Recycled carbon fiber PLA filament for additive manufacturing: morphological characterization and mechanical behaviour

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Introduction

The recycling process is one of the best ways to reduce the environmental impact so meeting the world growing demand of material in several industrial applications. In this context, 3D printing technology for manufacturing new products based on sustainable materials enables the use of secondary raw materials derived from recycling.

Goal

The aim of this study is to combine innovative three-dimensional fabrication technologies with recycling processes both addressed to the waste reduction.

Composites based on Polylactic acid (PLA) matrix reinforced by recovered carbon fiber (rCF) were prepared and then extruded into filaments. Neither additional treatment after CF recycling process nor additives have been used for the manufacturing of all filaments. All filaments have been characterized and tested in FFF 3D printing technique and tensile samples manufactured.

Materials

Polymer matrix: PLA 4043D (NatureWorks)
Reinforcement: Carbon fiber (rCF) recovered from PPS/CF scraps
CF recovery: by a patented thermal recycling process from ENEA
Composite blend preparation: PLA powders mechanically mixed with rCF fibers in four different compositions

Sample name	PLA wt%	rCF wt%
PLA-rCF3	97	3
PLA-rCF5	95	5
PLA-rCF10	90	10
PLA-rCF20	80	20

Filament extrusion and FFF 3D printing

Single screw extruder (Felfil Evo, Italy)

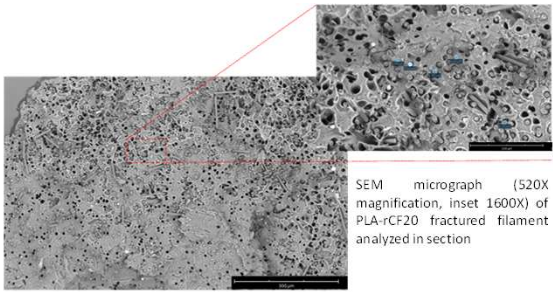
PLA-rCF20 filament
Diameter: 1.7-1.9 mm

PRUSA 3D
FFF printer

3D-printed specimens (10 × 50 × 2 mm)

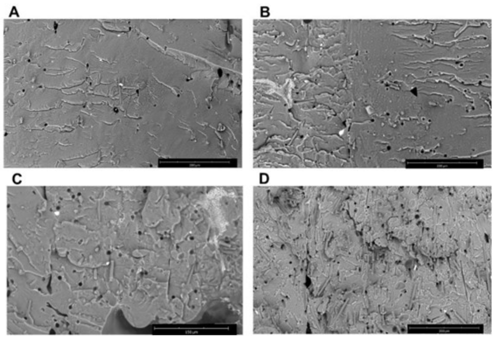
Results

Morphological Characterization



SEM micrograph (520X magnification, inset 1600X) of PLA-rCF20 fractured filament analyzed in section

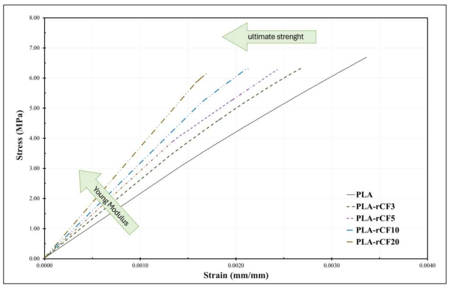
- Strong rCF alignment along with longitudinal direction of extrusion flow.
- Unidirectional alignment of fibers well visible in PLA-rCF20 attributable to the shear forces acting on the molten PLA during the extrusion process increasing as rCF concentration increases.



SEM images (magnification 750X) of cryo-fractured 3D printed specimens of (A) PLA-rCF3 (scale bar: 200 µm); (B) PLA-rCF5 (scale bar: 200 µm); (C) PLA-rCF10 (scale bar: 150 µm); (D) PLA-rCF20 (scale bar: 200 µm)

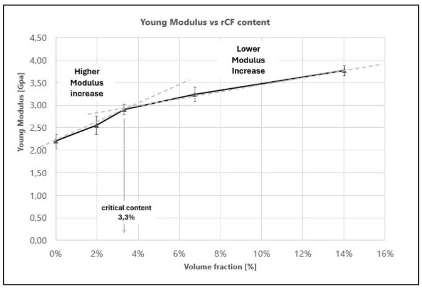
- rCF as fibres protruding from fractured surface.
- Indication of fibre pullout by the presence of many holes with similar geometrical shape and dimension as carbon fibre cross sections.
- Holes visible and increasing in number with increasing rCF content.
- No agglomerates of fibers at low rCF concentration unlike for sample with higher fiber content (PLA-rCF20).
- Most of the fibre surfaces visible uncoated with the matrix polymer indicating a weak matrix-filler interface.

Mechanical Characterization



Young modulus of PLA-rCF filaments at each filler content

- Young modulus increases as a function of the rCF content (wt%), from 2200 MPa for neat PLA to 3770 MPa for PLA-rCF20 filament.
- Critical strain at the failure reduced by increasing the filler content, leading to a fragile behavior combined with a slight strength decrease.



Young Modulus results vs. rCF volume fraction

- Two different behaviors of materials' stiffness: below a critical content (3.3% volume fraction) and above the critical volume content.
- Below the "percolation onset": filler able to reinforce the matrix with higher efficiency; above: the shear transfer between hosting matrix and filler is less efficient.

Conclusions

- All composite filaments, although no additional substances (e.g., stabilizer and/or compatibilizer) and treatment after CF recycling process, showed uniform dispersion of fibers, good extrudability and printability in a commercial FFF printer.
- SEM images showed no agglomerates of fibers at low rCF concentration unlike for PLA-rCF20 showing strong rCF alignment along with the longitudinal direction of the extrusion flow.
- An increase in the tensile modulus of about 70% compared to neat PLA resulted for filaments with higher rCF content (PLA-rCF20).
- The dependence of materials' stiffness identifies two different behaviors, below a critical content (3.3% vol) and above the critical volume content.
- Three-dimensional printed specimens from composite filaments were manufactured through a PRUSA 3D printer.

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