Deliverable D3.4

Report on plastic materials recovered and properties characterization

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Feasible Recovery of critical raw materials through a new circular Ecosystem for a Li-Ion Battery cross-value chain in Europe

WP 3 - Recycling & Materials Re-using Technologies for Li-Ion Batteries

D3.4 - Report on plastic materials recovered and properties characterization

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Contents

Table 1. Abbreviations and synonyms

ACRONYMS	DESCRIPTION
ABS	Polyacrylonitrile-Butadiene-Styrene
EoL	End of Life
EV	Electric Vehicle
FTIR	Fourier Transform Infrared spectroscopy
HDPE	High Density Polyethylene
NIR	Near-infrared
PA	Polyamide
PC	Polycarbonate
PPE	Polyphenylene ether
PP	Polypropylene

1. Executive summary

The current report is related to *Task 3.5 Recycling of plastics at lab-scale* and focuses on the plastic components and parts recovered from End-of-Life (EoL) batteries in electric vehicles (EV) after performing dismantling operations in previous tasks. The research aim is to carry out the processes for the sorting and identification of the different polymer materials, as well as properties characterization.

This report details the work performed within the scope of *Task 3.5*:

- Reception and sorting of plastic components and parts from dismantled EV battery pack.
- Identification of polymer type.
- Research of polymer grades to set benchmark properties.
- Definition of feasible case studies to proper recycling of plastic materials.
- Pre-treatments of plastic components to obtain thermoplastic samples for material properties characterization at lab-scale.

The outcomes of this *Task 3.5* will provide the base knowledge and data to perform further *Task 4.5 Scale-up for plastic materials recycling* within the scope of WP4.

2. Introduction

Plastic materials encompass a wide family of different polymer types, from commodity polyolefins used in large volume in the packaging sector to engineering grade polyamides used in high tech electronic components. Generally speaking, plastic materials offer convenient properties such as:

- Lightweight compared to materials like metals, which makes plastics ideal for reducing total weight in transport applications.
- Good mechanical properties and durability showing good chemical resistance, weatherability and corrosion resistance making plastic materials suitable for long-term use in various industrial applications.
- Versatility: plastic can be engineered to have a wide range of properties, from rigid to flexible, heat-resistant to insulating, transparent to opaque, etc.
- Ease of processing: plastics can be easily moulded at relative low processing temperatures into complex shapes using various techniques such as injection moulding, extrusion, 3D printing, etc.

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- Cost-effectiveness: Plastics are often more cost-effective than alternative materials like metals or glass, which contributes to their widespread use in various industries.
- Recyclability at their end life allowing reuse of plastic secondary raw materials in the manufacturing of new products.

These properties vary depending on the specific type of polymer and its formulation, specialty additives added and processing techniques. The benefits offered by plastic materials have driven plastic substitution of traditional materials such as metals, glass, ceramics or wood.

Automotive and transport sectors have taken advantage of plastic lightweight and versatility to make vehicles more energy efficient by reducing weight and thus allowing lower fuel consumption and cutting emissions. The average passenger car incorporates nearly 160 kg of plastic components which represent approximately 8.8 % of the total weight. This share is likely to increase in the new generation of electric vehicles (EVs) where plastic components play a significant role in the design, manufacturing and performance contributing power efficiency and longer driving range.

Some common plastic components found in EVs include:

- Battery housings and casings: Polymers such as PP, PPE or PA offer thermal insulation and corrosion protection for the battery pack.
- Connectors and enclosures: PA grades are used in the manufacturing of various electronic components (such as sensors, control units, etc.) providing dimensional stability, thermal resistance, electrical insulation and protection against moisture and other contaminants.
- Fluid systems: Polymers such as PA or HDPE are used in the manufacturing of pipes, tubes and ducts for cooling systems offering excellent thermal and chemical resistance.
- Charging port covers: PP, PC or ABS polymer grades are used in the manufacturing of plates and covers to protect electrical connections and charging ports preventing dust, dirt and moisture from entering the ports ensuring reliable operation.

The increasing adoption of EVs will boost the need for proper recovery of plastic components from EoL vehicles (including interior and battery packs). Managing these plastic components presents challenges and opportunities given the diverse range of plastics used in vehicle manufacturing. Nevertheless, effective management of these materials is crucial to reduce environmental impact, conserve resources, and promote sustainability in the automotive industry.

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3. Recycling of plastic components

3.1. Sorting and identification of plastic components

Project partners ACC, EURECAT and WATT4EVER performed the disassembling operations at their respective facilities in order to extract the cell modules and other components.

AIMPLAS has collected different plastic components that have been sent by those partners, and also by other partners (such as CARTIF or FRAUNHOFER) after the dismantling of battery cell modules.

The first stage in the pretreatment of plastic components consist of the sorting and classification of plastic parts according to shape, size and functionality. Figure 1 shows the different plastic parts extracted from battery pack HYUNDAI KONA EV.

Figure 1. Plastic parts extracted from battery pack dismantling.

The second stage has included the identification of polymer types by means of visual inspection (as some moulded parts include identification marking) and optical analysis of plastic parts samples applying near-infrared (NIR) spectroscopy using of handheld NIR analyser as depicted in figure 2, or Fourier Transform Infrared spectroscopy (FTIR) using laboratory analyser as depicted in figure 3.

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Figure 2. Polymer type identification with handheld NIR analyser.

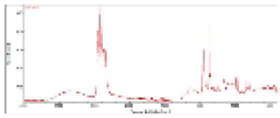
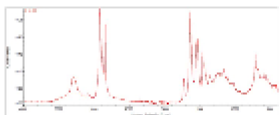
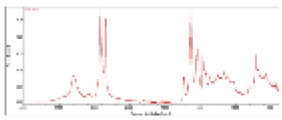
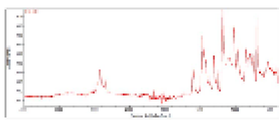
Figure 3. Polymer type identification in laboratory FTIR analyser.

Handheld NIR analyser allows quick and convenient identification of plastic parts featuring different geometry and size. This technique relies on the ability of the different chemical bonds in the polymer material to absorb NIR radiation at specific wavelengths. The device emits a broad spectrum of NIR light source onto the surface of the plastic part. A detector measures the intensity of the NIR reflected at different wavelengths. Data is analysed comparing the measured NIR spectrum of the sample with reference spectra stored in the device´s database so that results for polymer type match are displayed on the device´s screen.

However, its use is limited to non-black parts as black pigments tend to absorb a significant portion of the NIR light rather than reflecting it back making it challenging for NIR systems to accurately identify and differentiate. As a result, black plastic parts may not be identified as reliably as ligther-colored parts. In this case, specific Fourier Transform Infrared spectroscopy FTIR technique is performed using laboratory analyser. FTIR analysis measures the absorption of infrared light by a sample across a wider range of wavelengths providing detailed information about the molecular structure and chemical composition as different functional groups in molecules absorb infrared light at characteristic frequencies allowing a more accurate identification of chemical compounds. The resulting FTIR spectrum chart shows peaks at specific wavelengths corresponding to the absorption of IR radiation by different functional groups present in the sample. By comparing these peaks to reference spectrum database is it possible to match the polymer type material.

Table 1 summarizes outcomes of material identification analysis for the plastic parts extracted from EV battery pack dismantling.

Table 1. Plastic components identification results.

	Plastic part & function (weight)	Manufacture method	Polymer type	Identification technique
	Protective and insulation **panels** **(250 g)**	Compression moulding	Polypropylene PP	Visual, FTIR 
	Liquid cooling system **tubes (25 g)**	Extrusion	Polyamide PA 11	Visual, FTIR 
	Tube **fittings** **(6 g)**	Injection moulding	Polyamide PA 66	Visual, FTIR 
	Module cell pouch **frames** **(92 g)**	Injection moulding	Polyphenylene ether PPE	Visual, FTIR 

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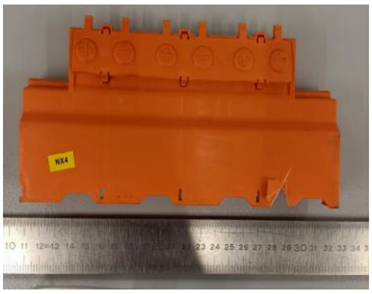
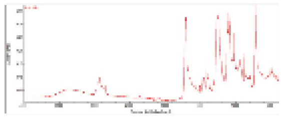
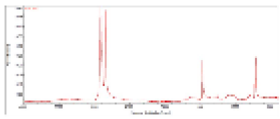
	Connector protective **covers** (**50 g**)	Injection moulding	Polypropylene PP	Visual, NIR 
	Connector protective **plates** (**10 g**)	Injection moulding	PolyAcrylonitrile-Butadiene-Styrene ABS	Visual, FTIR 
	Air cooling system **duct** (**125 g**)	Injection moulding	Polyehylene HDPE	Visual, FTIR 
	Sealing rubber **band** (**550 g**)	Compression moulding	Synthetic rubber EPDM	Visual

3.2. Case studies definition

The definition of the most feasible case studies for plastic components recycling has considered component functionality and material source availability and suitability for upscaling operations in further *WP4 Task 4.5 Scale-up for plastic materials recycling.*

- Case study #1 : Cell pouch frames from battery modules
- Case study #2 : Tubes from cooling system
- Case study #3 : Protective and insulating panels

For each case study the benchmarking polymer types and grades have been set according to product performance requirements. Depending on each plastic

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component, several pre-treatment operations have been performed with the aim of obtaining material samples and test specimens in order to perform material properties characterization at laboratory level.

3.2.1. Case study #1 Cell pouch frames

EV battery packs include several modules consisting of cell pouches connected and held by frames stacked (figure 4).

Figure 4. EV battery modules.

Frames are manufactured using thermoplastic polymer type polyphenylene ether (PPE) by means of injection moulding. Figure 5 shows frame after removing cell pouch.

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Figure 5. Cell pouch frames form battery modules.

3.2.1.1. PPE polymer type benchmark

Polyphenylene ether (PPE), often referred as polyphenylene oxide (PPO), is a high-performance plastic engineering grade offering excellent combination of high heat resistance, dimensional stability and superior mechanical strength. Main PPE properties include:

- Low density.
- High toughness and impact strength.
- High thermal resistance (up to 195ºC).
- High dimensional stability and low shrinkage.
- Hydrolytic stability and chemical resistance to acids and alkalis.
- Strong electrical insulating performance with low dielectric permittivity.
- Good flowability for injection moulding processing.
- Flame resistance with specialty additives.

In order to improve processability PPE is often blended with other polymers such as polystyrene (PS). In the same way, PPE composites incorporates glass fibres reinforcement to further enhance stiffness and dimensional stability, making it suitable for applications requiring higher performance under mechanical stress.

PPE main applications include:

- Electronic appliances internal components.
- Pumps, valves and fittings.
- Electric battery modules cell frames, top covers and housings.

Only few companies produce PPE resin globally including Saudi based SABIC and Japan based Asahi-Kasei or Mitsubishi. PPE polymer engineering grades

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are quite limited and commercial availability is often restricted to specialized markets and regions. Polymer grade NORYL™ RESIN NHP6012 10% glass fibre reinforced blend of PPE plus PS (provided by supplier SABIC) has been selected as a benchmark material.

3.2.1.2. Plastic frames pre-treatment

Cell frames incorporate metal inserts for connectors that are overmoulded in the manufacturing process (figure 6). These metal inserts need to be removed in order to recycle the thermoplastic part.

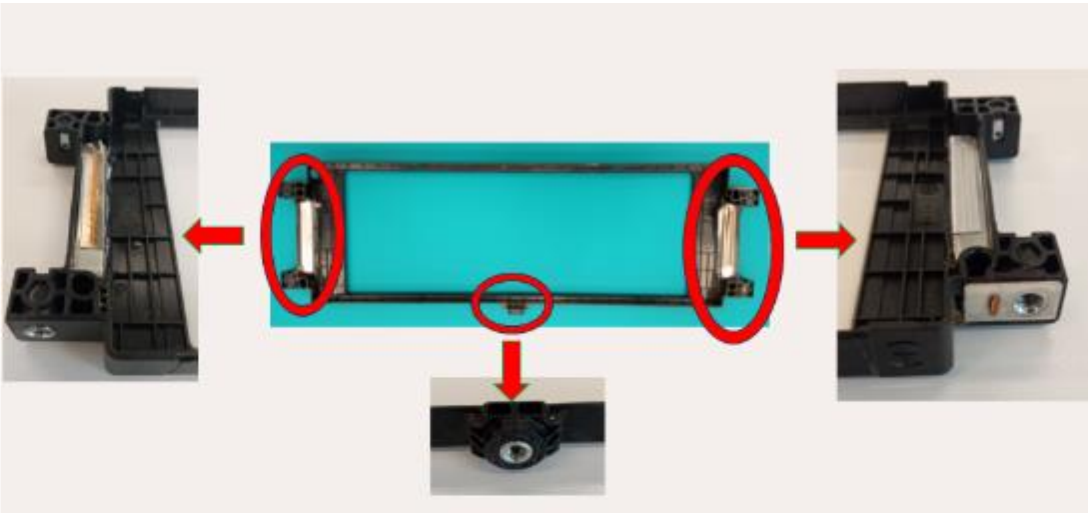

Figure 6. Metal inserts in the plastic frame.

The first stage in the pre-treatment consists of part crushing in order to reduce the part size. This stage is performed in the mill crusher as depicted in figure 7.

Figure 7. Mill crusher.

As a result of this stage the frames are crushed to parts with reduced size between 20-60 mm (figure 8).

Figure 8. Mixed reduced parts after crushing.

The second stage in the pre-treatment consists of metal separation. For that purpose, the mixed crushed parts pass through a hopper incorporating a grid of neodymium magnet rods that capture the ferrous inserts and particles (figure 9).

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Figure 9. Ferro-magnetic separator.

The plastic parts that come out from the ferro-magnetic separator still include some metal aluminium platens (figure 10).

Figure 10. Mixed reduced parts after ferro-magnetic separation.

Aluminium platens are removed by means of Eddy currents in a non-ferrous metal separator consisting of a short belt conveyor that delivers the material to be separated to the head drum (as depicted in figure 11).

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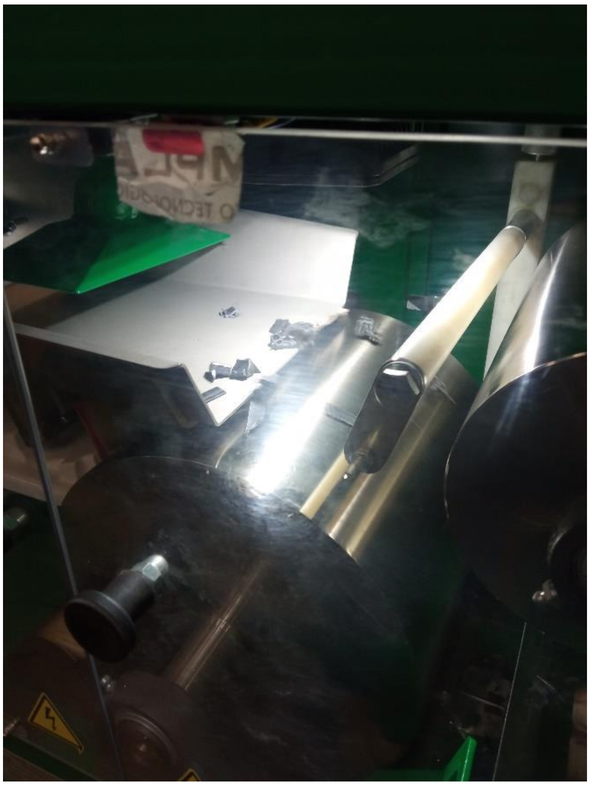

Figure 11. Non-ferrous metal separator.

As a result of this stage, the fraction of metal parts is removed from the plastic parts stream (metal fraction in a single frame represent approximately 62%(w/w). So that the next stage consists of the grinding of the plastic fraction using a shredder mill in order to obtain grinded plastic granulates with smaller particle size. The plastic parts are feed through a hopper to the shredder chamber where the rotor blades break down the plastic parts. The perforated screen plate helps to control the size of grinded particles that exits the shredder chamber (figure 12).

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Figure 12. Shredder mill and shredder chamber.

As an outcome of this last stage the PPE thermoplastic fraction is recovered as homogeneous plastic granulates with particle size between 4-8 mm (figure 13). Plastic material losses during the shredding process are negligible.

Figure 13. Plastic PPE granulates.

3.2.1.3. Plastic material properties characterization

In order to perform plastic material characterization standard test specimens have been obtained from rPPE plastic granulates by means of injection moulding (figure 14).

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Figure 14. rPPE standard test bars.

Table 2 summarises results from laboratory tests comparing the recycled material recovered from module frames to the benchmark material.

Table 2. PPE material properties characterization.

Property	Test method	Unit	Bechmark polymer NORYL™ RESIN NHP6012 10% GF	Recycled polymer rPPE from EV battery module frames
Tensile stress at break	UNE-EN ISO 27	MPa	82	78.1
Tensile strain at break	UNE-EN ISO 27	%	2.5	3.1
Flexural modulus	UNE-EN ISO 178	MPa	4000	4050
Flexural strength	UNE-EN ISO 178	MPa	132	118
Charpy impact resistance Notch @ 23ºC	UNE-EN ISO 179/1eA	kJ/ m^2	6	9.64
Charpy impact resistance Unnotch @ 23ºC	UNE-EN ISO 179/1eU	kJ/ m^2	25	34.58

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Heat Deflection Temperature 1.8 MPa	UNE-EN ISO 75	ºC	125	122
Heat Deflection Temperature 0.45 MPa	UNE-EN ISO 75	ºC	132	128
Rockwell M hardness	UNE-EN ISO 2039	--	90	167

Outcomes from material tests performed on recycled polymer PPE from EV battery module frames show that there is a decrease in mechanical properties related to tensile and flexural strength when compared to benchmark polymer. There is a 5% decrease in tensile stress and a 10% decrease in flexural strength. Also, there is approximately 3% decrease in heat deflection temperature (HDT). Nevertheless, recycled material shows higher impact resistance (for both notched and unnotched tests) and hardness. These overall results suggest that service conditions have led to some losses in the material toughness and thermal resistance.

3.2.2. Case study #2 Pipes and tubes cooling system

Electric vehicle (EV) battery packs are equipped with an internal liquid cooling system to manage temperature and prevent battery damage. This is crucial because batteries generate heat during charging or discharging and this affects performance, safety and battery degradation. The cooling system consists of different pipes and tubes that conduct the cooling liquid throughout the system (figure 15).

Figure 15. EV battery cooling system pipes.

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Pipes are manufactured using thermoplastic polymer type polyamide (PA) by means of extrusion. Figure 16 show pipe featuring Ø 16 mm (although some sections feature tubes Ø 10 mm).

Figure 16. Pipes extracted from battery pack cooling system.

Pipes and tubes are connected using fittings as depicted in figure 17. Fittings are also manufactured using thermoplastic polymer type polyamide (PA) by means of injection moulding.

Figure 17. Fittings extracted from battery pack cooling system.

3.2.2.1. PA polymer types benchmark

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Polyamide (PA) is a high-performance plastic engineering grade offering excellent combination of toughness, flexibility, thermal stability and resistance to wear. PA cover a wide range of polymer grades produced through different methods, including condensation polymerization of diamines and dicarboxylic acids or by ring-opening polymerization of lactams. NYLON or PA6 is the most common and versatile variant (produced by the polymerization of caprolactam) and is widely used in several applications: fibres, automotive components, electrical connectors and packaging films.

PA11 is the specific polyamide grade for the manufacture of extruded pipes due to excellent tensile strength, impact resistance and flexibility. PA11 is synthesized through by ring-opening polymerization of 11-aminoundecanoic lactam. Main PA11 properties include:

- Low density.
- High flexibility and good flex fatigue resistance.
- Good toughness and impact resistance.
- Chemical resistance to hydrocarbons, oils and salts.
- Wide range temperature performance resistance (-40 °C / 130°C).
- Easy processing (pipe extrusion, injection moulding).
- Hydrolytic stability and chemical resistance to acids and alkalis.
- High dimensional stability due to lower hydrophilic behaviour.

PA11 main applications include:

- Tubes in fuel lines.
- Compressed air and hydraulic hoses.
- Cooling system tubes.
- Cable sheathing.

Several companies produce PA resins globally including BASF, Celanese, Arkema, Evonik, Asahi Kasei or UBE. PA 11 grade RILSAN® BESN BLACK P210 TL (provided by supplier Arkema) has been selected as a benchmark material.

PA66 is the specific polyamide grade for the manufacture of injection moulding fittings due to excellent mechanical properties. PA66 is produced by the polymerization hexamethylenediamine and adipic acid. Main PA66 properties include:

- High tensile strength. PA66 compounds with glass fibre reinforcement offer enhanced stiffness providing dimensional stability and rigidity.

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- Resistance to a wide range of chemicals, oils, greases, solvents and alkalis.
- Heat resistance maintaining mechanical properties at elevated temperatures (up 170ºC).
- Abrasion resistance to wear and tear caused by friction and rubbing.
- Good electrical insulation properties.

PA66 main applications include:

- Automotive components such as engine covers, radiator fans, air intake manifolds, etc.
- Industrial components such as gears, bearings, and rollers.
- Electrical and electronic applications such as connectors, housings and circuit breakers.

PA 66 grade LEONA™ 1402S (provided by supplier Asahi Kasei) has been selected as a benchmark material.

3.2.2.2. Plastic pipes and fittings pre-treatment

Battery cooling system consists of different pipes joined by connectors and fittings. The first stage in the pre-treatment consists of disassembling of pipes manually removing fittings from tubes (figure 18).

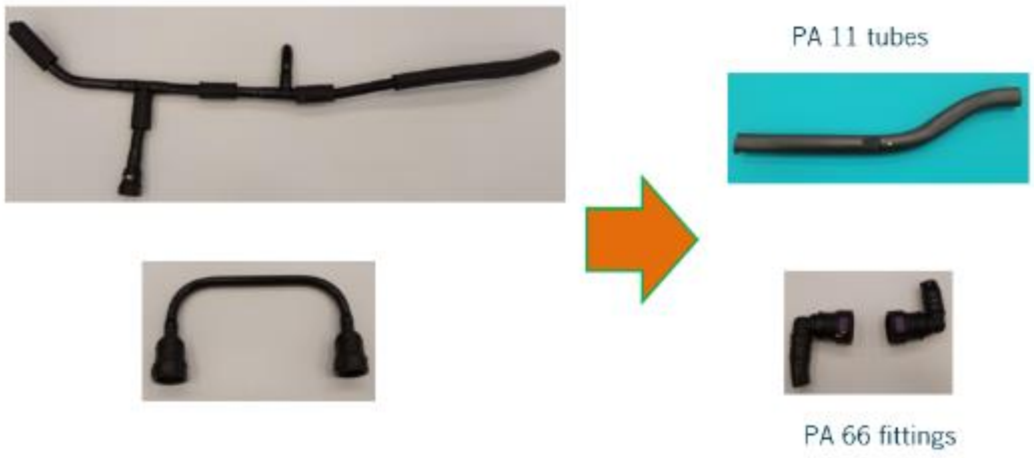

Figure 18. Tubes and fittings separation.

The next stage consists of the grinding of the plastic components using a shredder mill to obtain grinded plastic granulates with smaller particle size. The plastic parts are feed through a hopper to the shredder chamber where the rotor blades break down the plastic parts. The perforated screen plate helps to control the size of grinded particles that exits the shredder chamber (figure 19). Plastic material losses during the shredding process are negligible.

Figure 19. Thermoplastic granulates obtained after shredding.

As an outcome of this stage the PA thermoplastic material is recovered as homogeneous plastic granulates with particle size between 4-8 mm (figure 19).

3.2.2.3. Plastic material properties characterization

In order to perform plastic material characterization, standard test specimens must be manufactured from PA thermoplastic granulates by means of injection moulding. Regrettably the amount of rPA11 granulates recovered from pipes were not enough to run the injection moulding process not allowing the manufacture of sufficient test specimens for the whole set of tests. Additional

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samples of PA11 tubes are being collected to perform further recycling in *Task 4.5 Scale-up for plastic materials recycling*.

In the case of rPA66 granulates, enough material was available for the manufacture of test specimens by means of injection moulding (figure 20).

Figure 20. rPA66 standard test bars.

Table 3 summarises results from laboratory tests comparing the recycled material recovered from module frames to the benchmark material.

Table 3. PA66 material properties characterization.

Property	Test method	Unit	Bechmark polymer LEONA™ 1402S	Recycled polymer rPA66 from fittings
Tensile stress at break	UNE-EN ISO 27	MPa	82	77.2
Tensile strain at break	UNE-EN ISO 27	%	4.0	2.2
Flexural modulus	UNE-EN ISO 178	MPa	2700	5050
Flexural strength	UNE-EN ISO 178	MPa	113	141
Charpy impact resistance Notch @ 23ºC	UNE-EN ISO 179/1eA	kJ/m^2	6.0	6.3

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Charpy impact resistance Unnotch @ 23ºC	UNE-EN ISO 179/1eU	kJ/ m²	No break	32.44
Heat Deflection Temperature 1.8 MPa	UNE-EN ISO 75	ºC	70	233
Heat Deflection Temperature 0.45 MPa	UNE-EN ISO 75	ºC	190	243
Rockwell M hardness	UNE-EN ISO 2039	--	80	177

Outcomes from material tests performed on recycled polymer PA66 show that there is a decrease in mechanical properties related to tensile strength and strain when compared to benchmark polymer (decrease is approximately 6% and 45% respectively). The mechanical behaviour related to other properties (such as flexural modulus, flexural strength) that are noticeably higher than the benchmark polymer suggest that service conditions have led to significant losses in the material toughness as well as increased rigidity.

3.2.3. Case study #3 Protective and insulating panels

An EV battery pack include different large dimension panels (figure 21) that helps to protect battery modules and other components from vibrations and impacts, while also providing electrical and thermal insulation, minimizing the risk of thermal runaway.

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Figure 21. EV battery insulating panel.

Panels are manufactured using thermoplastic polymer type expanded polypropylene (EPP) by means of extrusion or moulding foaming. The foaming process allows to manufacture very lightweight parts (material density range from 20 kg/m^3 to 200 kg/m^3 depending on the specific formulation and manufacturing process) and the foam cell structure features numerous air pockets contributing to thermal insulation. Figure 22 shows different PP foamed panels extracted after EV battery pack dismantling.

Figure 22. PP foamed extracted from EV battery pack.

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3.2.3.1. EPP polymer types benchmark

Polypropylene (PP) is a thermoplastic polymer that is widely used in various applications due to its excellent combination of properties:

- Low density.
- High strength. Despite being lightweight, PP exhibits high tensile strength, stiffness and impact resistance.
- Heat resistance. Although PP features lower heat resistance compared to PPE and PA, still offer service temperature up to 100-120ºC.
- Chemical resistance to solvents, acids and alkalis.
- Easy processing by means of extrusion and injection moulding.

Expanded polypropylene (EPP) foam is a versatile material featuring lightweight, resilient and energy-absorbing properties. It is produced through a foaming process that involves the expansion of polypropylene beads using heat and pressure. EPP can be produced from various grades of PP resins, each tailored to specific performance requirements and processing conditions. High-Melt Strength Polypropylene (HMS-PP) resin have a molecular structure that exhibit good melt elasticity which is essential for the expansion process without collapsing, allowing the formation of uniform cell structures in the foam. PP grade Daploy™ WB140HMS (provided by supplier Borealis) has been selected as a benchmark material.

3.2.3.2. EPP panels pre-treatment

The first stage in the pre-treatment consists of the grinding of the EPP panels using a shredder mill to obtain grinded plastic granulates with smaller particle size. The panels are cut in smaller parts that are fed through a hopper to the shredder chamber where the rotor blades break down the parts. The perforated screen plate helps to control the size of grinded particles that exits the shredder chamber (figure 23). Plastic material losses during the shredding process are negligible.

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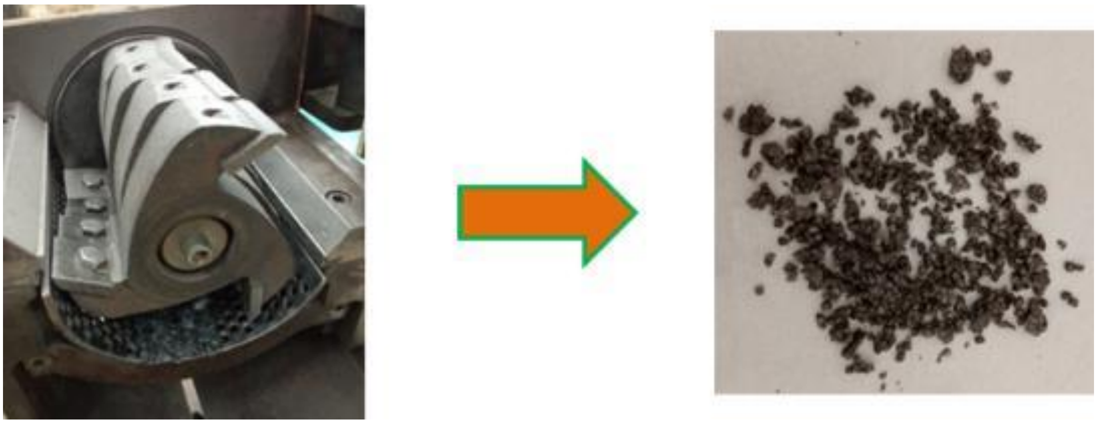

Figure 23. PP granulates obtained after shredding.

The second stage in the pre-treatment consists of the agglomeration of PP granulates into pellets offering higher bulk density. For that purpose, the equipment used is an agglomeration mill featuring a rolling presser. As an outcome the PP material granulates are agglomerated in the form of densified pellets (figure 24). Plastic material losses during the agglomeration process are negligible.

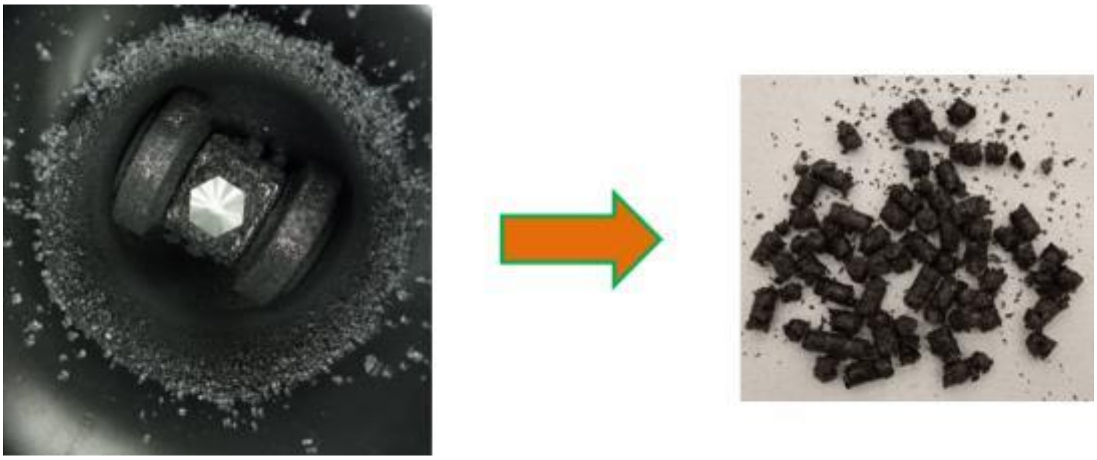

Figure 24. PP densified pellets obtained after agglomeration.

Although PP densified pellets obtained after agglomeration exhibit higher bulk density (in the range 0.4-0.5 kg/m^3), still it is not enough to assure continuous feeding in reprocessing equipment, and the pellets morphology tends to disaggregate into powders. So that the next pre-treatment stage has consisted of the melt extrusion of PP densified pellets by means of twin screw co-rotating

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extruder. Once the PP densified pellets are fed into the extruder, they are transported along the screw channel. Barrel heating system softens and compress the material up to melting point is reached (approximately 200ºC) to obtain homogeneous melt flow in the extruder compression zone. The thermoplastic material leaves the extruder though the die in the form of strands that are cooled in the water bath prior to being cut into rPP thermoplastic pellets featuring particle size 4-6 mm and uniform aspect ratio (figure 25). Plastic material losses during the melt extrusion process are in the range 3-5%.

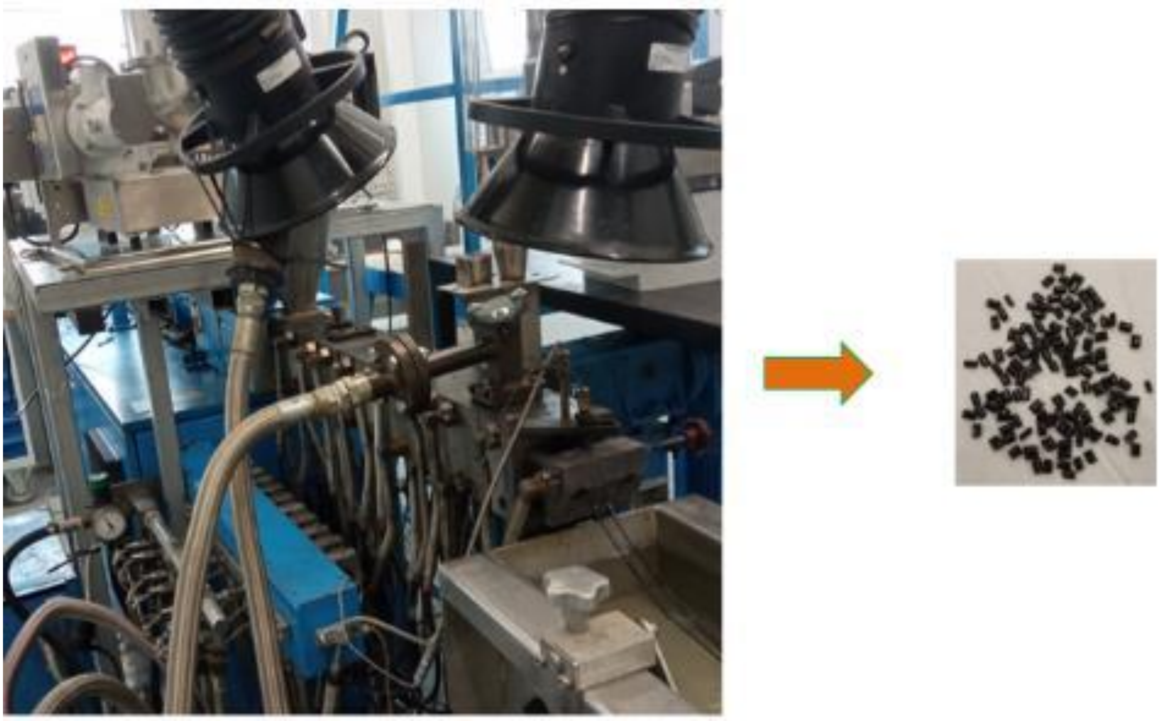

Figure 25. rPP thermoplastic pellets obtained after melt extrusion.

3.2.3.3. Plastic material properties characterization

In the case of EPP panels, properties characterization has consisted in the determination of foamed panels density and analysis of cell structure. Density result is included in table 4, Figure 26 shows microscope image analysis of material cell structure.

Table 4. EPP panels properties characterization.

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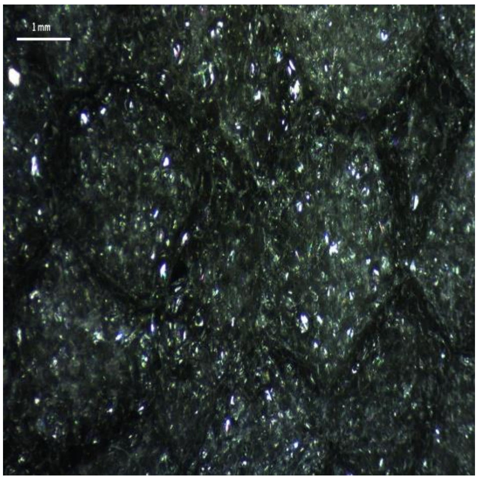
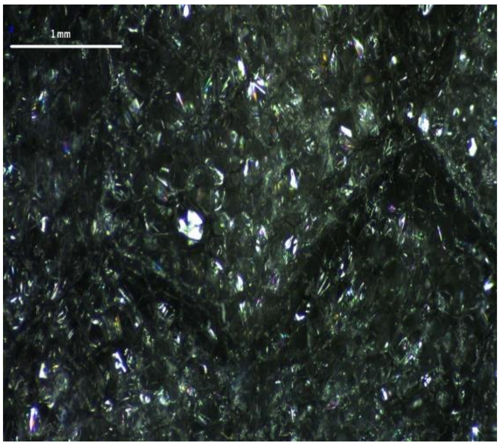
Property	Test method	Unit	EPP panels
Density	UNE-EN ISO 845	Kg/m^3	66



Cell size x10 magnify



Cell size x20 magnify

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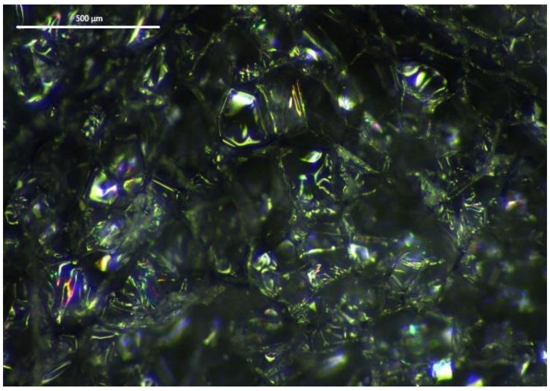

Cell size x50 magnify

Figure 26. Microscope image analysis of material cell structure.

In addition, the recycled PP thermoplastic granulates have been tested for melt flow index analysis.

Table 5. PP material properties characterization.

Property	Test method	Unit	Bechmark polymer Daploy™ WB140HMS	Recycled polymer PP from panels
Melt flow rate	UNE-EN ISO 1133-1 (230°C/2.16 kg)	g/10 min	2.1	16.1

Outcomes from material test performed on recycled polymer PP show higher melt flow rate suggesting that resin have a molecular structure that exhibit high flowability and lower melt strength, so that hampering foaming process stability.

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4. Conclusions

Recovery of plastic components after EV battery pack dismantling allows the proper recycling of plastic materials. The collection and sorting of the several plastic parts have shown the wide variety of plastic components that can be found in EV batteries, depending on size, geometry, dimensions and functionality, which is varying from large protective panels to small fittings and connectors.

In the same way, the identification methods based on optical analysis (NIR and FTIR spectroscopy) have led to the identification of the different polymer types used in the manufacturing of EV battery components. Indeed, the majority of the EV battery plastic components are made of engineering polymer grades, such as PPE used in battery module and covers, or PA used in tubes, fittings and connectors. Those are tailored for specific applications based on their properties such as mechanical strength, temperature resistance and chemical stability. The cost of polymer engineering grades can vary depending on several factors considering: feedstock prices, material formulation including specialty additives and modifiers, production costs and production volumes. Generally, the prices for polymer engineering grades are in the high-price end, ranging from 5 €/kg to 15€/kg. This fact emphasizes the convenience of their recycling for lowering material costs and savings by reducing reliance on virgin materials.

Definition of the most feasible case studies for EV battery plastic components recycling has been made considering material source availability and suitability for upscaling operations:

- Plastic frames from battery modules related to Case study #1 are the most abundant plastic parts recovered after EV battery pack dismantling. Frames are made of polymer PPE using injection moulding manufacturing method. These parts include overmoulded metal inserts that need to be removed prior to shredding pre-treatment to obtain homogeneous thermoplastic granulates.
- Battery cooling system consist of plastic pipes, tubes and fittings related to Case study #2. These components are made of different PA grades by means of extrusion and injection moulding respectively. Their performance is critical to assure smooth running of the battery helping to control thermal stability. Tubes can be separated from fittings and grinded into granulates.
- EPP panels related to Case study #3 are the larger dimensions components in the EV battery pack, although lightweight due to foamed low density structure. These panels provide impact protection and thermal insulation. Pretreatment of these panels must include several shredding, agglomeration and melt extrusion to obtain thermoplastic

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pellets featuring uniform aspect ratio suitable for proper recycling in foamed products.

For each case study the benchmarking polymer types and grades have been set according to product performance requirements. Laboratory tests have been performed at laboratory level for materials properties characterization using test specimens manufactured with corresponding thermoplastic granulates and pellets. Results from laboratory tests suggest that service conditions have led to some downgrading in plastic components and losses in the material properties performance.

Overall, the outcomes obtained from each case study will set the basis for reprocessing and upcycling of the recovered plastic materials in further *WP4 Task 4.5 Scale-up for plastic materials recycling*, with the aim of obtaining thermoplastic compounds formulated for their reuse in battery plastic parts or other high value applications.

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