INCIRCULAR

Deliverable number: D3.1 Protocols and requirements for the collection and sorting of industrial plastic waste defined

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INtegrating Cybernated Innovation to Raise the scale of Circular Units Looping Allied Regions

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R = Report, P = Prototype, D = Demonstrator, O = Other PU = Public PP = Restricted to other programme participants (including the Commission Services) RE = Restricted to a group specified by the consortium (including the Commission Services) CO = Confidential, only for members of the consortium (including the Commission Services) Restraint UE = Classified with the classification level "Restraint UE" according to Commission Decision 2001/844 and amendments Confidential UE = Classified with the mention of the classification level "Confidential UE" according to Commission Decision 2001/844 and amendments Secret UE = Classified with the mention of the classification level "Secret UE" according to Commission Decision 2001/844 and amendments

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EXECUTIVE SUMMARY

For Deliverable 3.1 ***"Protocols and Requirements for the Collection and Sorting of Industrial Plastic Waste"*** GORENJE IPC initiated the establishment of internal protocols for the classification and sorting of specific post-processing residues.

Collection of Waste: With the beginning of the project, an internal protocol was established within the production department at GORENJE IPC for sorting and collecting of post-industrial waste according to polymer types at subsequent production lines. It was decided that two diverse categories of polymer residue materials will be collected for this project: polypropylene (PP) with mineral fillers and PP containing glass fibres. The collection efforts were strategically planned within the production plant environment, ensuring minimal interference with regular production operations. Small units underwent primary selection, while large units were subjected to secondary selection to ensure thorough sorting before storage and processing.

Processing of Waste: Upon reaching the required quantity of raw material for each identified group (minimum 200 kg), the prepared feedstock was transported to OMAPLAST for further processing. At OMAPLAST, the received materials underwent to thorough visual and physical inspections. They were then milled to appropriate size fractions for further compounding via melt extrusion process. The milling process involved a combination of shredding and grinding technologies to achieve precise particle size reduction, ensuring uniformity and consistency in the resultant feedstock for further processing.

Preparation of Composite Formulations: Concurrently, TECOS compiled the technical specifications for natural fibres. The most optimal fibres were selected according to the available data of the manufacturer (appropriate aspect ratio) and ordered in small batches for the needs of characterization. Selected types of fibers were sent to UJA and ECO for additional characterization analyses: fiber length and thickness, oxide ash content, water and oil binding capacities, bulk density, and pH value, while TECOS performed the first screening of the morphological properties of all obtained fibers. The characterization results will serve as the basis for initial compounding tests, which are scheduled for the second quarter of 2024. Three batches of materials with varying filler contents (10 wt.%, 20 wt.%, and 30 wt.%) will be prepared, incorporating five different fiber samples in each batch to facilitate comprehensive evaluation and comparison of resulting material formulations.

Standards for Testing: A comprehensive array of tests and analyses are planned for plastic matrices and composites. These include melt flow index (MFI), density, shore hardness, weight loss, humidity resistance, tensile strength, impact resistance, shrinkage, FTIR, differential scanning calorimetry (DSC), and hyperspectral imaging (HSI). These standardized procedures and methodologies will provide insights into the physical, mechanical, and chemical properties of the materials, guiding material selection, formulation, and optimization processes for various applications.

ACTION DESCRIPTION

Deliverable 3.1 "Protocols and Requirements for the Collection and Sorting of Industrial Plastic Waste" is aligned with Milestone 13 "Collected and sorted plastic waste ready for modifications", which exists in a separate doc format and contains the most essential information about the prepared feedstock materials (polymeric residues GORENJE IPC) for further composite combinations.

GORENJE IPC in collaboration with other industrial project partners, undertook the collection, sorting, and determination of adjustments of feedstock for further development and material optimization strategies. Within WP3 the objective is to scale up the new innovative pilot production lines for the reusability of waste plastic material streams. This entailed the identification and selection of plastic waste materials in Gorenje IPC production operation. These plastic residues will in the next step go through transformation into innovative reinforced bio-based plastic materials, enhancing material reinforcement and enabling their use in new and improved products along the production line. Under WP3, a lean, efficient, and innovative production process was established for utilizing the innovative material. This deliverable not only fulfills its immediate purpose but also lays a profound foundation for subsequent milestones, notably for Deliverable D3.2 in M15, which involves the technical report on recycled plastics, fibers, and additives treatments and production.

The protocols and requirements established in Deliverable 3.1 provide essential guidelines and standards for the collection and sorting of industrial plastic waste. By exact defining the processes involved in gathering and categorizing different types of plastic waste, this deliverable sets the stage for efficient and effective handling of materials in subsequent stages of the project. Moreover, the insights gained from the collection and sorting process will serve as valuable inputs for the upcoming technical report in M15. The data gathered during the collection and sorting phase, including analyses of raw material inputs and quality assessments, will inform decisions regarding treatments and production methods for recycled plastics, fibers, and additives.

Understanding the characteristics and properties of the collected plastic waste, as outlined in Deliverable 3.1, is crucial for set up of appropriate treatment strategies. Whether it involves shredding, re-granulating, or other processing techniques, the protocols established here will guide the selection of methods that best suit the specific composition and condition of the materials. Furthermore, the protocols and requirements outlined in Deliverable 3.1 now serves as a benchmark against which the outcomes of subsequent treatments and production processes can be evaluated. By providing a standardized framework for assessing the quality and suitability of recycled plastics, fibers, and additives, this deliverable ensures consistency and reliability in the project's endeavors. In essence, Deliverable D3.1 not only lays the groundwork for effective waste management and material optimization strategies but also paves the way for informed decision-making and successful outcomes in future milestones, particularly in comprehensive technical report expected in M15.

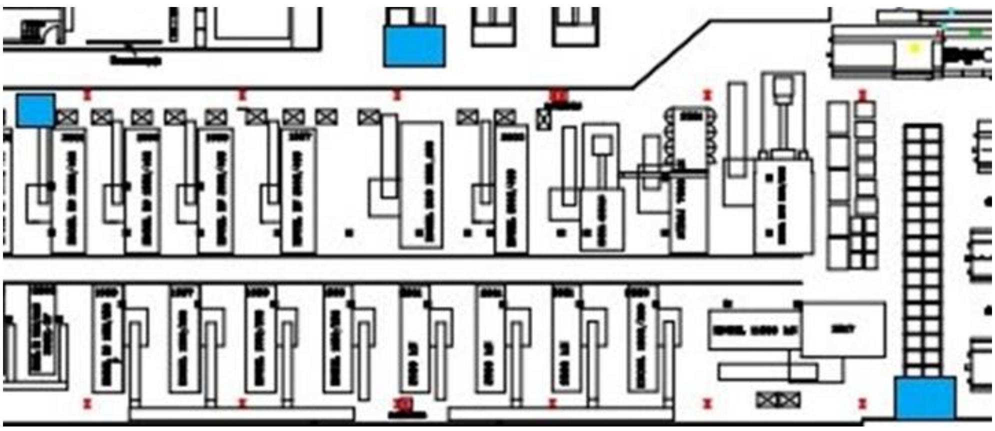
COLLECTION OF INDUSTRIAL RESIDUES

Key outcomes from the collection and sorting of plastic waste residues at GORENJE IPC:

Strategic locations of the collection points:

- *The positioning of collection points for industrial waste was carefully determined within the production plant environment.*
- *Three distinct points were designated strategically to ensure minimal interference with regular production operations.*

Approach for setting up of collection points optimizes the efficiency of waste collection efforts while minimizing the disruptions to ongoing production activities. By strategically locating the collection points, Gorenje ensures a seamless integration of waste management practices within its production infrastructure, facilitating smooth operations and sustainable waste handling processes.



Collection points in the Gorenje IPC production

The collection and sorting process yielded significant results, facilitated by specific strategies tailored to different types of collection units:

- Small units underwent primary selection, accompanied by adaptations in worker roles to streamline the sorting process effectively.
- Large units were subjected to secondary selection, ensuring thorough sorting before materials were prepared for storage and subsequent processing.

In the second phase, it is planned to replace the small units directly to large ones. And visual inspection will be directed directly for large units).

For storage, an innovative approach was adopted, leveraging the re-use of bags originally employed in production. This not only contributes to sustainability efforts but also maximizes resource efficiency. Following the thorough collection and sorting procedures, the collected and sorted plastic materials were delivered for evaluation and milling on February 16th at OMAPLAST. The total delivered quantity amounted to 1,570 kilograms.




Gorenje identified and categorized two distinct industrial residues for collection and sorting purposes:

1. **PP (talc), PP (CaCO3), and PP (no fillers), hereafter designated as “PP TD”**
2. **PP (GF) (Glass fibers 35% - 50%), hereafter designated as “PP GF”**

Industrial residues: PP (talc), PP (CaCO3), and PP (no fillers) and final parts from production

PP (GF) (Glass fibers 35 % - 50%) and final parts from production (uncolored examples)

The collected and accurately sorted plastic materials underwent a crucial phase of material characterization and milling, marking a significant milestone in the project's progress. On February 16th, 2024, a total quantity of 1,570 kilograms of these materials was delivered for evaluation and milling, signifying a substantial volume ready for processing. Upon arrival at OMAPLAST, two distinct types of materials were received, each designated for specific treatment:

- PP GF (glass-filled material): This material variant, characterized by its glass fiber content, holds promise for enhanced structural integrity and performance in composite formulations.
- MIX of PP TD + PP + PP CaCO3 (with or without mineral filler): This polymer blend encompasses a combination of polypropylene variants, including those with and without mineral fillers such as talc and calcium carbonate. Its versatility opens avenues for diverse applications and material optimizations.

At OMAPLAST the received materials were evaluated for their physical and chemical properties, laying the groundwork for informed processing decisions. Material characterization involved detailed analyses of key parameters such as composition, morphology, thermal stability, and mechanical properties. Subsequently, the materials were subjected to shredding and milling procedures tailored to their specific compositions and intended applications. The milling process aimed to achieve precise particle size reduction, ensuring uniformity and consistency in the resultant feedstock for further processing. This phase of material characterization and milling represents a critical stage in the project's journey, bridging the gap between raw materials and the development of composite formulations. It underscores the project's commitment to leveraging advanced manufacturing techniques and innovative materials to drive sustainable and high-performance solutions.

The milling process, crucial for transforming the delivered plastic lumps into refined feedstock, was executed through a meticulous combination of shredding, and grinding technologies, leveraging the expertise of both Lindner and Sorema OEM providers. The initial phase commenced with the shredding stage, facilitated by Lindner technology. Employing a specialized 150 mm screen, this first stage shredding process efficiently broke down the incoming lumps to a more manageable size. To ensure operational safety and integrity, concurrent ferrous metal extraction measures were integrated, guaranteeing the removal of any metallic contaminants from the processed material.

Shredding of Gorenje's plastic lumps at Omaplast facility

Following the preliminary shredding stage, the material underwent the further refinement through grinding, utilizing cutting-edge Sorema technology. This second stage grinder, outfitted with a finely tuned 10 mm screen, worked to further reduce the particle size of the shredded material. By subjecting the material to this secondary grinding process, a finer and more homogenized feedstock was achieved, enhancing its suitability for subsequent processing stages.

This comprehensive milling approach underscores GORENJE's commitment to precision and efficiency in material processing. By leveraging a combination of cutting-edge technologies and stringent safety measures, the milling process ensures the production of high-quality feedstock, laying a solid foundation for the development of advanced composite materials. No dedusting was performed. The final product was packed into large bags for shipment to the TECOS center.

Regrinded plastic residues done by OMAPLAST (Left: PP GF; Right: PP TD + Talc + $CaCO_3$)

TOTAL QUANTITY PREPEARED: 1.365 KG (SHIPPED TO TECOS ON 6.3.2024).

MATERIAL	FILLER	COLOR	GRINDING SIZE	QUANTITY IN KG	REMARKS
PP TD REGRIND	TALC	MIX LIGHT	<10mm	1.141	EXACT FILLER CONTENT NOT KNOWN
PP GF REGRIND	GLASS FIBRE	MIX LIGHT	<10mm	224	EXACT FILLER CONTENT NOT KNOWN

SAMPLE MATERIAL	FILLER	MFI 2,16 KG, at 230°C
PP TD REGRIND	TALC + $CaCO_3$	2,7g /10 min
PP GF REGRIND	GLASS FIBRE	5,7g /10 min

GORENJE's sorting efforts have been commendable, ensuring efficient and effective handling of materials throughout the process. However, it's worth noting the importance of maintaining cleanliness to the highest standard possible. Incorporating measures such as adding trolleys to production areas for the containment of hot melt materials instead of allowing them to be dispersed on the floor can significantly contribute to cleanliness and organization. By implementing this approach, not only can potential hazards be minimized, but the overall production environment can also be optimized for smoother operations. Additionally, such practices can lead to improvements in the quality of recycled granules, ultimately enhancing the overall efficiency and effectiveness of the recycling process.

PLASTIC MATRICES TESTING

The characterization of plastic matrices involves a comprehensive array of tests and analyses aimed at understanding the physical, mechanical, and chemical properties of the materials. Through a series of standardized procedures and methodologies, various parameters are evaluated to assess the suitability, performance, and potential applications of the plastic matrices.

Key tests include measuring the melt flow index (MFI) at specific temperatures to understand the material's flow behavior, determining density to ascertain its mass-to-volume ratio, and assessing shore hardness to gauge its resistance to indentation. Additionally, tests such as weight loss evaluation, humidity resistance, tensile strength, and impact resistance provide insights into the material's durability and stability under different conditions.

Advanced analytical techniques like Fourier-transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), and hyperspectral imaging (HSI) offer deeper insights into the material's chemical composition, thermal properties, and surface characteristics, respectively. These tests collectively contribute to a comprehensive understanding of the plastic matrices, guiding material selection, formulation, and optimization processes for various applications.

CHARACTERIZATION ANALYSES FOR SAMPLES				
Type of Analysis	**Standard**	**Due**	**Partner responsible**	**Status**
RECYCLED POLYMER MATRICES				
Melt flow Index (MFI) @ 230/190C	ISO1133/99	M5	OMAPLAST	DONE
Density	ISO1183/87	M6	OMAPLAST	In course
Loose of weight	ISO66/77	M6	OMAPLAST	In course
Humidity (8 min @ 130°C)	-	M6	OMAPLAST	In course
Tensile Test	ISO527/1-2	M6-7	GORENJE IPC	In course
Charpy Impact Test	ISO 179	M6-7	GORENJE IPC	In course
Shrinkage Test	ISO 2577	M6-7	GORENJE IPC	In course
FTIR	FTIR	M6-7	GORENJE IPC	In course
Differential Scanning Calorimetry	DSC	M7	TECOS	In course
Hyperspectral imaging	HSI	M7	TECOS	In course

COMPOSITE FORMULATION FROM REGRINDED PLASTIC LUMPS

Three batches of composite formulations with varying weight contents of fibres: 10 wt.%, 20 wt.%, and 30 wt.% will be prepared in M6-7. Each batch will incorporate five different fiber samples, resulting in a total of 15 material combinations. The composite formulations will be of following composition:

- **10 wt.% Fiber Content:**
  - Each formulation will contain 10 wt. % fiber content, distributed as follows:
    1. Formulation: rPP TD (4350g) + Fiber Sample (BC300, 500g) + CA (150g)
    2. Formulation: rPP TD (4350g) + Fiber Sample (B600, 500g) + CA (150g)
    3. Formulation: rPP TD (4350g) + Fiber Sample (PWC500, 500g) + CA (150g)
    4. Formulation: rPP TD (4350g) + Fiber Sample (ZZC500, 500g) + CA (150g)
    5. Formulation: rPP TD (4350g) + Fiber Sample (SIS250, 500g) + CA (150g)
- **20 wt.% Fiber Content:**
  - Each formulation will contain 20 wt. % fiber content, distributed as follows:
    6. Formulation: rPP TD (3850g) + Fiber Sample (BC300, 1000g) + CA (150g)
    7. Formulation: rPP TD (3850g) + Fiber Sample (B600, 1000g) + CA (150g)
    8. Formulation: rPP TD (3850g) + Fiber Sample (BC1000, 1000g) + CA (150g)
    9. Formulation: rPP TD (3850g) + Fiber Sample (BC300, 1000g) + CA (150g)
    10. Formulation: rPP TD (3850g) + Fiber Sample (SIS310, 1000g) + CA (150g)
- **30 wt.% Fiber Content:**
  - Each formulation will contain 30 wt. % fiber content, distributed as follows:
    11. Formulation: rPP TD (3350g) + Fiber Sample (BC300, 1500g) + CA (150g)
    12. Formulation: rPP TD (3350g) + Fiber Sample (B600, 1500g) + CA (150g)
    13. Formulation: rPP TD (3350g) + Fiber Sample (BC1000, 1500g) + CA (150g)
    14. Formulation: rPP TD (3350g) + Fiber Sample (BC300, 1500g) + CA (150g)
    15. Formulation: rPP TD (3350g) + Fiber Sample (SIS310, 1500g) + CA (150g)

This structured approach ensures a systematic testing across various fiber contents and types, facilitating a comprehensive evaluation and comparison of the resulting material formulations.

CONCLUSIONS

In conclusion, Deliverable 3.1 has established essential protocols and requirements for the effective collection and sorting of industrial plastic waste, marking a significant milestone in the project's progress. The collaboration between Gorenje IPC and other industrial partners has enabled the formulation of systematic procedures for gathering and categorizing specific post-processing residues, ensuring the efficient utilization of resources and materials.

The protocols outlined in this deliverable provide a solid foundation for subsequent stages of the project, particularly in the treatment and production of recycled plastics, fibres, and additives. By presenting clear guidelines for material handling and processing, this deliverable facilitates informed decision-making and optimization of material utilization strategies.

Moreover, the meticulous characterization and milling of collected plastic materials underscore the project's commitment to precision and efficiency. The integration of advanced technologies and stringent quality control measures ensures the production of high-quality feedstock, setting the stage for the development of innovative composite materials with enhanced properties. The insights gained from the collection and sorting process, along with the detailed material testing protocols established, will serve as invaluable resources for future project milestones. These include the comprehensive technical report expected in M15, which will further examine into the treatments and production processes of recycled plastics, fibers, and additives.

Overall, Deliverable 3.1 not only lays the groundwork for effective waste management and material optimization strategies but also paves the way for informed decision-making and successful outcomes in subsequent project phases. Through collaborative efforts and meticulous planning, the project continues to advance towards its objectives of sustainability and innovation in plastic waste management.