PolyCE

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

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1. Introduction

1.1. Task description

While the PolyCE project is focused on sustainably closing the loop for post-consumer recycled (PCR) polymers in electrical and electronical (EE) applications, it is conceivable to open this loop on the 'intake' side and to consider the use of PCR plastics from a different origin than waste from electronical and electrical equipment (WEEE). A primary waste stream to be eligible for this would be secondary resources from end-of-live-vehicles (ELV), as many of these products are composed of the same polymers typical to WEEE, such as ABS, PC and their blends. Other potential symbiotic streams have been identified within task 1.7. Within this task, it will be evaluated in how far these PCR plastics have the necessary properties to be eligible for reuse in EE products, thus letting the resource loops of other products blend into the one of WEEE.

1.2. Objectives & approach

Within this task the objective is to explore **other waste streams** for their suitability in **new EE application**. This report explores three challenging waste materials from non WEEE-sources.

This task deliberately explored materials with a high difficulty for implementation. The authors believe that materials that are easily recycled and implemented, which are sourced from other waste streams will find their way by efforts from industry itself. The opportunity given by the PolyCE project is thus used to **explore more challenging streams**. Three materials each having their recycling challenge were selected and explored.

- **Polycarbonate** (PC) sourced from building & construction (B&C) materials, used in low-end applications
- **Polystyrene** (PS) from upcoming new recycling technologies for post-consumer packaging waste
- **Polypropylene** (PP) from lab waste, currently not collected nor recycled

In this report, issues that can occur within recycling are tackled and results are used as input to **improve material quality**, enable use in **higher-end applications**, serve as **verification** of new recycling technologies and showcasing the **potential** of currently untapped sources.

The use of other input stream is not something reserved for the future but can already be seen as a valuable addition for the production of new EE products today. To showcase the possibilities, **examples** of the use of non WEEE-sourced materials in the other **demonstrator cases** are briefly discussed at the end of this report.

2. Polycarbonate case from Building and construction (B&C) sector

This case study investigates the feasibility to use PCR polycarbonate from B&C waste in hairdryer parts. At the time of writing, this material is only used in low-end application. With these trials the goal is to **explore the untapped potential** of this material stream and give **feedback to the supplier** on how the material performs and where the material is lacking. This in the end could result in revealing the potential of this waste stream which is now only implemented for downcycling. Selecting a PC source is also not randomly chosen. Within WEEE recycling, PC is often not recycled separately and is rather recycled together with PC/ABS. This results in having recycled PC/ABS material with high PC content and pure recycled PC sourced from WEEE not being a commodity. The goal of these tests is to check the possibility to produce **high gloss deep black PC** for the use in high-wattage hair dryer and open the loop for the intake of recycled PC from non-WEEE sources. Compounding trials and material analysis are performed by Sitraplas.

2.1. Materials & methods

2.1.1. Materials

The polymer sample used in this study, see Figure 1, is supplied by Van Werven (The Netherlands) and is sourced from post-consumer B&C waste. The sample is sorted and cleaned at the Van Werven facilities and provided in the form of shredded flakes. Two samples of the same material were received, the second being received after communication of the results of the first sample. Note that both samples are from different shipments. Availability of the raw material is approximately 15 tons/month.

Sample 1: First flake sample received
Sample 2: Second flake sample received, drying and flake size improved

Next to the PCR PC materials supplied by VanWerven, two PIR PC were utilized during these trials. Both material sources and detailed information cannot be shared due to confidentiality. PIR1 PC and PIR2 PC differ in their viscosity where the latter has the lowest. When reporting PIR PC in this document this refers to PIR1 PC unless mentioned otherwise.

FIGURE 1: SAMPLE 2: PCR PC VAN WERVEN, SOURCED FROM B&C WASTE

2.1.2. Sample preparation

Compounding of the material was done by Sitraplas with a ZSK 26 Mcc co-rotating twin screw extruder from COPERION. Processing was conducted at rotational speeds between 550 and 600 rpm. Compounding included melt filtration of 200 µm mesh size.
Temperature profile of different screw zones starting from the intake was 255-290-295-305-310-305-310°C.

Injection moulded samples were prepared in order to compare material properties via standard ISO methods. All samples were injection moulded using an Arburg 420S injection moulding machine, obtaining specimens according to ISO 527, and ISO 179 standards and Plaque specimen for colour measurement. Processing parameters based on DIN21305-2 can be found in appendix.

2.1.3. Mechanical properties

During the tensile test, several properties are determined (Tensile strength, Tensile stress at yield, Tensile stress at yield, Elongation at yield, Elongation at break, Tensile modulus). The test is executed according to DIN EN ISO 527 (23 °C; 50 % r.h.) on a Zwick Roell testing machine, using a static load cell. A clip-on extensometer (gauge length 50 mm) was used to measure the strain during the elastic deformation with a tensile speed of 1 mm/min. The extensometer was removed after yield strain. Afterward, the test was continued at 50 mm/min until specimen failure.

Impact test was carried out for notched and unnotched specimen. All specimen were produced by injection moulding. Impact tests were performed according to EN ISO 179, on a Zwick Roell testing machine.

2.1.4. Thermal analysis

DSC measurements were performed using a Polymer DSC 2 from METTLER TOLEDO and analysed with (STAR SOFTWARE), according to EN-ISO1358. A correction was run before each measured set. Samples of 5-7.5 mg were prepared in an aluminium crucible with pierced lid. A thermal cycle, heating from 50-250 °C, and cooling from 250-50 °C, in a nitrogen atmosphere (30 ml/min), was conducted. All heating/cooling rates were 30°C/min.

Vicat softening temperatures were obtained according to ISO 306 by using an Öko Vicat/HDT-tester from COESFELD. The applied method was VST/B50.

2.1.5. Spectroscopical analysis

FTIR analysis was conducted with an ALPHA FTIR spectrometer from BRUKER equipped with attenuated total reflectance (ATR; ZnSe-crystal) sample module. The measurements were analysed with a Bruker software (range 4000-600 cm^{-1}).

2.1.6. Rheological measurements

The melt flow rate (MFR) provides the basis of characterization of the flow behaviour of thermoplastic polymers. The MFI/MFR defined the mass/volume of polymer, flowing in ten minutes through a capillary of a specific diameter for a specific temperature and load. The test is executed according to DIN EN ISO 1133 (300°C; 1,2 kg). Test was performed at BMF-001 Melt flow extrusion plastometer from ZWICK/ROELL.

2.1.7. Ash content

Ash content was determined by means of pyrolysis according to ISO 3451 A. three samples of ≈ 10 g were heated to 600°C for 3 hours in a muffle oven in ceramic crucibles.

2.2. Results

2.2.1. Sample 1:

High water content (> 3,5 m%), see Figure 2, was noted in sample 1 on top of an unpleasant odour. It was perceived to smell like organic solvents. The origin of these issues is unknown but have been communicated with the supplier to be addressed.

FIGURE 2: HIGH WATER CONTENT OF SAMPLE 1

Injection moulding of sample 1 (100 % PCR) was possible. The samples presented surface defects (streaks). After the injection moulding, the tool shows surface pollution and corrosion. The main observation here is the poor surface quality that was not up to standard for the intended application, see Figure 3.

FIGURE 3: LEFT: IMPACT SAMPLE; RIGHT: CORROSION OF TOOL

DSC and FTIR measurements were performed on flakes selected based on colour to identify the types of polymer present in the sample, see Figure 4. Dark green, grey, black and transparent flakes were measured by FTIR.

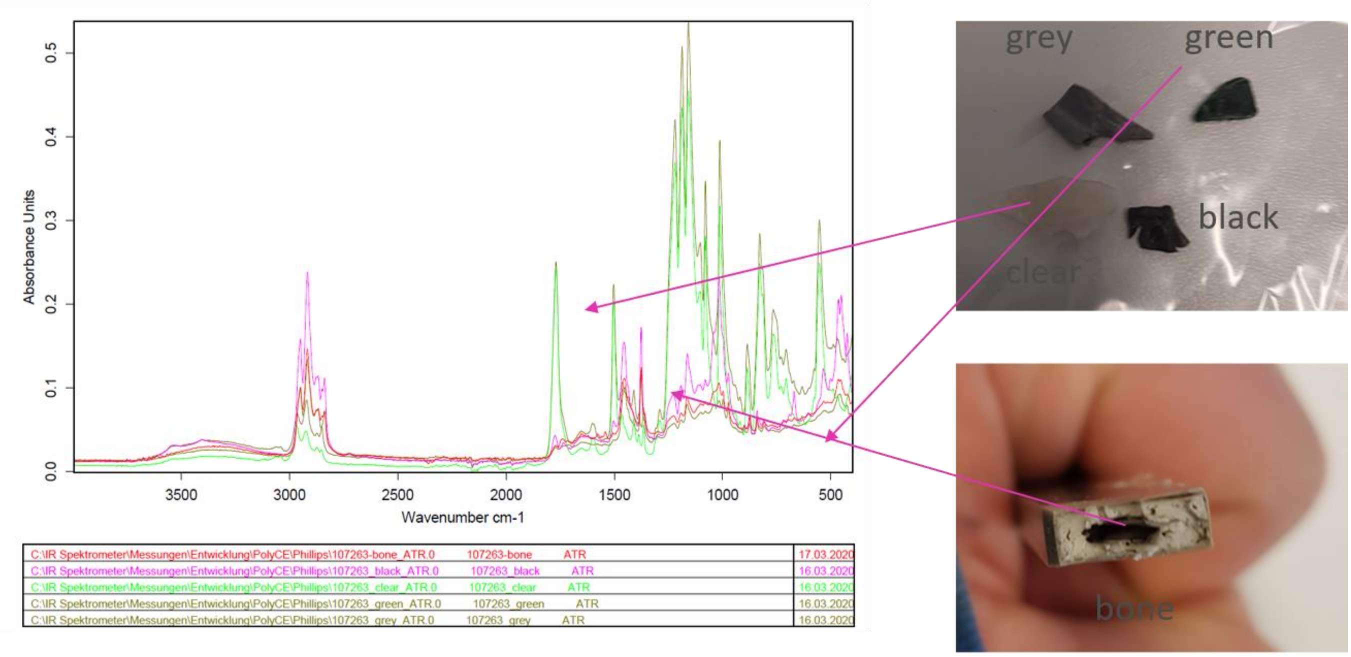


FIGURE 4: FTIR MEASUREMENTS OF PCR PC FLAKES

The dark green flakes were identified as a polyolefin, the other flakes as polycarbonate. DSC measurements on the dark green and transparent flakes were performed to confirm the results obtained from the FTIR measurements. Dark green samples were identified as polypropylene and the transparent flakes were confirmed to be polycarbonate. Results can be found in the appendix B. It is possible that the contamination of PP in the sample came from shredding the material without sufficient cleaning of the shredder. Compounding with melt filtration of 200 µm of the material was performed in various combinations with a post-industrial recycled (PIR) PC grade. Trials were performed in a 0/100, 10/90, 20/80 and 30/70 ratio (m%/m%) of PCR PC/PIR PC respectively. Due to the large shredding size <30 mm of the PCR PC material combined with high water content and high contamination of different polymers it was not possible to compound the material by itself, only the 20/80 PCR PC/ PIR PC trial succeeded. More information can be found in appendix.
As a result, from the experiences with the sample preparation and composition analysis of sample 1, a second sample was requested. The issues that needed to be addressed were communicated with the supplier and are listed below.

- High water content (> 3,5 m%), preferred to be between 0,5 and 0,7 m%.
- High viscosity required the need to add material with lower viscosity (PIR PC) to output an injection mouldable grade
- Finer shredding required for lab scale testing.
- Smell similar to organic solvents observed
- Contamination of PP and rubbers.

2.2.2. Sample 2:

In discussion with the supplier a second sample was provided to further explore the possibilities of PCR PC sourced from Building & Construction. The second sample was shredded more finely, the smell is significantly better and contained less residual water and polyolefin contaminations.

FIGURE 5: BROKEN INJECTION MOULDED SPECIMEN SAMPLE 2

Injection moulding of the sample 2 without compounding showed to be troublesome, see Figure 5. The material displays a very brittle behaviour and breaks in the mould during injection, resulting in issues for the injection of the material. The characterization of the material is showing a low value for impact resistance and a high viscosity (MVR 2.25 cm³/10min).
DSC and FTIR measurements were performed on the injection moulded samples from both sample 1 and 2 and compared. DSC results shows an unusual curve for both samples, normally a single glass transition at 140°C is expected for PC, here several peaks are seen that can be pointed to other polymer (e.g. PMMA) contaminations, most likely it is PP. Sample 2 shows less PP contamination compared to sample 1, which is also confirmed by FTIR. Results can be found in appendix D-E.
Compounding of sample 2 was performed in a two-stage compounding process presented in Figure 6 to obtain optimal material quality. The first step included melt filtration of 200 µm and compounding of the material in the desired ratio (60/40, m%/m%, PIR PC/PCR PC respectively using PIR1). The injection moulding of the material after the first compounding step showed to not be possible, the material is to brittle, has a rather high MVR (31 cm³/10min) and shows a not satisfiable surface quality. In the second step additives (antioxidants, colours, impact modifier) were added and again a melt filtration step of 200 µm. Next to this, 25% PIR PC (PIR2) with an MVR value of 3 was added to decrease the total MVR of the compound to improve injection mouldability. Here the choice was made to use PIR PC instead of PCR PC to not further decrease the aesthetical and processing properties. After the second compounding step an injection mouldable grade was obtained in a 70/30 ratio (m%/m%) PIR PC/ PCR PC respectively. Initially it was intended to use a melt filtration of 100 µm in second compounding stage. However, this was not possible due to the high amount of contaminations (fillers and/or other polymers) present in the material.

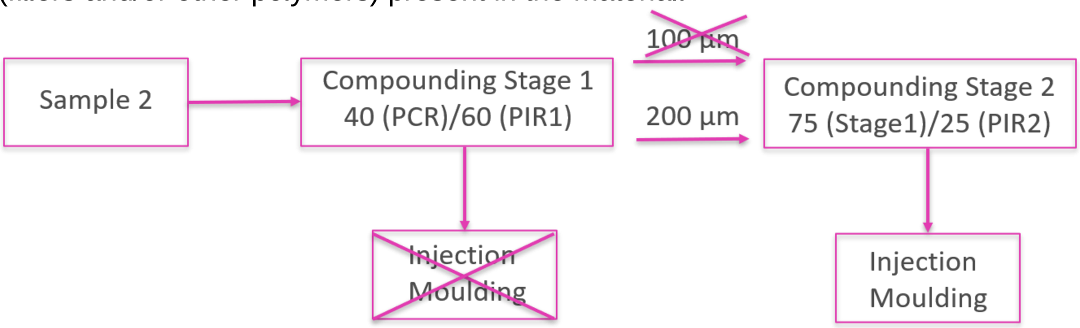


FIGURE 6: TWO-STAGE COMPOUNDING PROCESS

The ash content of the material was determined at Ghent University to give an idea of the amount of non-polymeric contamination present. Results show an ash content of 1,1 m% ± 0,2. Likely to be a mix of minerals and glass fibres, see Figure 7. This amount of contamination is not sufficient to cause blockage of the melt filter. It is likely that a certain number of thermosets (rubbers, silicones, crosslinked polymers) are present in the sample. These thermosets combined with the mineral contamination could cause blockage of the melt filter. As it's not possible to perform a melt filtration step with mesh size 100 µm, it was not possible to obtain the esthetical quality required for the intended application. However, the final compound (70/30 PIR PC/PCR PC) has virgin-like mechanical and physiochemical properties.

FIGURE 7: ASH CONTENT PC FLAKES SAMPLE 2

2.2.3. Properties

In Table 1 all the measured properties of the samples are listed. When looking at melt volume rate, a clear increase is seen after compounding, indicating a material suited for injection moulding. The increase in MVR can be pointed to the addition of a PIR recycled grade which has a higher MVR than the pure PCR material and the melt filtration step that removes all "large" impurities that have an effect on the viscosity of the material. Tensile properties are comparable to virgin, likewise for impact and Vicat softening temperature.

TABLE 1 PROPERTIES OF MATERIAL AND COMPOUNDS. NB =NON BREAK

	Sample 1		Sample 2	
Material	**Flakes**	**80/20 compound**	**Flakes**	**70/30 compound**
PCR amount (m%)	100	20	100	30
Melt Volume-Flow Rate (cm³/10min)	3	20.72	2.25	28
Tensile Modulus (MPa)	2550	2475	2400	2300
Yield stress (MPa)	59	64.09	/	59
Yield strain (%)	8.46	6.2	/	5.65
Elongation @ break (%)	/	23.33	/	/
Impact strength (notched) (kJ/m²)	10	11,8	7	20
Impact strength (unnotched) (kJ/m²)	112.0	NB	/	NB
Vicat-softening-temperature (°C)	134.7	142,7	/	135
Density (g/cm^3)	1.19	1.19	1.19	1,19
Ash content (m%)	/	/	1.1 ± 0.2	/

2.3. Discussion of application testing

In this work, the feasibility to use PCR PC sourced from B&C waste was explored. At the time of writing, this material is only used in low-end applications. Within this case the opportunity was taken to investigate the possibility to use this stream in higher- end applications. The intended application in mind was high wattage hair dryer covers. The most important critical to quality values of this application are ball pressure test at elevated temperature and aesthetical quality (high gloss, deep black). Aiming at this rather high quality end application was choses on purpose. If the material were to be suited for this application, the material could be rolled out for many other applications as well. However, with the material in its current state it was not yet possible to reach the quality desired for the intended application. The biggest issue being the aesthetical quality of the material, as melt filtration with a mesh size of 100 µm was not feasible for industrial compounding. This notwithstanding, the material obtained in the final trials is of good quality, showing properties (mechanical and thermal) similar to virgin polycarbonate. Unfortunately due to the high viscosity it is not feasible to obtain an injection mouldable grade with neat PCR material, instead a certain amount of PIR polycarbonate (final compound = 70/30 PIR PC/PCR PC) was added. Within the project test parts were produced with the final compound. Results from these trials are unfortunately not optimal. The first trial happens with standard drying conditions. The results are shown in Figure 8. Results of the second trial with extreme drying conditions can be seen on Figure 9. Under normal drying conditions a lot of streak marks can be seen on the surface of the material. Although better under extreme drying conditions the issue remains present. Due to this streaks the homogeneity of the material properties can be affected and is therefore not accepted as a suitable grade to produce EE products.

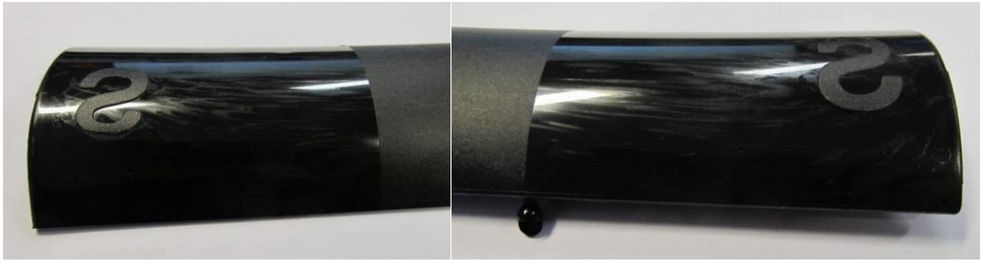


Figure 8: PC mouding trial 1 – standard drying conditions

Figure 9: PC moulding trial 2 – extreme drying conditions

2.4. Conclusion

It is possible to conclude that the polycarbonate sourced from B&C used in this study is for now, **not yet suited** to produce an injection mouldable PC grade **for high-end** (aesthetical) applications like high-wattage hairdryer covers. Compounded with 70 m% PIR PC, the material shows virgin-like properties and could be suited for applications where esthetical quality is less relevant as e.g. internal structural parts. However as recycling and recycling technology keeps improving, the material does show **potential** to be used in the EEE sector in the future. To accelerate the **quality improvement**, the issues encountered in this research are shared with the supplier to improve upon in the future. Some specific issues to this source were **high water content** of sample 1, however this was already resolved with the second sample that was received. A certain amount of **polyolefinic residue** was detected in the material, most likely coming from shredding or less likely, insufficient sorting efficiency. The main point of improvement is based on the inability to use a melt filter of 100 µm, the exact composition of the contamination blocking the filter is unknown. However, ash content was determined and is well below the threshold to cause any blockage. It is likely fines or **residues of thermosets** (silicones, rubbers, …) are causing these issues. Specific attention could be put on this issue during sorting of the material. In Table 2 an overview of the properties of the final compound are shown in a technical datasheet (TDS).

TABLE 2: TDS OF FINAL PC COMPOUND

PROPERTY		UNIT	VALUE	COMMENTS	TEST METHOD
GENERAL					
Name		-	rPC compound		
Composition		-	PCR PC/PIR PC[1] 30/70 m%		
Origin		-	Post-consumer waste Building & construction		
APPEARANCE					
Colour		-	Black		
Transparency		-	No		
Shape		-	Re-granulate		
PHYSICAL - determined after injection moulding					
Melt Flow Index (MFI)		Cm³/10 min	28	300°C;1.2kg	ISO 1133
Density		g/cm³	1.19		ISO 1183
MECHANICAL - determined on injection moulded test bars					
Modulus	tensile	MPa	2300		ISO 527
Yield strength	tensile	MPa	59	0.2% offset	ISO 527
Strain at yield	tensile	%	5.65	0.2% offset	ISO 527
Strain at break	tensile	%	/		ISO 527
Impact (notched at 23°C)		kJ/m²	20	23°C	ISO 179-1
Impact (un notched at 23°C)		kJ/m²	NB	23°C	ISO 179-1
THERMAL					
Vicat softening temperature		°C	135	50°C/h; 50N	ISO 306

[1] Source Post-industrial recycled polycarbonate confidential

3. Polystyrene case

This case study investigates the feasibility to use **post-consumer recycled polystyrene** (PCR PS), sourced from **packaging waste**, in **fridge liners**. In the large scale demonstrator task 7.7, Whirlpool attempted to use PCR PS sourced from WEEE to produce fridge liners. From a technological point of view no major issues were encountered and the material was found suited for implementation into production. However, one key requirement for the material used in this application is **food contact** approval. This requirement could unfortunate not be fulfilled by the material sourced from WEEE. One major hurdle for this is the use of PU based insolating layers. A possible solution would be to switch back to EPS insolating layers. However, this solution would only make sense if implemented by the large majority of the industry. The trial discussed in this report was set up to investigate the possibility to use food safe recycled PS from packaging sources. This recycled material stream is **currently** only available in **small quantities** but upscaling of the production is ongoing. The goal of this study is to evaluate the **suitability** of the material to be used **in new EE applications** once the material is available in large quantities. The material used is supplied by Styrenics Circular Solutions (SCS), a joint industry initiative and the driving force behind the acceleration of styrenics recycling through innovative technologies and solutions. The SCS members, COEXPAN, Exiba, ELIX Polymers, Greiner Packaging, INEOS Styrolution, Intraplás, Repsol, Tomra, Total, Trinseo and Versalis (ENI) have committed to:

- Unlock the unique potential of styrenics for true circularity by engaging with the whole value chain
- Develop and scale-up innovative technologies to recycle styrenics back into high-quality applications, even for food contact
- Create a market pull away from incineration and landfill towards game-changing recycling solutions for styrenics

SCS explores both chemical (dissolution and depolymerisation) and mechanical recycling technologies to obtain their goals. In this work only material from mechanical recycling processes are used. Note that SCS uses a **proprietary cleaning process** which can achieve 99.9% purity. To obtain food contact approved material, both super cleaning (Gneuss and others being explored) and challenge tests with Fraunhofer IVV are applied. The first application for an EFSA opinion has been launched and awaiting response. The material obtained from the SCS processes are already tested as a **drop-in solution** for packaging applications (yogurt cups) with great success. SCS is working on scaling up production with a first goal to reach **33 kT/y** of recycled PS in 2021.
Two material samples were received and tested. First, flakes received from small scale pilot trials and secondly, pellets which are compounded and melt filtered by a partner of SCS. Both flakes and pellets are evaluated and the potential for use in C&F applications is discussed based on mechanical and physical analysis. The PS flakes are analysed as an indicator of the quality of the stream.

3.1. Materials & methods

3.1.1. Materials

The materials used in this study are supplied by SCS and are provided in the form of both shredded flakes and pellets (compounded & melt filtered by SCS) (Figure 10). Both material samples are sourced from post-consumer household waste and undergo a proprietary treatment to achieve food contact compliancy. Availability estimated to be 33 kT/y in 2021.

FIGURE 10: PELLET AND FLAKE SAMPLE AS RECEIVED

3.1.2. Sample preparation

Two types of test specimen are prepared, the first specimen are prepared from extruded sheets consistent with application driven properties, in this case fridge liners which are produced by extruding large sheet and are then thermoformed. The second specimen are prepared by injection moulding to compare properties with the TDS of the target material.

Sheets are extruded with a Brabender 19 single screw extrusion machine with a screw diameter of 19 mm. A slit die is used to produce sheets of Ca. 30 x 1,5 mm² and a calender machine ensured even cooling and thickness of the sheets. Processing parameters can be found in the appendix. Before processing samples are dried at 60 °C for a minimum of 5 hours. After conditioning (>48 h; 23°C; 50% RH), dog bone test bars (type 5) were punched out from the sheets according to ISO 527-3.

Injection moulded sample are prepared complying to ISO 527 and ISO 179. All samples were injection moulded using a ENGEL e-victory 28 T injection moulding machine. Processing parameters can be found in appendix. An overview of the prepared samples can be found in Table 3.

TABLE 3: OVERVIEW PREPARED SPECIMEN PCR PS

Sample name	Sample/Material	Processing/specimen
PS-SF	Flake (re-grind)	Extrusion (Sheet)
PS-SP	Pellets (compounded)	Injection moulded (bar, dog-bone)
PS-IF	Flake (re-grind)	Extrusion (Sheet)
PS-IP	Pellets (compounded)	Injection moulded (bar, dog-bone)

3.1.3. Mechanical tests

Tensile tests are performed according to EN ISO 527-3 (on sheet specimens) and EN ISO 527 (on injection moulded specimen), after conditioning (>48 h; 23°C; 50 % RH), on an Instron 5565, using a 5kN static load cell. A clip-on extensometer with gauge length 12.5 mm is used for sheet specimens, gauge length 50 mm for injection moulded specimen to measure the strain during the elastic deformation (1 mm/min), injection moulded specimens were additionally tested at 5 mm/min to compare with the properties of the target material. The extensometer is removed after a strain of 6 % for sheets and 5 % for injection moulded specimens. Afterward, the test continued (50 mm/min) until specimen failure.

Impact strength is measured only on the injection moulded samples according to ISO 179 (pendulum energy 2.75 J; Tinus Olsen model Impact 503).

3.1.4. Physical analysis

The melt flow index (MFI) or melt flow rate (MFR) provide the basis of characterization of the flow behaviour of thermoplastic polymers. The MFI/MFR is performed according to EN 1133 at a temperature of 200°C and a load of 5 kg on a Tinus Olsen MP 1200.

FTIR is performed on samples with a thickness >1 mm, according to ASTM E168, E1252. The instrument used is a Bruker Tensor 27, with OPUS (vs 6.5) software and a ZnSe-crystal in ATR mode (range 4000-600 cm^{-1}).

3.2. Results

3.2.1. Samples preparation

During sample preparation, both for extruded sheet specimen and injection moulded specimens, some results are noted regarding the odour perception, appearance and processing.

- Odour perception

  During processing a slight “recycled” smell is noted for the specimens produced from the flake sample. For the specimens produces with the pellet sample, the smell is hardly noticeable after the sample has cooled down.

- Processing difficulties

  Both during specimen preparation with extrusion and injection moulding of the flake sample an expected feeding difficulty is found due to bridge forming at the intake. The feeding required manual agitation during processing, resulting in a variable output. Contaminations in the flake sample showed issues during extrusion, see Figure 11. The reason for the presence of these contaminations is discussed with the supplier and can be attributed to the fact that all batches are still prepared on pilot scale. This means that processing happens between the day-to-day processes of the industrial partner. Here, it is possible that some residues contaminated the pilot run, most likely due to not sufficiently cleaned shredders. No such processing issues are encountered with the pellet sample that was received.

FIGURE 11: CONTAMINATION FLAKE SAMPLE DURING EXTRUSION

- Appearance

  Colour clouds are sporadically present on the injection moulded specimen prepared with the flake sample, see Figure 12. On the other hand this is not seen for the specimen prepared with the pellet sample. Black dots are observed in both injection moulding and extrusion of specimens with the flake material.

FIGURE 12: COLOUR CLOUDS IN INJECTION MOULDING SAMPLE FROM FLAKES

Although most of these attention points are inherently linked to the use of an uncompounded flake material, processing did not impose major issues. This shows that the quality of the flake sample is already quite high. However, compounding remains a necessary step to ensure material homogeneity, remove contaminations (melt filtration) and improve processing and aesthetics. The use of the material as a re-grind (flakes) is not recommended.

3.2.2. Mechanical tests

In Table 4 the results of the sheet specimens prepared according to ISO 527-3 are shown. A brittle failure is observed for all specimen. A first result that can be found is a significant difference in stiffness, where PS-SP shows a higher stiffness. This can be attributed to the absence of contaminations acting as stress concentrations. Next to this a slight drop in yield stress, tensile strain and stress at break is noted for the PS-SP. However, it must be noted the variance in these results and the strain at break is a lot smaller, indicating more homogeneous material properties.

TABLE 4 MECHANICAL PROPERTIES SHEETS

Material	**PS-SF**		**PS-SP**	
	Mean	**Stdev (±)**	**Mean**	**Stdev (±)**
E-modulus (MPa)	1505	81	1769	76
Yield stress 0,2% offset (MPa)	22.0	1.4	19.5	0.51
Tensile strain 0,2% offset (%)	1.38	0.10	1.02	0.05
Tensile stress @ break (MPa)	25.0	1.4	22.8	0.5
Tensile strain @ break (%)	44.06	11.8	45.5	4.9
Figure of failure type	 Brittle		 Brittle	

The injection moulded specimens are tested with an initial tensile speed of both 1 mm/min and 5 mm/min. This, to compare the results according to the EN ISO 527 standard and the requirements set for the intended end-application. In Table 5 the results of these tests are presented. No major difference can be seen between both used methods. Focussing on the difference in stiffness between the specimen, PS-IF only has a slightly lower value than of PS-IP. The slight difference can be pointed to the contaminations seen at the break surface. Compared to the target material the both specimens exceed the minimum value that is required. When comparing the E-modulus with the results obtained for the extruded (sheet) specimen, a significant difference can be noted. This major difference can be attributed to the way of processing. The sheets are processed using a calender machine with chill rolls set at 20°C while the injected moulded samples are produced in a mould set at 40°C. This difference in temperature has a major effect on the mechanical properties. In order to verify this statement a small scale trial is set-up where a small amount of tensile test are performed (results not reported) on sheets produced with chill rolls set at a 40°C. The result confirmed the statement with an average E-modulus of 2130 MPa. Looking at the yield stress only minor differences can be seen between both testing protocols and specimens. The values also exceed that of the target material. Compared to the extruded specimens the yield is significantly higher which is also a result of processing parameters. For both yield strain and stress at break, values show only a minor variation with PS-IP having only slightly higher values. Strain at break is significantly higher for PS-IP, which can be related to the absence of contaminations acting as stress concentrations. Looking at the impact values no significant difference between the specimen can be noted. However, the impact requirements for the target application are not met, here a gap of 1 kJ/m² remains. Closing this gap is however within the possibilities of today's technologies by utilizing the required impact modifiers during compounding.

Material	**PS-IF**	**PS-IF**	**PS-IP**	**PS-IP**	**Target**

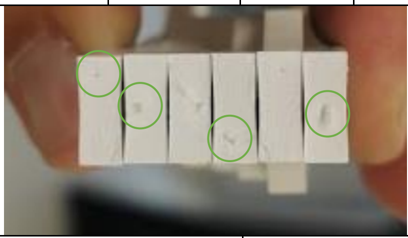
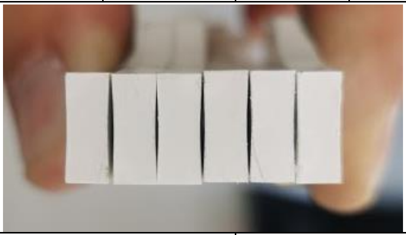
Test speed	1 mm/min		5 mm/min		1 mm/min		5 mm/min		5 mm/min
E-modulus (MPa)	2375	±74	2371	±59	2392	±54	2364	±64	1280
Yield stress 0,2% offset (MPa)	26.6	±0.4	26.5	±0.2	27.3	±0.4	27.2	±0.4	14
Tensile strain 0,2% offset (%)	1.27	±0.02	1.27	±0.03	1.29	±0.02	1.31	±0.02	/
Tensile stress @ break (MPa)	23.1	±0.8	23.0	±1.0	24.6	±0.7	24.2	±0.6	/
Tensile strain @ break (%)	31.95	±8.30	31.77	±9.28	42,24	±7.41	42.93	±8.14	/
									
Impact (KJ/m²)	7.09		±0.52		7.07		±0.54		8

TABLE 5 MECHANICAL PROPERTIES INJECTION MOULDED SAMPLES

3.2.3. Physical analysis

During the preparation of the PS-SF specimens, a presence of contaminations, as seen on Figure 11, is observed. FTIR measurements identified these contaminations as PET and silicone particles. PET is commonly used in packaging applications and is often collected together with polystyrene products, so it is conceivable that some PET contamination is present in this material stream. The silicone particles are identified as polydimethylsiloxane, a non-conducting, silicone based elastomer which is commonly used in biomedical or medical applications. It is unknown how this materials ended up in the PS stream but it is conceivable that the source lies with residues from a shredder which is not dedicated solely to this PS stream. Both types of contaminations are however, easily removed with melt filtration steps.
The melt flow rate is determined to estimate the ability of the material to be utilized in the current industrial production processes (extrusion). Results, as seen in Table 6, show that the MFR value is slightly higher for the PS-SP. This is to be expected due to the absence of non-melting contaminations. Compared to the target material, the MFR is only slightly to high but this can be compensated with application driven compounding.

TABLE 6: MFR RESULTS

Material	**PS-SF**	**PS-SP**	**Target**
Melt density (g/cm³)	0.96	0.97	/
Melt Flow Rate (g/10min)	5.0	5.4	1.8-5.0
Melt volume rate (cc/10min)	5.1	5.5	/

Note: Test parameters 200°C, 5 kg

3.3. Conclusion

In this work, the feasibility to use PCR PS sourced from household waste is explored. The intended application in mind is fridge and fridge door liners. The most important critical to quality values of this application are food contact approval and ESC. For the flake sample it can be concluded that:

- A high quality material can be obtained after compounding and melt filtration.
- Using the flake material (re-grind) is not recommended due to remaining contaminations, colour inconsistency and a slight smell.
- On a property level the material is of great quality.

Regarding the pellet sample:

- A very high quality material is obtained from the processes applied by SCS.
- Optimization on impact and flow behaviour are still required but are within todays technological abilities.
- Great potential to be implemented for the production of fridge and fridge door liners.

However, the performance of the material regarding environmental stress cracking is still unknown. Finally two uncertainties remain:

- Food grade approval needs to be obtained from EFSA, for now the first application is under review but an approval is not yet received.
- Availability of the material in the near future is unknown. SCS is for the moment starting to scale up production, aiming at a production of 33 kT/y. With already many interested parties in the packaging industry the amount of material available for other industry branches like EEE-producers is unknown.

TABLE 7: TDS OF PS PELLET SAMPLE

PROPERTY		UNIT	VALUE	COMMENTS	TEST METHOD
GENERAL					
Name		-	rPS		
Composition		-	Recycled Polystyrene 100%		
Origin		-	Post-consumer household waste		
APPEARANCE					
Colour		-	White		
Transparency		-	No		
Shape		-	Re-granulate/pellets		
PHYSICAL					
Melt Flow Index (MFI)		g/10 min	5.4	200°C; 5kg	ISO 1133
Melt density		g/cm³	0.97	200°C; 5kg	ISO 1133
Melt volume rate		cc/10 min	5.5	200°C; 5kg	ISO 1133
MECHANICAL					
Modulus	tensile	MPa	2392 ±54	1 mm/min	ISO 527
Yield strength	tensile	MPa	27.3 ±0.4	0.2% offset	ISO 527
Strain at yield	tensile	%	1.29 ±0.02	0.2% offset	ISO 527
Strain at break	tensile	%	42.24 ±7.41		ISO 527

Impact (notched at 23°C)	kJ/m²	7.07 ±0.54	23°C	ISO 179-1

4. Polypropylene case

This case study investigates the feasibility to use PCR polypropylene from lab waste for the production of **talc filled rPP** to be used in **coffee machine frames** and a high quality **neat homopolymer PP** (hPP) grade for the production of **exteriors**. The material is sourced from labs within Ghent University and can be considered to be representative for wet research labs. The neat hPP material is of **high purity** and a potential input stream for the production of new EE-products. However, the material is at the time of writing **not yet collected** for recycling. This has several reasons, the most prominent being that the logistics needed for collection are quite intensive as no single collection point is set up yet. At **Ghent University alone**, availability is estimated at **3 ton/year**, which is a fairly low amount for industry-level recycling. The key is to **collect from multiple labs** to obtain larger amounts and prevent these high quality materials from being incinerated. In this case the potential of this untapped source of high quality material will be explored and showcased. With this the authors hope to put pressure on instances **creating collection schemes** to recycle this and other sources of untapped smaller waste streams. Compounding trials and material analysis are performed by Sitraplas.

4.1. Materials & methods

4.1.1. Materials

The polymer sample used in this study is collected within Ghent University and is sourced from post-consumer lab waste, being carrier boxes for sterilized disposable pipet tips. These pipet trays are a hefty packaging product and never come in contact with hazardous substances. Once all pipets are used up the product is discarded and collected for incineration. The sample for this trial was collected and shredded at the Centre for Polymer and Material Technologies. No sorting efforts were required due to the homogeneity of the waste stream. The sample was provided in the form of shredded flakes as seen on Figure 13, with an average flake size of about 0,5 cm with both blue and translucent particles. A small contamination of black pieces could be observed. These were removed during compounding. Scanning the material for metals showed a negative result, no metal pieces were found. The bulk density of the material un-shredded is measured at 66,5 kg/m³ and shredded at 395 kg/m³.

In this study is a high aspect ratio talc grade from Imerys is used. Steaplus HAR T77 is a high performance mineral filler with a specific gravity of 2,75 g/cm³ and a B.E.T. (ISO 9277) value of 19m²/g. For more information see Appendix E.

FIGURE 13: PP FROM LAB WASTE: THE WASTE PRODUCT AND THE RESULTING SHREDDED PLASTICS

4.1.2. Sample preparation

Compounding of the material was performed by Sitraplas with a ZSK 26 Mcc co-rotating twin screw extruder from COPERION. Processing was conducted at rotational speeds between 550 and 600 rpm. Compounding included melt filtration of 250 µm mesh size.
Temperature profile of different screw zones starting from the intake was 200-245-250-260-260-240-260°C.

Injection moulded samples were prepared in order to compare material properties via standard ISO methods. All samples were injection moulded using an Arburg 420S injection moulding machine, obtaining specimens according to ISO 527, and ISO 179 standards and Plaque specimen for colour measurement. Processing parameters based values found in appendix F.

4.1.3. Mechanical properties

During the tensile test, several properties are determined (Tensile strength, Tensile stress at yield, Tensile stress at yield, Elongation at yield, Elongation at break, Tensile modulus). The test is executed according to DIN EN ISO 527 (23 °C; 50 % r.h.) on a Zwick Roell testing machine, using a static load cell. A clip-on extensometer (gauge length 50 mm) was used to measure the strain during the elastic deformation with a tensile speed of 1 mm/min. The extensometer was removed after the yield strain. Afterward, the test was continued at 50 mm/min until specimen failure.

Impact test was carried out for notches and unnotched specimen. All specimen was producing by injection moulding. Impact tests were performed according to EN ISO 179, on a Zwick Roell testing machine.

4.1.4. Thermal analysis

Vicat softening temperatures were obtained according to ISO 306 by using an Öko Vicat/HDT-tester from COESFELD. The applied method was VST/B50.

4.1.5. Spectroscopical analysis

FTIR analysis was conducted with an ALPHA FTIR spectrometer from BRUKER equipped with an ATR (ZnSe-crystal) sample module. The measurements were analysed with a Bruker software (range 4000-600 cm^{-1}).

4.1.6. Rheological measurements

The melt flow rate (MFR) provides the basis of characterization of the flow behaviour of thermoplastic polymers. The MFI/MFR defined the mass/volume of polymer, flowing in ten minutes through a capillary of a specific diameter for a specific temperature and load. The test is executed according to DIN EN ISO 1133 (230°C; 2,16 kg). Test was performed at BMF-001 Melt flow extrusion plastometer from ZWICK/ROELL.

PolyCE

4.2. Results

4.2.1. Neat rPP

Both mechanical, rheological and thermal properties of the neat rPP source were tested to be compared to a representative PP-grade. An overview of the material properties of neat rPP compared with the a target PP grade can be found in Table 8.

TABLE 8: NEAT RPP AND VIRGIN PP PROPERTY OVERVIEW

Material	Neat recycled PP (nrPP)	Target virgin grade (nvPP)
Source	PCR lab-waste	Virgin
colour	Blue and translucent	White
Density (kg/m³)	906	905
E-modulus (MPa)	1382	1400
Yield stress 0.2% offset (MPa)	31	35
Tensile strain 0.2% offset (%)	9.25	/
Tensile strain @ break (%)	27	/
Melt Flow Rate (g/10min)	69	21
Impact unnotched @ 23°C (kJ/m²)	44	/
Impact notched @ 23°C (kJ/m²)	2.05	2
Vicat softening temperature (°C)	87.8	80 (HDT B)

When comparing the properties of nrPP to the target material it is possible to see that both materials are quite similar. Neither impact resistance nor E-Modulus showed any major differences. When looking at the yield strength nrPP only shows a slightly lower value. When focussing on the thermal properties it is difficult to make a comparison as only the HDT value of the target material is known. However, the Vicat softening temperature is typically a bit higher and can give a rough indication. The biggest difference between both materials lies in the rheological properties, with nrPP showing a melt flow rate more than three times as high as the target material. This could give issues during injection moulding as a less viscous material has a higher risk for the occurrence of flash. However, adapting process parameters like lowering barrel and mould temperature could result in positive results together with a decrease of processing energy costs.

The injected specimen were analysed by IR spectroscopy. The spectra are showing signals typical to virgin PP. The IR-spectra of the specimen are shown in appendix G.

4.2.2. rPP+Talc

Both mechanical, rheological and thermal properties of the rPP/talc were tested to compare with a representative virgin PP/talc-grade. The compounding of the rPP with the talc grade did not show any problems. For feeding of the talc two side feed streams are used. More details can be found in Table 9.

TABLE 9: PROCESSING OVERVIEW PP/TALC

Processing parameter rPP+talc	
Temperature	200-260°C
Pressure	12 bar
Torque	44%
Throughput	40 kg/h
Talc feed streams (side feeding)	2

Characterisation was performed on injection moulded samples. An overview of the material properties of rPP/talc compared with the a target vPP/talc grade can be found in Table 10.

TABLE 10: RPP/TALC AND VIRGIN PP/TALC PROPERTY OVERVIEW

Material	recycled PP +talc (rPP/Talc)	Target virgin grade (vPP/Talc
Source	PCR lab-waste	Virgin
colour	Blue	Black
Density (kg/m³)	1220	1220
Talc filling % (m%)	40	40
E-modulus (MPa)	5300	4700
Yield stress 0.2% offset (MPa)	29	32
Melt Flow Rate (g/10min)	42	21
Impact unnotched @ 23°C (kJ/m²)	8	/
Impact notched @ 23°C (kJ/m²)	1.4	1.2
Vicat softening temperature (°C)	92	100 (HDT B)

Comparing the properties of the rPP+talc to the target vPP/Talc it is possible to see that both materials are very comparable. A slightly lower yield stress and a slightly higher impact resistance can be noted for rPP/Talc. When looking at the stiffness a significant difference can be noted with rPP/Talc being 600 MPa higher than the target material giving room to further optimize other properties. A big difference in rheological properties can be noted with the rPP/Talc having an MFR value more than twice as high as the target material. This could give processing issues due to a higher probability of flash. However, lowering the barrel and/or mould temperature could prevent this and help to lower processing energy costs. When looking at the thermal properties it is difficult to make a comparison as only the HDT value of the target material is known. However, as a rule of thumb, the Vicat softening temperature is usually higher. We can conclude that further optimization of the thermal properties if this material compound would be needed to be implemented for applications requiring high heat stability.

4.3. Conclusion

In this work, the feasibility to use PCR PP sourced from lab waste is explored. The flakes show to be of high quality and are a **suitable input material** for compounding into high quality hPP and rPP/talc grades. The intended application are internal frames for coffee machines (rPP/Talc) and external panels (nrPP). The most important critical to quality values of this application are high stiffness and thermal properties (HDT). For the **nrPP** sample it can be concluded that a high quality material can be obtained with **comparable properties** to a representative **virgin PP** used in the EEE-industry. The **rPP/Talc** sample showed to have the

extremely high stiffness requirements needed without losing to much impact and would be a suitable candidate with great potential to be implemented for the production of internal frames. However, the performance of the material regarding **HDT/Vicat is lower** than is required. **Further research** regarding this topic could help to further close the gap. The most important point of attention for this material is **sourcing**. At the time of writing this material is **not yet collected** for recycling and is instead incinerated. With this work the authors have proved the potential of this lost plastics stream. The labs of Ghent University alone produce an average of 3 T/year. This alone is too small to be economically viable. A possible solution could be a **collection scheme** targeting **multiple labs** to collect this material separately. Below, an TDS of both neat rPP and rPP+Talc can be found in Table 11 and Table 12.

TABLE 11: TDS OF THE NEAT RPP

PROPERTY		UNIT	VALUE	COMMENTS	TEST METHOD
GENERAL					
Name		-	rPP		
Composition		-	Recycled Polypropylene 100%		
Origin		-	Post-consumer lab waste		
APPEARANCE					
Colour		-	Blue, Translucent		
Transparency		-	No		
Shape		-	Shredded flakes		
PHYSICAL - determined after injection moulding					
Melt volume rate		g/10 min	69	230°C; 2.16 kg	ISO 1133
MECHANICAL - determined on injection moulded test bars					
Modulus	tensile	MPa	1382	1 mm/min	ISO 527
Yield strength	tensile	MPa	31	0.2% offset	ISO 527
Strain at yield	tensile	%	9.25	0.2% offset	ISO 527
Strain at break	tensile	%	27		ISO 527
Impact (unnotched at 23°C)		kJ/m²	2.05	23°C	ISO 179-1
Impact (notched at 23°C)		kJ/m²	44	23°C	ISO 179-1
Vicat softening temperature		°C	87.8	5N; 50K/h	ISO 306

TABLE 12: OVERVIEW PROPERTIES RPP+TALC

PROPERTY	UNIT	VALUE	COMMENTS	TEST METHOD
GENERAL				
Name	-	rPP +talc		
Composition	-	Recycled Polypropylene + 40 m% HAR talc		
Origin	-	Post-consumer lab waste		
APPEARANCE				
Colour	-	Blue		
Transparency	-	No		
Shape	-	Pellets		
PHYSICAL - determined after injection moulding				
Melt volume rate	g/10 min	42	230°C; 2.16 kg	ISO 1133
MECHANICAL - determined on injection moulded test bars				
Modulus tensile	MPa	5300	1 mm/min	ISO 527
Yield strength tensile	MPa	29	0.2% offset	ISO 527
Impact (unnotched at 23°C)	kJ/m²	1.4	23°C	ISO 179-1
Impact (notched at 23°C)	kJ/m²	8	23°C	ISO 179-1
Vicat softening temperature	°C	92	5N; 50K/h	ISO 306

5. Examples within other demonstrators

The use of other input stream is not something reserved for the future but can already be seen as a valuable addition for the production of new EE products today. To showcase the possibilities, examples of the use of non WEEE-sourced materials in the other demonstrator cases are briefly discussed in the following paragraphs.

5.1. Recycled ABS from automotive in 3D printing

FIGURE 14: SENSEO TOP COVER 3D PRINT PIR ABS

One of the promising materials used in the manufacture of the Senseo top cover demonstrator, produced by additive manufacturing (AM) *via* fused filament fabrication (FFF), is a post-industrial recycled plastic (PIR) **ABS from the automotive industry**. This ABS has good physical properties, comparable to the ones found for virgin materials (Young modulus = 1.76 GPa; tensile strength at yield = 38.5 MPa; strain at yield = 2.6%; elongation at break = 8.7%; Charpy notched impact resistance = 14.0 kJ/m²; MFR @ 270°C/2.16 kg = 8.2 g/10min). As this ABS is form a PIR source, it is practically absent of contaminants, and its extruded filaments presented good dimensional stability, later contributing to a more reliable AM process. During the FFF of the demonstrator, the material showed good flowability at a nozzle temperature of 240-260°C. It was possible to manufacture a 3D printed part, see Figure 14, using a relatively small layer thickness (0.15 mm), noticeably increasing the surface quality of the part. However, a machine with a temperature-controlled chamber (envelope temperature) at *ca*. 60°C and heated printing bed (80 – 90°C) is advised to avoid warpage of the produced parts.

5.2. PCR PP from packaging in Pezy Wisensys bracket demonstrator Bracket

Pezy is a full-service product development agency with a team of 85 specialists in design, engineering, electronics and industrialization. In 2009, Pezy became the first design agency with Cradle-to-Cradle accredited designers. Creating a circular product means to make a design where materials can be recycled on a similar quality level and is made from those recycled materials. Pezy was challenged by their client, Wireless Value, to create a circular electrical device without any concessions on the functional and aesthetical requirements. The challenge was to create a plastic housing that is made from Post-Consumer Recycled plastics coming from a WEEE (Waste Electrical and Electronic Equipment) stream and to make it fully recyclable according to the design guidelines created in the PolyCE project.

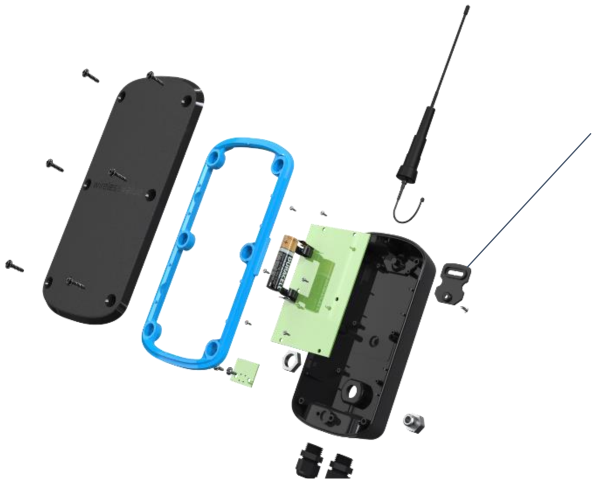


FIGURE 15: WISENSYS MEDIUM FROM PEZY DEMONSTRATOR

The Wisensys product family is mainly produced from PCR ABS sourced from WEEE. Only in regard to functionality other materials needed to be used. This is also discussed in more detail in deliverable 7.4. This example focusses on one part of the medium sized Wisensys module where material sourced from another waste stream is used. One feature of this product is a removeable bracket, as can be seen on FIGURE 1Figure 15. This feature allows to hang the module on the wall, strap it to a post or enable other mounting possibilities. The properties inherently linked with ABS are not in compliancy with the needs of this part.

Polypropylene, a material available with a wide variety of grades and properties does meet the requirements. Although PP is available in a grade sourced from WEEE, the properties did not meet the required impact properties. The suitable **PP grade** was found in a PCR grade sourced from **packaging waste**. This is an example that shows that recycled materials used in EE-products do not necessarily need to come from WEEE sourced materials and that opening the loop for other waste streams can be complementary as long as it fulfils the requirements of the product/part.

5.3. PCR and PIR Polycarbonate in ONA lighting demonstrator

FIGURE 16: ONA DEMONSTRATOR CONCEPT

Ona is a design editorial with a strong link with the world of architecture, design, art and culture with a passion to create lighting designs and creating custom lamps for their clients. Ona's goal was to develop a high-end design fixture for LED lighting, as seen on Figure 16, with consideration of the Design for/from Recycling strategies and start implementing PCR/PIR plastics in future high-end lighting components. From the beginning ONA set out to design a product with a noble appearance. Challenging requirements for recycled plastics like transparency/translucency or high gloss were needed to achieve this goal. In the concept stage, plastics sourced post-consumer waste were preferred. However, during the development stage it was clear that materials of this quality (transparency) are nearly non-existent. Therefore, **PC** from both post-industrial and post-consumer sources, and from other sources than WEEE, are used. A noble appearance of the final product could be achieved by sourcing only the best recycled materials available from **packaging and other waste sources**. This example shows that opening the loop can enable certain new EE-products to be made from recycled plastics.

6. Conclusion

This report started with the objective to explore other waste streams for their suitability in new EE-applications. In order to achieve this three material sources were explored and characterized. **PCR Polycarbonate** from B&C, **PCR Polystyrene** packaging and **PCR Polypropylene** from lab waste. Each of these material sources imposed their own hurdles and challenges and were explored on their potential to be implemented in the EEE-market.
The PC source: is currently only in low-end application, or so-called downcycling. With this task we tried to explore the potential of this source to be used in high-end applications. Unfortunately this source proved to be **very challenging** and could only be processed in combination with a purer PIR PC source in a 70/30, PIR/PCR ratio. The end result however showed to be promising. A **black PC** with **virgin like properties** could be produced and could be suitable for internal parts of EE-products. However, **moulding trials** showed that **streaks** are present even under extreme drying conditions. Due to this, the material **cannot be accepted** for the production of EE-products, as homogeneity of the material properties cannot be assured. The issues were shared with the material supplier and can be used to set up new business opportunities, **finetune the sorting process** or justify new investments. This material source is of now **not yet suited as input** for the EE-market. However the potential is proven and could find its way into new EE-products in the future/.
The PS source: explored in this report is sourced from PCR household packaging waste by Styrenics Circular Solutions, a joint industry initiative. The material is currently not yet available in large quantities as the recycling plants are still in start-up with an estimated production of **33 kT/year** in 2021. This material source was selected because of the claim to deliver a **food contact approved PS** due to a unique decontamination process. As is explained in more detail in D7.6, food contact approved PS could be interesting for the production of fridge and fridge door liners. The properties of this material except for MFR and impact showed to **comply with the demands** of the target material. Both MFR and impact could be improved within today's technology. One property that could not be characterized is the **ESC resistance** and should be checked before industrial trials are set-up. Finally some huddles remain at the time of writing. The first being that food contact approval is not yet received but a request for **review is filed**. The second being the **availability**, with an estimated 33 kT/year and many interested partners in the food packaging industry it remains uncertain how much material will be available for other industries.
The PP material: is sourced from the labs of Ghent University. The pipet trays (collected product) are a hefty packaging for pipets and never come in contact with hazardous substances. Today, these are collected with other plastic waste and **incinerated**. The biggest hurdle to use this material is the **collection** of the material itself. However, the goal of this study was to prove the **hidden potential** of this material stream. For the **neat rPP** sample it can be concluded that a high quality material can be obtained with **comparable properties** to a representative virgin PP used in the EEE-industry. The **rPP/Talc** sample showed to have the **extremely high stiffness** requirements needed without losing to much impact and shows great potential to be implemented for the production of internal frames. A last remaining gap regarding HDT/vicat does require further research.

Overall it can be concluded that all materials explored in this report show to have the potential to be implemented in the EEE-industry and opening the loop is can be considered as a great addition to increase the use of recycled materials in new EE-products. The materials explored were selected as they are difficult to source or not available yet from recycled WEEE waste. Even though some hurdles remain with all these material they all show to be suitable candidates as an input stream. If these rather difficult sources show the potential to be implemented, more established and readily available sources should be considered when looking for materials to be used in new EE products.

Appendix

Appendix A: processing datasheet PC

PROCESSING ADVICE

SITRAPLAS

General processing advice for SITRALON® (PC)

Drying

SITRALON® (PC) must be dried prior to processing. The tolerated moisture content should be less than 0.02%.

The optimal drying temperature for SITRALON® is shown in table 1.

When processing SITRALON® (PC) take care that the granules are processed in dry conditions. An excessive content of moisture in the plastic melt can lead to surface defects in the form of streaks as well as hydrolytic degradation.

Engineering thermoplastic	Drying-temperature (°C)	Dry air dryer (hour)	Fresh air dryer (hour)
SITRALON® (PC)	100	2 - 3	2 - 4

Table 1: drying temperatures

Injection Molding

The material SITRALON® (PC) can be processed on all standard injection molding machines. To achieve optimum properties we recommend the following melt temperatures

Enineering thermoplastic	Melt temperature (°C)	Mold temperature (°C)
SITRALON® (PC)	280 -300	80 - 110

Table 2: processing temperatures

Overheating or leaving the melt in the cylinder for an extended period of time can result in material damage i.e. a reduction in strength and surface defects in the form of streaks.

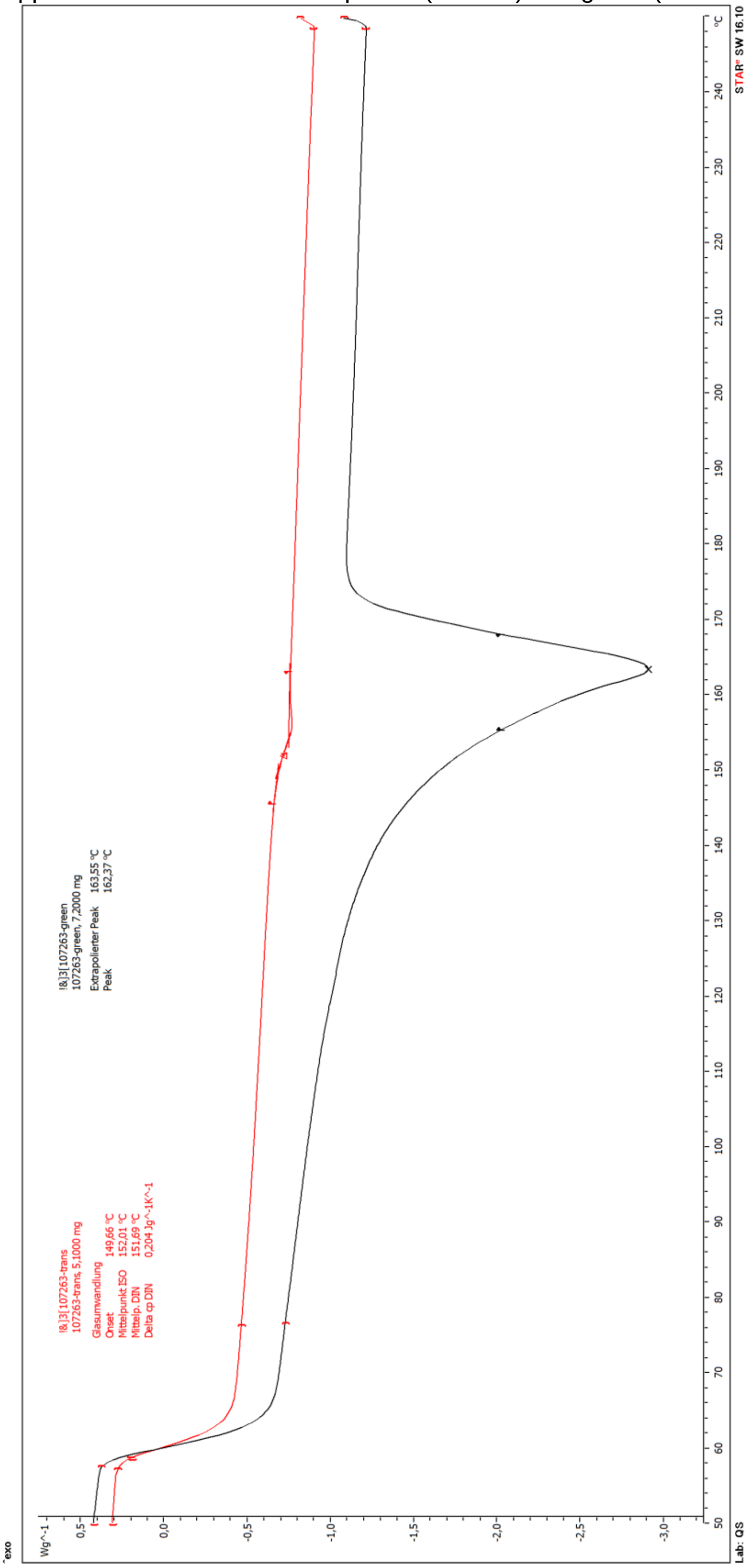
The product-specific information is not to be understood as guarantees. Each user has to assess the product under its own responsibility for the intended purpose.

Geschäftsführung:
Tim Hencken

Handelsregister:
HRB 8229
Amtsgericht Bad Oeynhausen
USt-Id.-Nr.: DE242701328

Bankverbindung:
Sparkasse Herford (BLZ 494 501 20)
KTO: 140 203 019

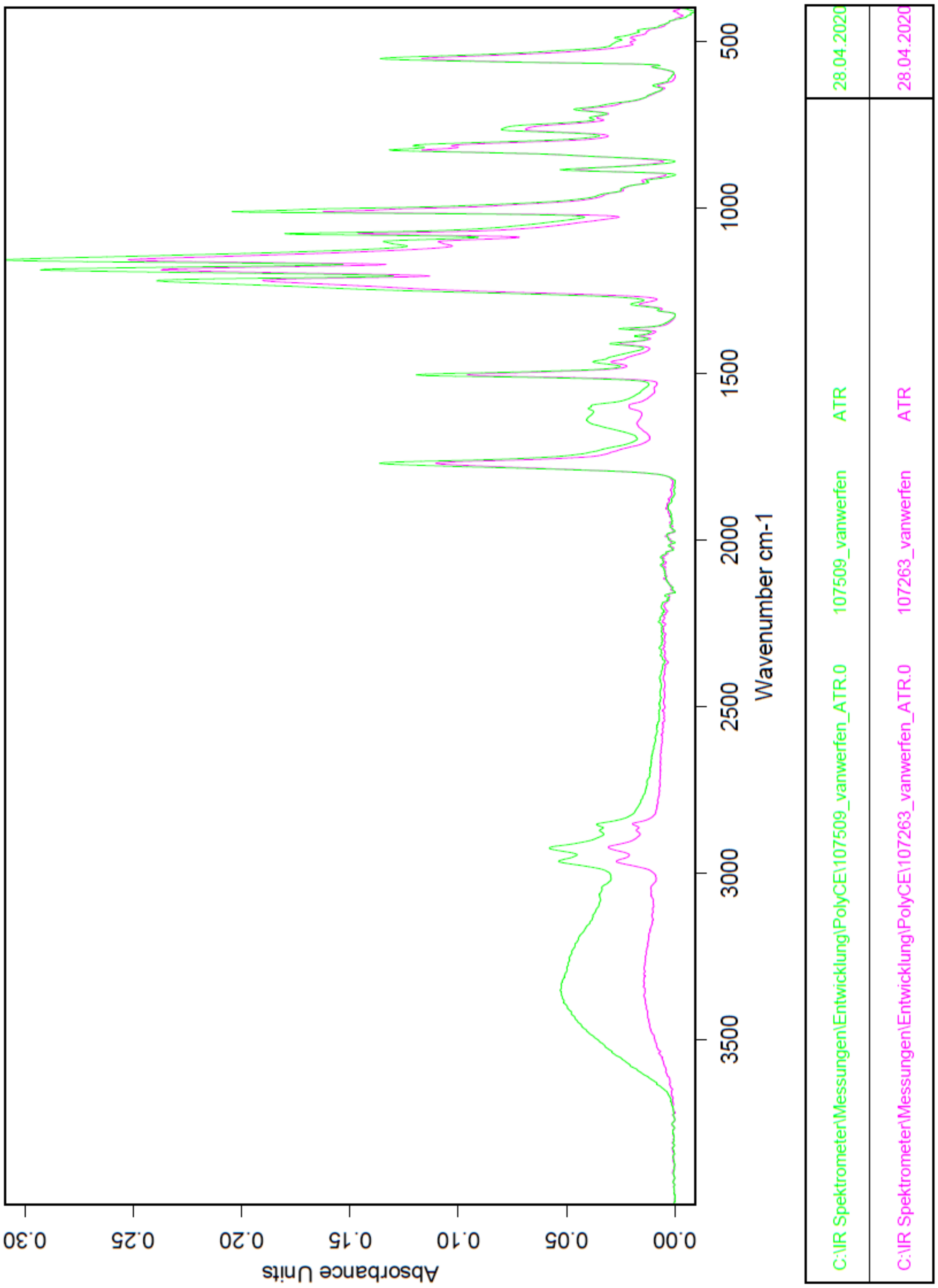
Appendix B: DSC results transparent (red line) and green (black line) flakes:



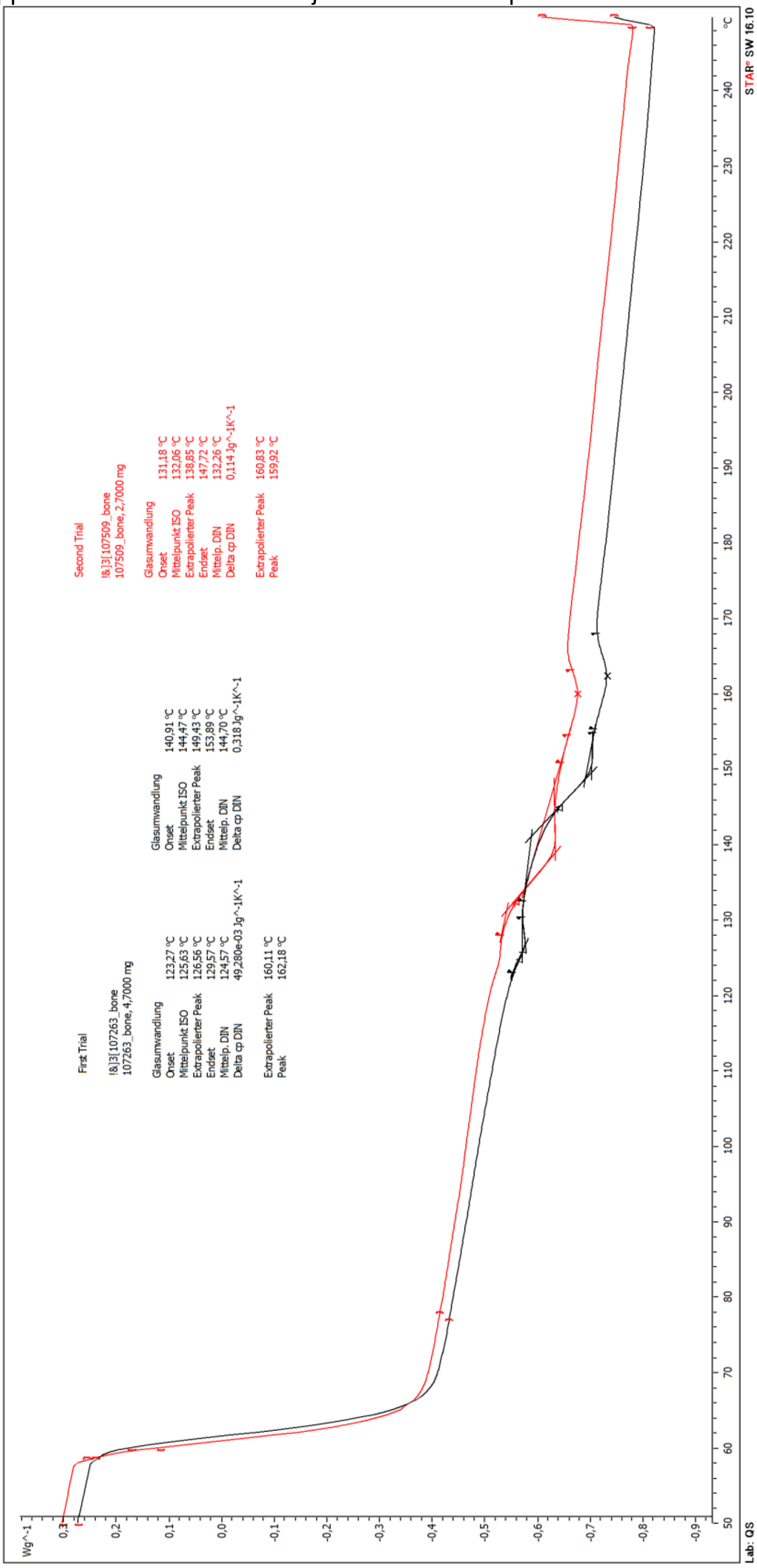
Appendix C: Overview of compounding trials Sample 1

PCR amount	Processable	MVR	Tensile Modulus	Impact strength (notched)	Impact strength (unnotched)	Vicat Softening Temperature	Surface quality
[%]	[-]	[-]	[MPa]	[kJ/m^2]	[kJ/m^2]	[°C]	[-]
100	No	N.a.	N.a.	N.a.	N.a.	N.a.	n.i.O
90	No	N.a.	N.a.	N.a.	N.a.	N.a.	n.i.O
30	No	N.a.	N.a.	N.a.	N.a.	N.a.	n.i.O
20	Yes	20.72	2475	11.8	N	142	n.i.O

Appendix D: FTIR results of injection moulded specimen of neat PC flakes from sample 1 and 2:



Appendix E: DSC results of injection moulded specimen of neat PC flakes from sample 1 and 2:



Appendix F: Ash content measurements:
Notes: 3h @ 600°C

sample	sample weight (g)	Crucible weight (g)	ash + crucible weigth (g)	ash content (g)	Ash content (%)
1	10.024	81.614	81.724	0.110	1.1%
2	10.008	73.078	73.203	0.126	1.3%
3	10.333	77.645	77.735	0.090	0.9%
mean					1.1%
stdev					0.2%

Polystyrene case

Appendix A: Processing parameters: extrusion

Machine and material			
Machine	Brabander 19	Screw speed (RPM)	110
Single Screw	■	Double screw	☐
Material	Recycled Polystyreen flakes		
Drying time (h)	8	Drying temperature (°C)	60
Main feeder	Manually agitated	Secondary feeder	/
Thermal			
Temperature profile (°C)	140-170-190-210		
Die			
Die type	Slit die		
Die specs and settings	/		
Cooling			
Chill rolls ■	Water bath ☐	Filament stretch set-up ☐	
Other cooling settings (speed, thickness…)	Calander speed: 0.8 Calander Temp: 20°C		
Notes and sketches			
Sheet thickness 1.5mm Feeding difficult Breakage of extrude due to impurities Slight smell			

Machine and material			
Machine	Brabander 19	Screw speed (RPM)	110
Single Screw	■	Double screw	☐
Material	Recycled Polystyreen pellets		
Drying time (h)	5	Drying temperature (°C)	60
Main feeder	Manually agitated	Secondary feeder	/
Thermal			
Temperature profile (°C)	140-170-190-210		
Die			
Die type	Slit die		
Die specs and settings	/		
Cooling			
Chill rolls ■	Water bath ☐	Filament stretch set-up ☐	
Other cooling settings (speed, thickness…)	Calander speed: 1.6 Calander Temp: 20°C		
Notes and sketches			
Sheet thickness 1.7mm Easy processing			

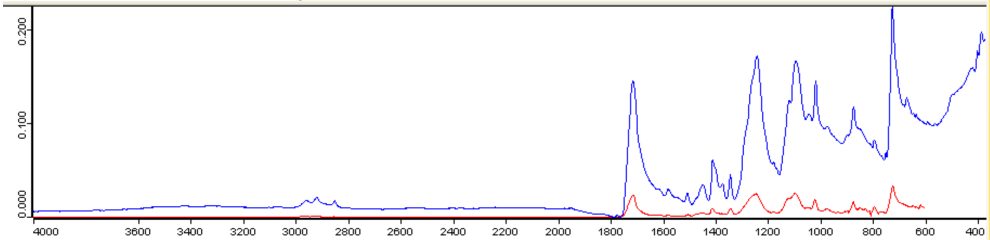
Appendix B: Processing parameters: Injection moulding

Machine and material			
Material	(HI)PS flakes		
Machine and screw	Engel 28 T	Mold type	ISO
Drying time (h)	4-5	Drying temperature (°C)	60
Thermal			
Temperature profile (°C)	220-210-200-190	Mold temperature (°C)	40
Injection			
Speed (mm/s)	100	Pressure - peak value (bar)	917
To holding pressure (mm)	■ 19	To holding pressure (s)	☐
To holding pressure (bar)	☐	Clamping force (kN)	280
Holding pressure			
Pressure (bar)	450	Time (s)	5
Buffer residue (mm)	5,86		
Dosing			
Speed (%)	75	Length (mm)	70
Pressure (bar)	100	Delay (s)	3
Decompression before dosing (mm)	3	Decompression after dosing (mm)	5
Other			
Cooling time (s)	15	Sample mass (g)	22,22
Notes			
- Black dots - Bit smelly - Jetting due to contaminations blocking the gate - Inconsistent feeding, difficult - Inconsistent results			

Machine and material			
Material	(HI)PS compounded pellets		
Machine and screw	Engel 28 T	Mold type	ISO
Drying time (h)	4-5	Drying temperature (°C)	60
Thermal			
Temperature profile (°C)	220-210-200-190	Mold temperature (°C)	40
Injection			
Speed (mm/s)	100	Pressure - peak value (bar)	936
To holding pressure (mm)	■ 19	To holding pressure (s)	□
To holding pressure (bar)	□	Clamping force (kN)	280
Holding pressure			
Pressure (bar)	450	Time (s)	5
Buffer residue (mm)	5,86		
Dosing			
Speed (%)	75	Length (mm)	70
Pressure (bar)	100	Delay (s)	3
Decompression before dosing (mm)	3	Decompression after dosing (mm)	5
Other			
Cooling time (s)	15	Sample mass (g)	22,25
Notes			
- Easy processing - Faint smell perception, dissipates after cooling			

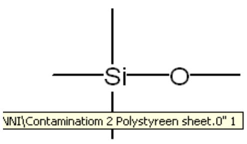
Appendix C: FTIR measurement PET contamination:

Polymer Classification	Polyethylene Terephthalate (PET)
Trade Name	Petlon 4630
Manufacturer	Bayer AG
Colour	black
Chemical / Physical Description	30% glass fibres
Source of Spectrum	BRUKER OPTIK GMBH, Ettlingen, Germany
Type of Spectrometer	TENSOR 27
Measurement Technique	Attenuated Total Reflectance (ATR), Diamond-Crystal

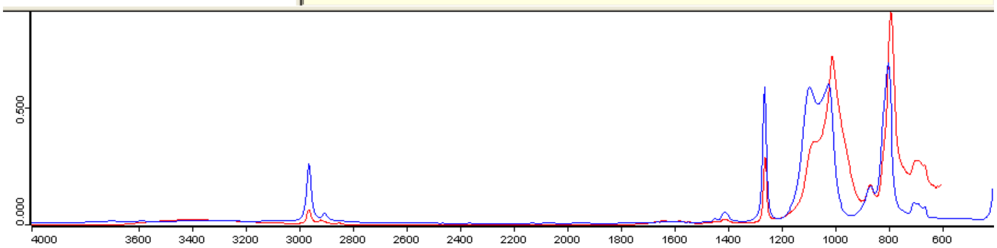


30 Hits	Hit Quality	Compound Name	Entry No.	Molecular formula	Molecular weight	CAS number
1.	811	Polyethylene Terephthalate (PET)	183			
2.	736	Polybutylene Terephthalate (PBT)	187			
3.	727	Polybutylene Terephthalate (PBT)	185			
4.	718	Polybutylene Terephthalate (PBT)	37			
5.	718	Polybutylene Terephthalate (PBT)	39			
6.	718	Polycarbonate / Polybutylene Terephthalate (PC + PBT)	195			
7.	701	Polybutylene Terephthalate (PBT)	193			
8.	700	Polycarbonate / Polybutylene Terephthalate (PC + PBT)	191			
9.	698	Polycarbonate / Polybutylene Terephthalate (PC + PBT)	192			

Appendix D: FTIR measurement Silicone contamination:



Compound information	
Compound Name	POLY(DIMETHYLSILOXANE)
Molecular Formula	Si1C2H6O1
Molecular Weight	
CAS Registry Number	63148-62-9
Sample Preparation	CAST FILM FROM THF ON KBR
Comment	molecular formula means constitutional repeating unit



30 Hits	Hit Quality	Compound Name	Entry No.	Molecular formula	Molecular weight	CAS number
1.	554	POLY(DIMETHYLSILOXANE)	334	Si1C2H6O1		63148-62-9
2.	518	POLYDIMETHYLSILOXANE	186			
3.	484	Polypropylene (PP)	109			
4.	480	SILICONGREASE 300 MEDIUM	337			
5.	475	Polyurethane-Reaction Injection Molded Polyurethane-Glycol (PUR-RIM-GLYCOL)	16			
6.	475	Polypropylene (PP)	89			
7.	468	Structural Reaction-Injection Moulding (S-RIM)	11			
8.	467	Polyethylene Terephthalate (PET)	183			
9.	463	NAPHTHALENE	292	C10H8	128.19	91-20-3

Appendix D: Impact raw data

Sample	flakes		compound	
Average dimensions (thickness x width) mm	7.966 x 3.925		7.973 x 3.919	
	Impact value (kJ/m²)	Value (J)	Impact value (kJ/m²)	Value (J/m)
Mean	7,09335	0,223256	7,068128	0,22079
stdev	0,515638	0,016338	0,538336	0,016814

Appendix E: Steaplus Har T77 talc datasheet

Product Data Sheet
Steaplus HAR® T77

Description & Applications

Steaplus HAR® T77 is produced using a new delaminating process developed by Imerys Talc.
Steaplus HAR® T77 is much more lamellar than other conventionally micronized grades and provides improved mechanical properties when compounded in polypropylene. Higher flexural modulus and HDT, better dimensional stability (low CLTE, shrinkage) are obtained versus conventional talcs, without impairing ductility of the moulded parts.
Steaplus HAR® T77 is recommended for use in applications which do not require whiteness.
Steaplus HAR® T77 is densified and has excellent flow properties for easy handling and high extruder throughput.

Typical Properties

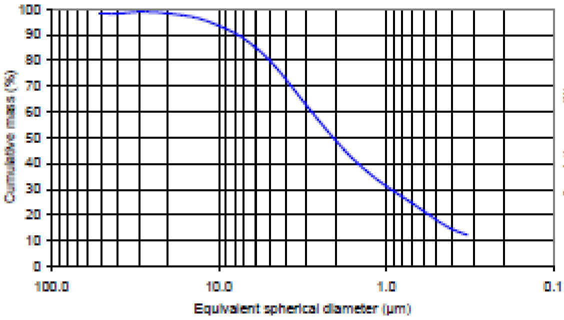
Whiteness (Minolta CR300, illuminant D65/2°) Y	73
L* (CIE)	88.3
a* (CIE)	-0.1
b* (CIE)	-0.2
B.E.T. (ISO 9277)	19 m^2/g
Specific gravity (ISO 787/10)	2.78 g/cm^3
Tapped bulk density (ISO 787/11)	0.8 g/cm^3
Loose bulk density (EN 1097/3)	0.65 g/cm^3
Hardness (Mohs' scale)	1

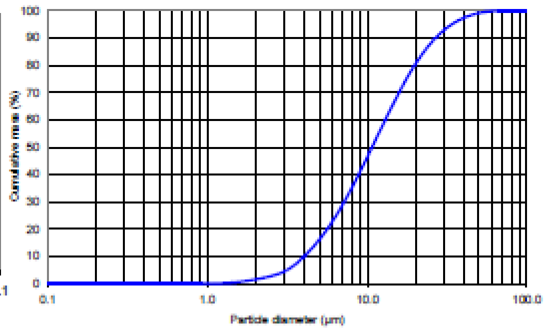
Chemical Analysis (by X-ray fluorescence)

SiO_2	55.3%
MgO	31.1%
Al_2O_3	3.4%
Fe_2O_3	0.8%
CaO	0.8%
Loss on ignition at 1050°C	7.1%
Loss on ignition at 625°C	1.9%
Moisture content at 105°C (ISO 787/2)	< 0.8%

Particle Size Distribution by Sedigraph
Sedimentation analysis, Stokes' Law (ISO 13317-3)
Median Diameter – D50: 2.1µm
D95: 11.2µm

by Laser Mastersizer
Laser diffraction, Mie Theory (ISO 13320-1)
Median Diameter: D50: 11.2µm
D95: 35µm





Notice: Although the data listed are typical, they are not production specifications. The supplier provides the data in good faith, however it makes no warranty or representation of any kind, express or implied, regarding the information given or product described including any warranty of suitability for a particular purpose.

For more information, please visit www.imerystalc.com

POL/TFR/ENG/10/2011

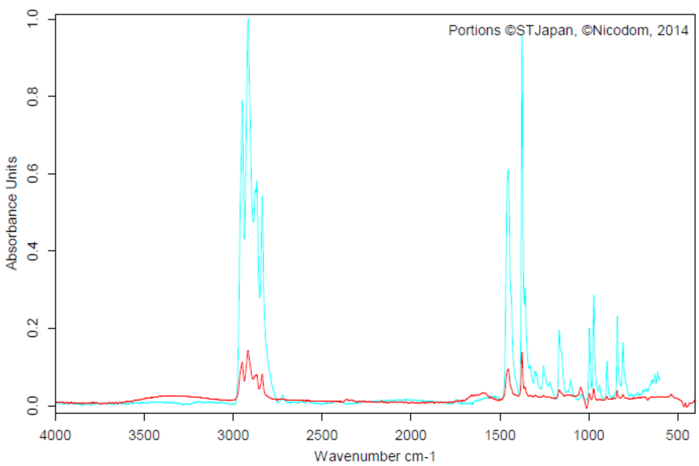
IMERYS Talc

Appendix F: Processing parameters rPP

Process information		
Preprocessing	**Value**	**Unit**
Pre drying temperature	80	°C
Pre drying time	2 - 3	h
Max. humidity for molding application	0,1	%
Extrusion		
Recommended melt temperature	200	°C
Molding		
Recommended melt temperature	200 - 240	°C
Melt Temperature Range	190 – 250	°C
Recommended Mold Temperature	40	°C
Mold Temperature Range	30 – 60	°C
Recommended Screw Back Pressure	100 – 150	bar

Appendix G:

Bibliothekssuche **27.01.2021 14:18:58**



Compound Name	POLYPROPYLENE, ISOTACTIC #2
Molecular Formula	(C3H6)n
Molecular Weight	
CAS Registry Number	9003-07-0
Sample Preparation	ATR single bounce
Comment	polypropylene
Reference	353/ MP0198
Copyright	(c) 2014 Nicodom
Eintrag Nr.	627
Bibliotheksname	ATR-LIB-POLYMERS-2-472-2.S01

Color	Hit Quality	Compound name	CAS Number	Molecular formula	Molecular weight
	830	POLYPROPYLENE, ISOTACTIC #2	9003-07-0	(C3H6)n	

Color	File	Path	Spectrum Type
	PP_labwaste_ATR.0	C:\IR Spektrometer\Messungen\Entwicklung\PolyCE	Anfragespektrum

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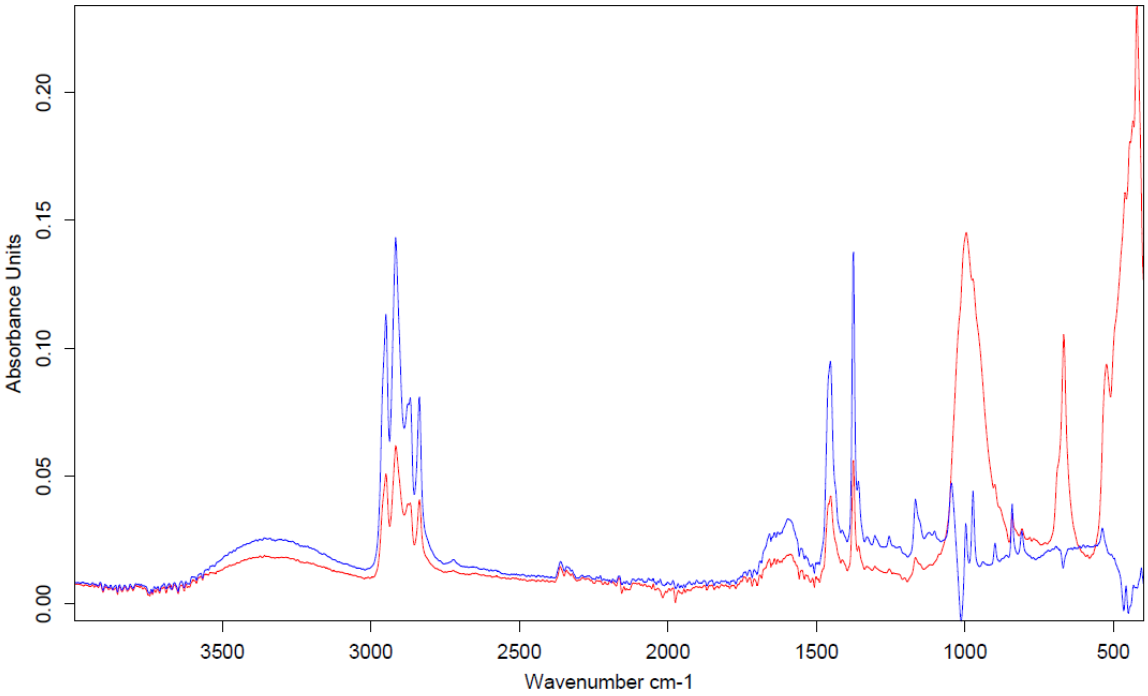
Appendix H:



C:\IR Spektrometer\Messungen\Entwicklung\PolyCE\PP_labwaste_ATR.0 PP_labwaste ATR	27.01.2021
C:\IR Spektrometer\Messungen\Entwicklung\PolyCE\PP_labwaste+40%Talc_ATR.0 PP_labwaste+40%Talc ATR	27.01.2021

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