Deliverable report

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CREATOR CONSORTIUM

PARTICIPANT NUMBER	ABBREVIATION	ORGANISATION
1	ICT	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung – Institut für Chemische Technologie
2	VLB	Volbas S.A.
3	MOS	Machinefabriek Otto Schouten BV
4	CLR	Coolrec BV
5	REL	Treee SRL
6	GKR	Fundacion Gaiker
7	TCK	Transfercenter fur Kunststofftechnik GmbH
8	RMA	Erema Engineering Recycling Maschinen und Anlagen Ges.m.b.H
9	CTB	Centre Scientifique & Technique De L'industrie Textile Belge
10	MAI	Maier S. Coop.
11	DAW	DAW SE
12	CYC	Cyclefibre S.L.
13	CID	Fundacion Cidaut
14	KLU	Kuhne Logistics University GmbH
15	OVM	Openbare Vlaamse Afvalstoffenmaatschappij
16	RWE	RWEnergia Robert Wudarczyk
17	ITB	ITRB Group LTD

DOCUMENT HISTORY AND CONTRIBUTION OF THE PARTNERS

VERSION	REVISER	CONTENT
V0	Antonio Buonocore (CYC)	First draft
V1	Rocco Lagioia (ITB)	Review and additions
V2	Irma Mikonsaari (ICT)	Review

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Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung – Institut für Chemische Technologie	ICT	Revision

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LIST OF ABBREVIATIONS

ABBREVIATION	DESCRIPTION
ABS	Acrylonitrile butadiene styrene
CAGR	Compound annual growth rate
FF&E	Furniture, fixtures and equipment
LCA	Life cycle analysis
LCC	Life cycle cost
UAV	Unmanned air vehicle
WP	Work package

1 INTRODUCTION AND OBJECTIVES

The EU-funded project CREAToR focusses on process development and demonstration to remove hazardous, already banned bromine-containing flame-retardants from thermoplastic material waste streams. The project investigates the use of a continuous purification technology: extractive extrusion with supercritical CO_2 and natural deep eutectic solvents (NADES) as extractive media.

The project covers the whole value chain, from collecting thermoplastic waste streams from construction and building, and from the electrical and electronic equipment sectors, to 2nd generation use of the materials. Supporting developments spanning the secondary raw material value chain are a more accurate sorting of waste fractions in terms of their bromine content, the re-additivisation of purified materials with non-hazardous flame retardants, an integrated logistics concept and a harmonised material purity classification concept. These will create a closed-loop solution, transforming waste streams that are currently incinerated at a cost into value-bringing secondary raw materials.

The economic viability of CREAToR will be validated through material benchmarking and LCA/LCC assessment for the whole value chain, resulting in two 2nd generation materials: polystyrene (PS) for use in insulation foams for construction and building, and acrylonitrile butadiene styrene (ABS) in aesthetically decorated interior parts for the automotive sector. The strong industrial/recycler presence in the consortium will ensure the market relevance of the developments and the rapid commercialisation of the results after the end of the project.

WP4 Benchmarking the material reuse evaluates the use of the recyclate in new applications. The present deliverable includes a description of prototypes manufactured with recycled purified materials with an additive manufacturing process, a depiction of the process itself, an assessment of the problems encountered and the solutions identified or implemented in order to address these drawbacks.

Due to its high quality requirements, the aerospace sector has been identified as the main target for the additive manufacturing, in order to prove that CREAToR's recycled, purified materials can meet such stringent requirements, hence making them apt for any other industrial sector.

The demonstrator is a physical component 3D printed by Cyclefiber: a UAV (Unmanned Air Vehicle) fairing with a maximum envelope dimension of 500 mm X 300 mm using recycled ABS filaments extruded in the facilities of Centexbel. The component has successfully met the requirements of the manufacturability test.

Once the CREAToR recycling process and resulting compounds and accompanying physical demonstrators are validated, the consortium will proceed to explore additional consumer products and their market readiness and potential market adoption in the FF&E (furniture, fixtures and equipment) market segment. The additional demonstrators, not included in the original GA plan, have been explored following specific requests from potential early adopters. The FF&E have been, at the time of release of this report, digitally simulated; their physical manufacturing will be completed by the end of the project and the relevant information included as an annex to deliverable D8.2 Plan for the dissemination and exploitation of the results (2) in April 2023.

2 3D DEMONSTRATOR FOR AEROSPACE APPLICATION

2.1 MANUFACTURING: RECYCLED ABS FOR UAV FAIRING

2.1.1 DESCRIPTION OF THE COMPONENT

Based on the materials and compounds developed by Centexbel and reported in detail in the public deliverable D4.3 Production of 3D printing filament, Cyclefiber has used additive manufacturing to produce a demonstrator component for an aerospace application.

The aerospace application is a UAV (unmanned air vehicle) fairing with an approximate envelope dimension of 500 mm x 300 mm with double curvature, manufactured using a recycled ABS filament. Due to its aerodynamic requirement, the component demands a low surface roughness (i.e.: a low deviation from the theoretical aerodynamic surface finish (Figure 1)).

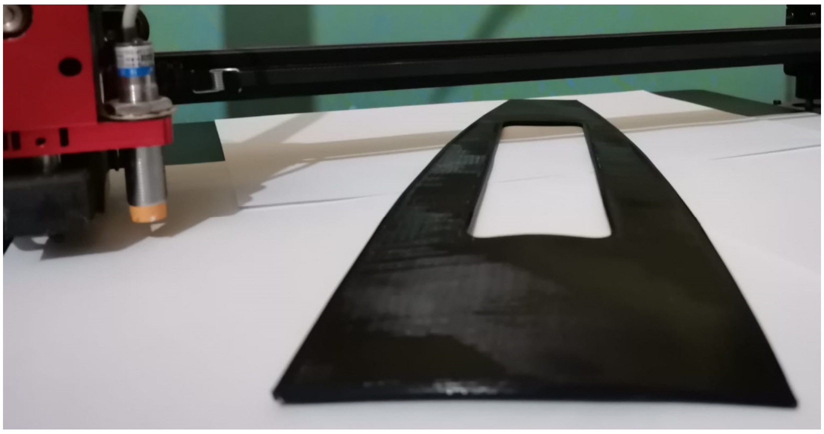

Figure 1 UAV demonstrator

Cyclefiber manufactured 12 test coupons for material/components characterisation: 4 prototypes of a UAV fairing component for the manufacturability test, 2 prototypes of a UAV fairing component to showcase the real component, and 4 prototypes of the electrical system supporting clip. The latter, even if technologically a success, has been evaluated as less interesting from a commercial point of view than the double curvature UAV fairing.

As discussed in Chapter 2.1.2.2 of this report, Cyclefiber implemented a fine-tuning of process parameters, component inner geometry and 3D printer parameters, achieving a stable and repeatable production.

The quality requirements for assembly purposes have been demonstrated, as well as more stringent aerodynamic surface smoothness, which was judged to meet the aerospace requirement on visual inspection. No additional surface smoothness quantification has been deemed necessary by the Cyclefiber Technical Director Antonio Buonocore, thanks to his 30 years experience in aerospace structural design.

2.1.2 DESCRIPTION OF THE MANUFACTURING PROCESS

2.1.2.1 MANUFACTURABILITY TEST: COUPON MANUFACTURING

In November 2020 Cyclefiber started manufacturability tests using filaments processed by Centexbel in an industrial environment, to prove that simple test coupons without any out-of-plane curvature achieve the expected surface finish.

Figure 2 below illustrates the process that converted the waste feedstock to a recycled filament.

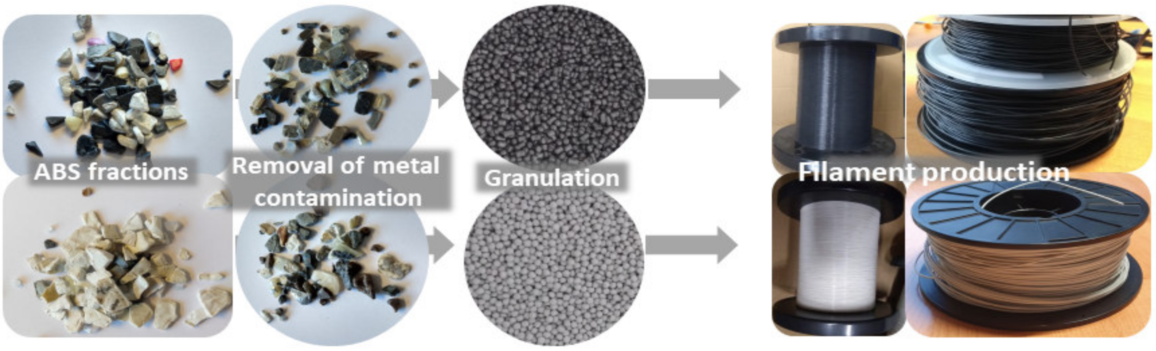

Figure 2 Centexbel filament production process

The final product is a 3D printing filament made of 100 % recycled ABS. This represents an innovation in its own right, since the market does not offer a comparable certified 100 % recycled product (Figure 3).

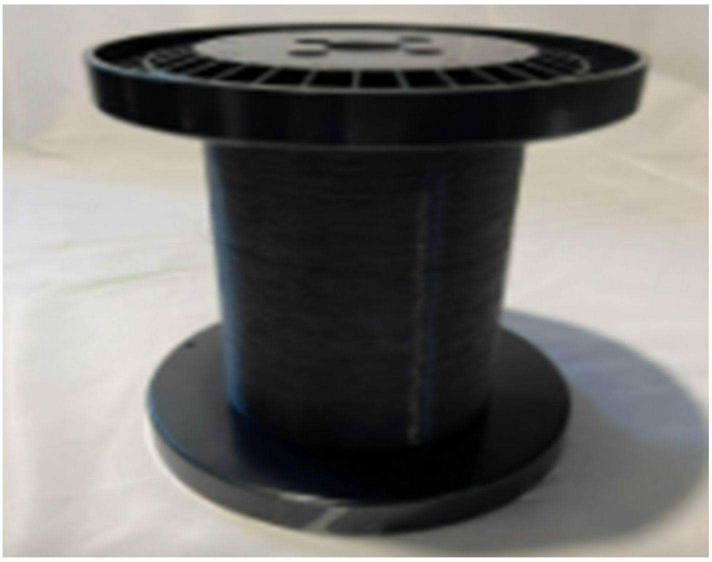

Figure 3 ABS filament

The manufacturing process was implemented with a 3D printing device "CREABOT F430".

The software used for component design, filament deposition and tests is Simplify 3D, which was found to be extremely helpful in setting up new printing parameters and optimising the 3D printing device for the recycled materials.

For instance, the internal honeycomb pattern was highly beneficial in reducing the spring-back of the material.

The spring-back of a curved specimen is defined as the difference between the corner angle of a specimen (under stress-free conditions, after being extracted from its tool and cured at room temperature) and that of its tool (which represents the initial condition of the specimen before extraction from its tool). In the case of 3D printing, the tool is the flat hot bed of the printer (Figure 4 and Figure 5).

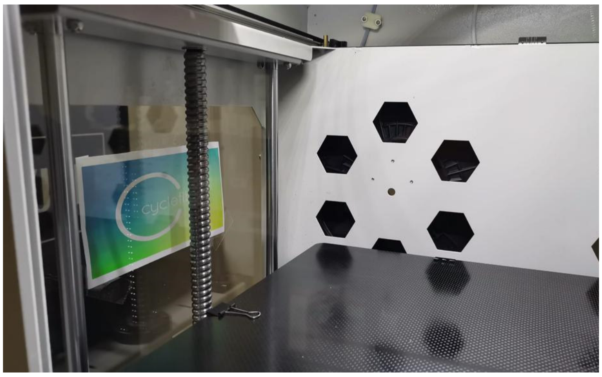

Figure 4 Cyclefiber CREABOT F430 chamber

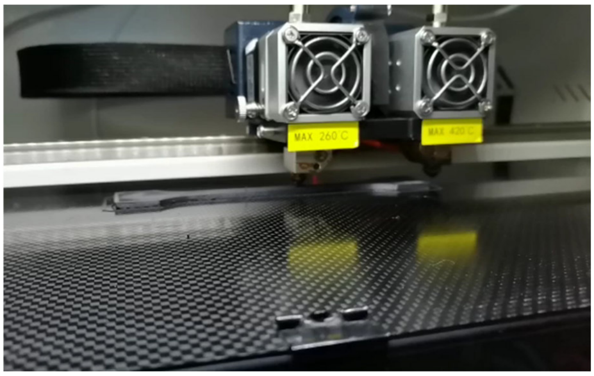

Figure 5 Cyclefiber CREABOT F430 extruder

Table 1 below illustrates the printing parameters used in the coupon tests.

Table 1: Processing parameters for the coupon testing

Printing parameters	
Coupon test dimensions	Prototype 1: L=150 mm W=25 mm T=4 mm Prototype 2: L=150 mm W=25 mm T=20 mm
Dimension of the filament	1.75 mm
Bed temperature	120 °C
Chamber temperature	100 °C

A manufacturability test with coupons of standardised geometry has been conducted by Cyclefiber with two ABS grades - an ABS commercial virgin material and the CREAToR recycled ABS material - in order to compare the newly developed material with a market-accepted benchmark standard material.

Figure 6 below clearly indicates that the recycled ABS coupon test prototypes present two main types of printing defects which occurred during the processing:

- Thermal shrinkage: prototypes made of recycled ABS show non-negligible bending resulting from high volumetric contraction of colder substrates
- Adhesion of the sample to the substrate. This causes detachment difficulties and low surface quality.

Such printing defects are potentially related to the material itself, but they are not a significant hinderance. On the contrary, they are typical defects once presented even by the commercial virgin ABS in its first appearance on the market. Most importantly, they can be resolved by tuning the parameters of the 3D printer.

Figure 6 3D printed tensile test dog bones.

2.1.2.2 Component manufacturing

The core of the aerospace demonstrator is the additive manufacturing of the UAV fairing with both an ABS commercial virgin material and the CREAToR recycled ABS materials, as depicted in Figure 7.

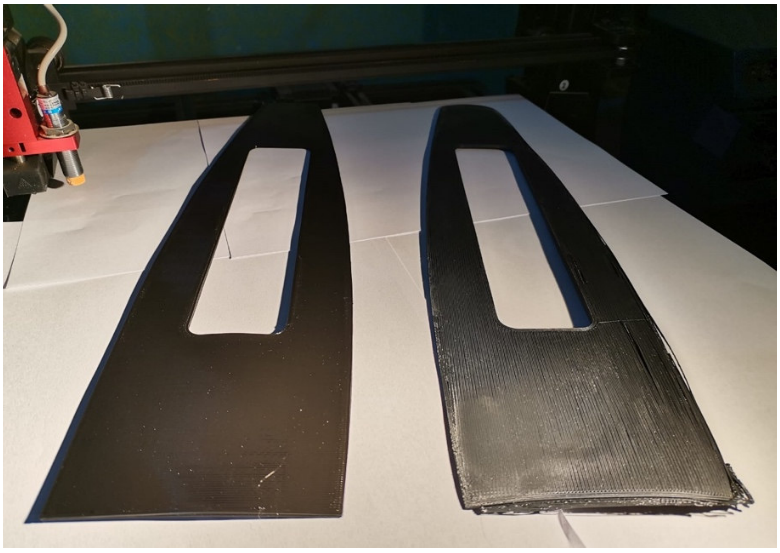

Figure 7 3D printed UAV fairing. Left: virgin ABS, Right: recycled ABS

The drone fairing printing test was carried out according to the parameters shown in Table 2.

Table 2: Parameters for the drone fairing printing

Drone fairing printing	
DIMENSION OF THE FAIRING	L = 500 mm
DIAMETER OF THE FILAMENT	0.2, 1.75, 2.85 mm

The recycled ABS prototypes in Figure 7 show two main types of printing defects:

1) Layer separation: the merge of the layers is unsatisfactory
2) Warping of the material

Cyclefiber then programmed new experimental trials in order to investigate and solve those defects by adjusting the printer parameters and the component lay-up.

In summary, in order to overcome the defects that appeared in the first tests, Cyclefiber adjusted the process and product parameters:

- Simplify3d slicing software was introduced in order to set and fine-tune the 3D printer parameters as accurately as possible
- The component was re-designed with 4 layers for the lower side, 4 layers for the top side and 3 layers for the contour
- The component was re-designed from an 100 % filling percentage to 50 % with a honeycomb section, thus optimising the internal load transfer and reducing weight and printing time
- The temperature of the hot bed was increased from room temperature to 50 °C, in order to reduce the spring-back effect in the layers adhering to the tool; the extruder temperature was set at 240 °C and the closed chamber at 50 °C in order to match the hot bed temperature
- The nozzle diameter was set at 0.4 mm, the extruder at 0.4 mm and the primary layers at 0.3 mm

By implementing these parameter modifications, Cyclefiber obtained structural integrity, eliminating the spring-back and achieving a good adhesion of the sample to the substrate and a good smooth surface, as shown in Figure 8.

The coupons successfully passed the coupon stress-strain test.

CONCLUSION

The **CREAToR recycled purified ABS compound** is suitable for 3D printing filament extrusion and the 3D printing manufacturing process for an aerospace component.

The **CREAToR 3D printing filament** is suitable for manufacturing aerospace components.

The **CREAToR 3D-printed aerospace demonstrator** successfully passed the manufacturability and characterisation test, and presents a surface roughness in line with aerospace standards (Figure 8).

The CREAToR process has proven to be capable of delivering additive manufactured components for the aerospace industry. This sector was originally selected as the most demanding in terms of material characterisation and properties and final component standards.

Figure 8 CREAToR 3D-printed UAV fairing

The extra mile. The results, presented both at Ecomondo in November 2022 and at the Innovation Forum 4Plastic 2022, have raised interest and attracted the attention of the hotel industry.

The consortium identified an additional potential exploitation pathway for its expertise in 3D printing filaments based on recycled polymers, namely the hotel FF&E (furniture, fixtures and equipment) market segment. The sector is extremely interested in 100 % recycled and 3D-printed components from its own plastic waste. Additionally, the 3D printing process offers a highly competitive advantage, since it allows customisation based on the hotel request in shape and size on a daily basis, and customisation for hotel guests at the time of their reservation.

After analysis of the FF&E market, it has been evaluated that the global hotel furniture market size was USD 4.3459 billion in 2021 and is expected to reach USD 5.6214 billion in 2028 – an increase of 3.7 %. Additionally, the global furniture market is projected to grow from USD 493.6 billion in 2021 to USD 720.2 billion by 2028, with a CAGR of 5.5 % in the 2021-2028 period. A reported surge of 171 % has been identified for the keyword "sustainable furniture" over 2019 in the UK. This surge in interest will enhance the market growth in the future.[1]

[1] *https://www.businessresearchinsights.com/market-reports/hotel-furniture-market-102094*

For this reason Cyclefiber took the initiative to explore, without employing CREAToR resources, but, finally, for the benefit of the CREAToR project, the feasibility, manufacturability and quality of FF&E components. A shortlist of components has been identified (i.e.: bed-side lamp, tray, hanger, hotel fire-escape map, candle holder, flower vase, swimming pool glasses) and one of them selected as an additional demonstrator (Figure 9).

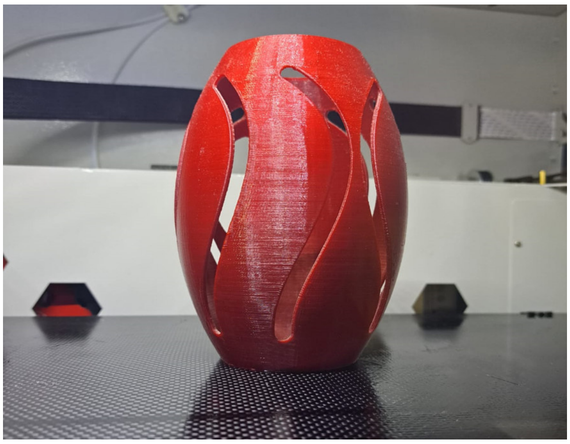

Figure 9 CREAToR 3D printed hotel appliance

The CREAToR ABS recycled material, the compounds, the 3D-printed filament and the 3D-printed components have thus been validated for application, achieving the expected results and demonstrating that additional products are ready for market uptake.