data (ISO 179-2:1997/Amd 1:2011)

ISO 180 ***IZOD***

Plastics - Determination of Izod impact strength (ISO 180:2000)

Plastics - Determination of Izod impact strength - Amendment 1 (ISO 180:2000/Amd 1:2006)

ISO 527 ***Tensile Testing***

Plastics - Determination of tensile properties - Part 1: General principles (ISO 527-1:2012)

Plastics - Determination of tensile properties - Part 2: Test conditions for moulding and extrusion plastics (ISO 527-2:2012)

Plastics - Determination of tensile properties - Part 3: Test conditions for films and sheets (ISO 527-3:1995)(+AC:2002)

Plastics - Determination of tensile properties - Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites (ISO 527-4:1997)

Plastics - Determination of tensile properties - Part 5: Test conditions for unidirectional fibre-reinforced plastic composites (ISO 527-5:2009)

ISO 306 ***Vicat Softening Temperature***

Plastics - Thermoplastic materials - Determination of Vicat softening temperature (VST) (ISO 306:2013)

ISO 1133 ***MFI***

Plastics - Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics - Part 1: Standard method (ISO 1133-1:2011)

Plastics - Determination of the melt mass-flow rate (MFR) and melt volume-flow rate (MVR) of thermoplastics - Part 2: Method for materials sensitive to time-temperature history and/or moisture (ISO 1133-2:2011)

ISO 1183 ***Density***

Plastics - Methods for determining the density of noncellular plastics - Part 1: Immersion method, liquid pyknometer method and titration method (ISO 1183-1:2012)

Plastics - Methods for determining the density of non-cellular plastics - Part 2: Density gradient column method (ISO 1183-2:2004)

Plastics - Methods for determining the density of non-cellular plastics - Part 3: Gas pyknometer method (ISO 1183-3:1999)

ISO 1518 ***Scratch Resistance***

Paints and varnishes - Determination of scratch resistance - Part 1: Constant-loading method (ISO 1518-1:2011)

Paints and varnishes - Determination of scratch resistance - Part 2: Variable-loading method (ISO 1518-2:2011)

ISO 2813 ***Gloss***

Paints and varnishes - Determination of gloss value at 20 degrees, 60 degrees and 85 degrees (ISO 2813:2014)

ISO 10350 ***Single point data***

Plastics - Acquisition and presentation of comparable single-point data - Part 1: Moulding materials (ISO 10350-1:2007)

Plastics - Acquisition and presentation of comparable single-point data - Part 1: Moulding materials (ISO 10350-1:2007/Amd 1:2014)

Plastics - Acquisition and presentation of comparable single-point data - Part 2: Long-fibre-reinforced plastics (ISO 10350-2:2011)

ISO 11357 ***Differential Scanning Calorimetry***

Plastics - Differential scanning calorimetry (DSC) - Part 1: General principles (ISO 11357-1:2016)
Plastics - Differential scanning calorimetry (DSC) - Part 2: Determination of glass transition temperature and glass transition step height (ISO 11357-2:2013)
Plastics - Differential scanning calorimetry (DSC) - Part 3: Determination of temperature and enthalpy of melting and crystallization (ISO 11357-3:2011)
Plastics - Differential scanning calorimetry (DSC) - Part 4: Determination of specific heat capacity (ISO 11357-4:2014)
Plastics - Differential scanning calorimetry (DSC) - Part 5: Determination of characteristic reaction-curve temperatures and times, enthalpy of reaction and degree of conversion (ISO 11357-5:2013)
Plastics - Differential scanning calorimetry (DSC) - Part 6: Determination of oxidation induction time (isothermal OIT) and oxidation induction temperature (dynamic OIT) (ISO 11357-6:2008)
Plastics - Differential scanning calorimetry (DSC) - Part 7: Determination of crystallization kinetics (ISO 11357-7:2015)

ISO 11664 *Color*

Colorimetry - Part 1: CIE standard colorimetric observers (ISO 11664-1:2007)
Colorimetry - Part 2: CIE standard illuminants (ISO 11664-2:2007)
Colorimetry - Part 3: CIE tristimulus values (ISO 11664-3:2012)
Colorimetry - Part 4: CIE 1976 L*a*b* Colour space (ISO 11664-4:2008)
Colorimetry - Part 5: CIE 1976 L*u*v* Colour space and u', v' uniform chromaticity scale diagram (ISO/CIE 11664-5:2016)
Colorimetry - Part 6: CIEDE2000 Colour-difference formula (ISO/CIE 11664-6:2014)

8.4 Standards for recycled plastics

The series of British Standards “Plastics – Recycled plastics – Characterization of *polymername* (Abbreviation) recyclates” (NBN EN 15342, 15344, 15345, 15346, 1538) contain required and optional characteristics along with the according testing method. Both the required and the optional characteristics differ depending on the material.

NBN EN 15342

Plastics - Recycled Plastics - Characterization of polystyrene (PS) recyclates

NBN EN 15343

Plastics - Recycled Plastics - Plastics recycling traceability and assessment of conformity and recycled content

NBN EN 15344

Plastics - Recycled Plastics - Characterisation of Polyethylene (PE) recyclates

NBN EN 15345

Plastics - Recycled Plastics - Characterisation of Polypropylene (PP) recyclates

NBN EN 15346

Plastics - Recycled plastics - Characterisation of poly(vinyl chloride) (PVC) recyclates

NBN EN 15347

Plastics - Recycled Plastics - Characterisation of plastics wastes

NBN EN 15348

Plastics - Recycled plastics - Characterization of poly(ethylene terephthalate) (PET) recyclates

CEN/TR 15353

Plastics - Recycled plastics - Guidelines for the development of standards for recycled plastics

CEN/TS 16010

Plastics - Recycled plastics - Sampling procedures for testing plastics waste and recyclates

NBN EN ISO 16103

Packaging - Transport packages for dangerous goods - Recycled plastics material (ISO 16103:2005)

CEN/TS 16861

Plastics - Recycled plastics - Determination of selected marker compounds in food grade recycled polyethylene terephthalate (PET)

ASTM D5577 – 94
Standard Guide for Techniques to Separate and Identify Contaminants in Recycled Plastics
ASTM D5814 – 10
Standard Practice for Determination of Contamination in Recycled Poly(Ethylene Terephthalate) (PET) Flakes and Chips Using a Plaque Test
ASTM D5991 -09
Standard Practice for Separation and Identification of Poly(Vinyl Chloride) (PVC) Contamination in Poly(Ethylene Terephthalate) (PET) Flake
ASTM D6265 – 09
Standard Practice for Separation of Contaminants in Polymers Using an Extruder Filter Test
ASTM D6288 – 09
Standard Practice for Separation and Washing of Recycled Plastics Prior to Testing
ASTM D72009 – 06
Standard Guide for Waste Reduction, Resource Recovery, and Use of Recycled Polymeric Materials and Products

8.5 Standards additionally mentioned in the UL Yellow Card:

ASTM D 149 Dielectric Strength
ASTM D 257 Volume Resistivity
ASTM D 495 High Voltage, Low Current Arc Resistance
ASTM D 1042 Dimensional Stability
ASTM D 2303 Inclined Plane Tracking
ASTM D 3638 Comparative Tracking Index
ASTM D 3874 Hot Wire Ignition
IEC 60695-2-12 Glow-Wire Flammability
IEC 60695-2-13 Glow-Wire Ignition
IEC 60695-10-2 IEC Ball Pressure
IEC 60695-11-10 Flammability
IEC 60112 IEC Comparative Tracking Index
UL 94 Flame Class
UL 746A High Arc Ignition
UL 746B Relative Thermal Index