Recycled PP for 3D printing: material and processing optimization through design of experiment

RECYCLED PP FOR 3D PRINTING: MATERIAL AND PROCESSING OPTIMIZATION THROUGH DESIGN OF EXPERIMENT

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Introduction

In the last few years, the environmental concerns related to the plastic waste pollution have promoted a gradual transition from linear to circular economy models, which provide the opportunity to produce pollution-free plastics with profound socio-economic and environmental benefits. The extension of material life and the complete recovery of materials at their end of life are the basic components of this new economic paradigm. In this framework, the development of efficient recycling strategies for polymer-based materials is of crucial importance, since the continuous re-utilization of wastes and scraps should ideally eliminate the use of virgin resources and promote the complete valorization of material wastes [1].
On the other hand, additive manufacturing (AM), also known as 3D printing, is becoming a key industrial process that could play a relevant role in the transition from linear to circular economy. In fact, AM technologies are expected to transform the production processes, due to their ability to transform a numerical model into a deposition of material to create a 3D-printed part. In particular, the layer-by-layer approach of AM processes offers the opportunity to produce parts with complex geometries, or consolidated assemblies that are not attainable using traditional production processes for thermoplastics, such as extrusion or injection molding, while reducing the amount of required material and waste produced. Furthermore, the use of AM processes allows for the production of printed objects that are fully customizable and tailored to obtain specific properties in an efficient and cost-effective way, overcoming the typical disadvantages of conventional technologies, such as the design and the cost of manufacturing the molds for the production of individual parts [2].
Currently, the use of waste or recycled thermoplastics for the development of 3D-printed parts is an emerging area. In this context, some authors have started studying the formulation of filaments originated from homogeneous plastic wastes derived from 3D printed parts, polyethylene terephthalate bottles or low-density polyethylene bags; besides, some recycled filaments are already commercially available [3].
In this work, we clearly demonstrated the suitability of blends based on virgin (PP – ISPLEN PB170G2M filled with talc particles) and recycled polypropylene (r-PP - BRETENE) for FDM processing. In particular, the processing conditions for achieving a material with adequate rheological and thermal properties were optimized using a Taguchi's design of experiment method. The formulations showing the best performance in terms of FDM processability were then processed through a Next 1.0 Advanced filament making machine (3Devo), aiming at producing a filament with a nominal diameter of 1.75 mm; besides, 3D printed parts were obtained by using a Roboze One 3D printer. Finally, the mechanical properties and the morphology of the printed samples were assessed.

Results and discussion

In a first part of the work, PP/r-PP blends with different weight ratios (namely, 50/50, 60/40, 70/30, 80/20, 90/10) were produced using a a mini-extruder Xplore MC 15, and the FDM processability of the obtained materials was verified through rheological measurements. In fact, as widely documented in the literature, several rheological requirements need to be satisfied in order to classify a thermoplastic as FDM-printable [4]. The most strict criterium concerns the occurrence of a yield stress behavior in quasi zero-shear conditions, which guarantees low propensity of the filament to drip after the extrusion step and a good shape stability of the extrudate at the exit of the nozzle and also during the deposition step. The results obtained from the rheological tests showed that the blends containing 30 and 40 wt.% of r-PP exhibit the better performance in terms of yield stress, allowing the selection of these two materials for further processing.
At this point, the processing conditions of the selected blends were optimized using Taguchi Design of Experiments method in order to maximize the yield stress value, while minimizing the crystallinity content of the material (adversely affecting the shrinkage and, hence, the quality of the printed part). In particular, the type of screw (soft and hard configurations), temperature of the die (190 or 210 °C), screw rotation speed (150 or 400 rpm) and feed rate (low and high output) were considered as the variable parameters.
Looking at the results of the Taguchi's analysis on the blend containing 30 wt.% of r-PP reported in Figure 1, it is evident that the yield stress value is strongly affected by the screw speed, while the other considered parameters have a less influence. More specifically, the higher the screw rotation speed the higher the yield stress, likely due to the beneficial effect of the shear experienced by the melt during the compounding at high rotation speed on the morphology and, hence, on the rheological response of the blend.

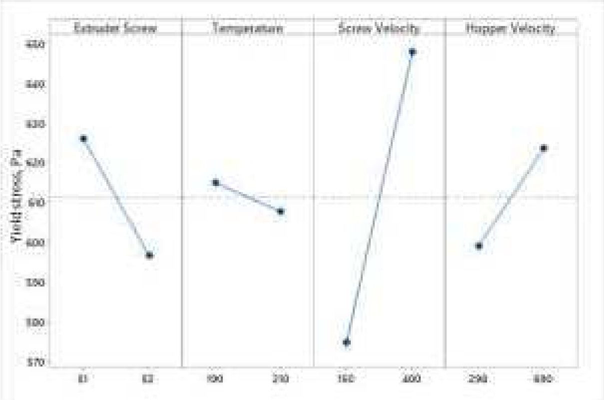


Figure 1: Main effects plot for yield stress of the blends.

Using the optimum conditions both blends (with 30 and 40% of r-PP) were then used to produce filaments suitable for FDM process. Also in this case, the processing conditions adopted during the production of the filament (such as temperature, fan speed and screw velocity) were accurately optimized, and the quality of the obtained filaments was verified through morphological analyses. As can be observed from the SEM micrograph reported in Figure 2, the produced filaments do not show problems related to oval cross section, as the differences between the diameters evaluated in two perpendicular directions are minimal. Furthermore, adequate surface roughness were observed.

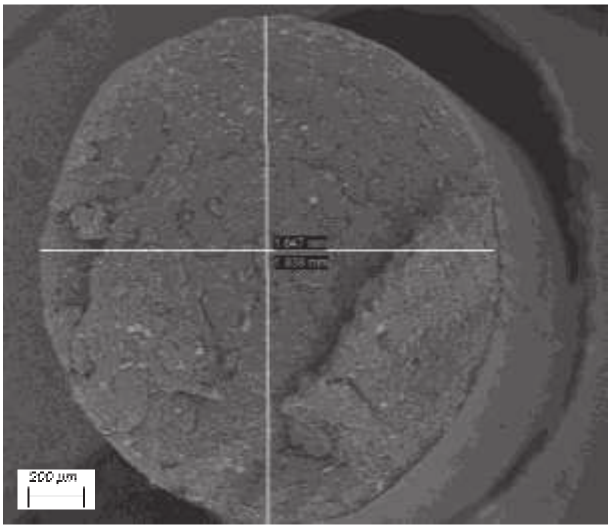
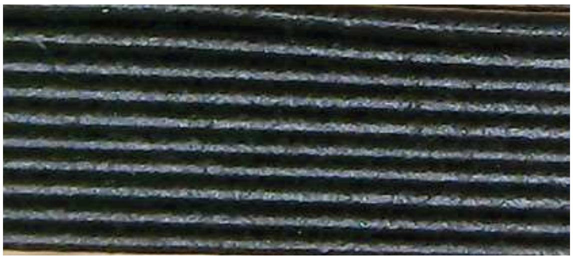


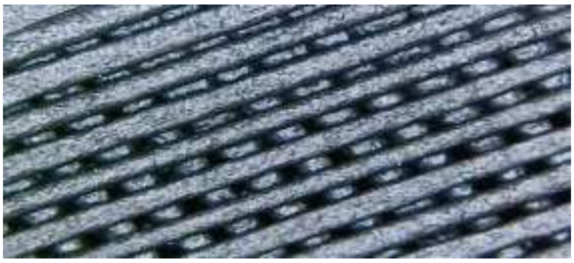
Figure 2: SEM micrograph of the filament based on PP-rPP blend containing 40 wt.% of r-PP.

In Figure 3, some optical observations of details of FDM printed parts are reported. A good adhesion between subsequent deposited layers can be noticed; besided, a homogeneous fill pattern was achieved, confirming the suitability of the produced materials for FDM applications.

Finally, the mechanical properties of FDM printed specimens were evaluated through tensile tests. The obtained results pointed out that the content of r-PP has a negligible effect on the elastic modulus and tensile strength values, while it has a more pronounced influence on the elongation at break of the sample. In particular, higher elongational at break values were obtained for the blend containing 40 wt.% of r-PP, notwithstanding the adequate ductility of the system containing lower loading of recycled phase.



(a)



(b)

Figure 3: Optical micrographs of the (a) side and (b) upper surfaces of a FDM-printed part based on PP-rPP/60-40 blend.

Conclusions

This work clearly demonstrated the possibility of exploiting recycled PP for the formulation of filaments suitable for FDM 3D printing processes. In particular, a Taguchi design of experiment method was used to optimize the processing conditions of PP/r-PP blends showing adequate rheological and thermal characteristics for FDM. Blends containing 30 or 40 wt.% of r-PP were selected for the production of filaments and for the subsequent 3D printing through FDM. The morphological observations of the filaments and of the printed parts allowed verifying the quality of the produced samples, confirming the effectiveness of the proposed method in achieving FDM printable materials. Finally, the mechanical characterization of the printed samples showed that adequate tensile properties were obtained, further demonstrating the possibility of using recycled polymers for AM processes, paving the way for a sustainable exploitation of these materials in the general framework of the new circular economy vision.

References

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