DOI: 10.21062/mft.2022.017 http://www.journalmt.com

Mechanical Properties of Recycled Polymer Materials in Additive Manufacturing

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The publication focuses on tensile strength testing of samples produced by additive Fused Filament Fabrication technology. Four materials PLA, rPLA, PETG and rPETG were tested. The polymeric materials are PLA (polylactic acid), PETG (polyethylene terephthalate glucol) and recyclates of these materials. The materials were made into samples for tensile testing according to ASTM D638. Tensile diagrams were created from the measured data. Statistical processing and comparison of the measured data is performed in the publication. Two groups of materials were compared. Recycled polymeric materials and virgin polymeric materials. In the discussion, a comparison of the mechanical properties of recycled materials for 3D printing versus virgin materials for 3D printing by Fused Filament Fabrication technology is made.

Keywords: Additive Manufacturing, Polymer Materials, ASTM D638, Recycled Materials, Material Properties

1 Introduction

Additive manufacturing (3D printing) is a progressive manufacturing technology that enables a new look at the principles of product construction and design. There are many manufacturing technologies in the additive manufacturing field that have a direct impact on the cost of prints and the availability of production. This publication is focused Fused Filament Fabrication (FFF) technology, which is one of the most affordable additive manufacturing technologies for polymer materials. In addition to manufacturing technology, technical materials are also an important area of additive manufacturing. There are currently a number of manufacturers offering a wide range of materials or filaments on the market. However, the vast majority are so-called virgin polymer materials. Recycled materials can bring a whole new perspective to additive manufacturing. If their application is also advantageous in technical practice, this approach can help in waste management and reduce the ecological footprint in plastic waste production. Recycled filaments, together with additive manufacturing, fit perfectly into the circular economy trend. Due to the variability of the additive manufacturing process, it is important to precisely define the production parameters of samples for testing the quality of additive manufacturing products. This publication verifies the effect of perimeter on the tensile strength of 3D printed samples by FFF technology made from recycled filaments [1, 2, 3].

2 Material and methods

A total of 40 samples were produced and tested. Four different materials were tested. Two materials were recyclates rPLA, rPETG and two virgin materials were PLA, PETG. Ten samples of each material were produced and tested. These are recycled polymer materials from which filament with a diameter of 1.75 ± 0.05 mm is produced. Heat towers (see Fig. 28 Heat towers) were created to determine the optimum printing temperatures. This is a method where the test print is printed at different nozzle temperatures, with the initial temperature corresponding to the manufacturer's maximum recommended temperature of +5 °C and the lowest recommended nozzle temperature of -5 °C. The nozzle temperature was gradually reduced in 5°C increments.

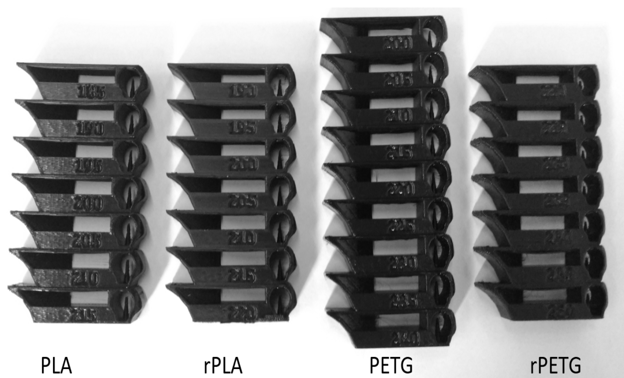

Fig. 28 *Heat towers*

The specimens were modelled in CAD software Autodesk Fusion 360 according to ASTM D638 standard. The 3D model was then exported to *.stl format. It was then uploaded into PrusaSlicer 2.3.0 where the printing parameters were defined. The samples were printed from virgin PLA and PETG materials and recycled rPLA and rPETG materials. The printing temperature was selected depending on the printing heat towers. For the PLA material, the nozzle temperature was chosen to be 220 °C ± 5 °C and the print pad temperature was chosen to be 60 °C ± 5 °C. For the PETG material, a nozzle temperature of 240 °C ± 5 °C was selected. For 3D printing of the recycled materials, the same print profiles as for the virgin materials mentioned above were used. The printing of the samples was derived from the Generic PLA print profile for the PLA and rPLA material and the Generic PETG print profile for the PETG and rPETG material in PrusaSlicer 2.3.0. The sample infill was defined to be 100% and the number of perimeters was chosen to be 0 (see Fig. 29 Specification of samples). The layer height was chosen to be 0.2 mm. The nozzle diameter was chosen to be 0.4 mm.

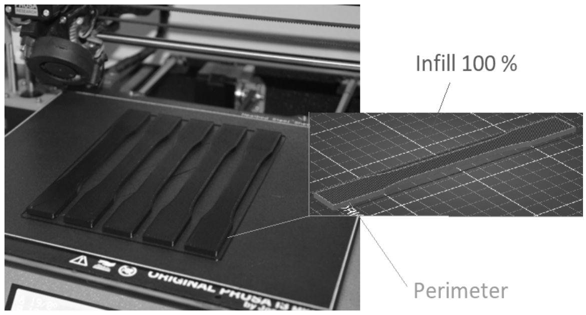

Fig. 29 *Specification of samples*

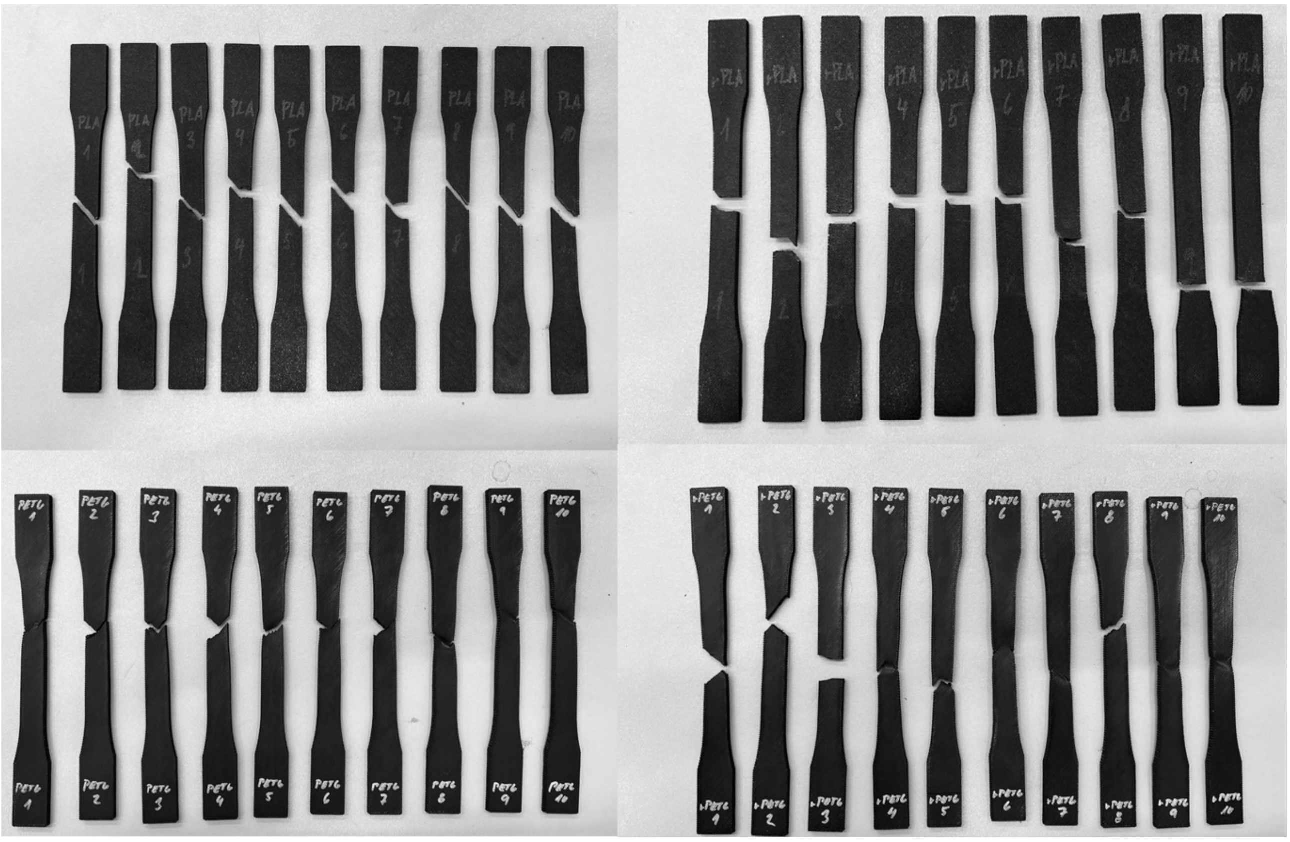

Fig. 30 *Tested samples*

3 Results and discussion

The measurements were carried out on a ZDM 5/51 universal tensile machine according to ASTM D638. The jaw speed was set at 5 mm/min..

The highest tensile strength was measured for the samples printed from rPLA material, where the ultimate tensile strength was found to be 45.53 ± 0.75 MPa. The lowest tensile strength was measured for rPETG material at 41.62 ± 3.34 MPa (see Table 1 Measured values). Similar values were found in publications Tensile Testing of 3D Printed Materials Made by Different Temperature and Investigation of tensile property-based Taguchi method of PLA parts fabricated by FDM 3D printing technology [5, 6]. For clarity, tensile diagrams for specimens with minimum, middle and maximum tensile strength are shown in the graphs (see Fig. 4 Tensile diagram of samples PLA and rPLA). The specimens made from recycled PLA material show higher tensile strength than the specimens made from virgin PLA material.

Tab. 1 *Measured values of tested materials*

		Tensile strength [MPa]									
		1	2	3	4	5	6	7	8	9	10
Material	PLA	42.26	41.83	42.76	43.06	42.32	42.32	42.17	42.14	42.05	41.90
	rPLA	46.23	43.50	46.42	45.48	45.85	45.67	45.43	45.52	45.55	45.27
	PETG	42.31	42.10	42.18	43.75	43.20	43.23	42.97	43.02	43.39	43.75
	rPETG	41.94	41.44	32.74	41.66	41.84	44.94	41.77	41.59	44.39	41.44
		Median [MPa]		Average [MPa]		Standard deviation [MPa]					
	PLA	42.21		42.28		0.36					
	rPLA	45.53		45.49		0.75					
	PETG	43.11		42.99		0.58					
	rPETG	41.62		40.92		3.34					

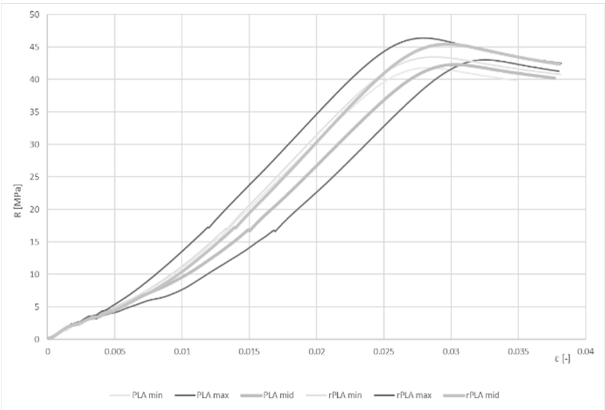

Fig. 31 *Tensile diagram of samples made by PLA and rPLA*

It can be seen from the tensile diagrams for the specimens made from recycled PETG material that there is a large difference between the minimum and maximum tensile strength values (see Fig. 5 Tensile diagram of samples PETG and rPETG). The mean values of the tensile diagrams of the samples made from rPETG and PETG materials show similar strength parameters.

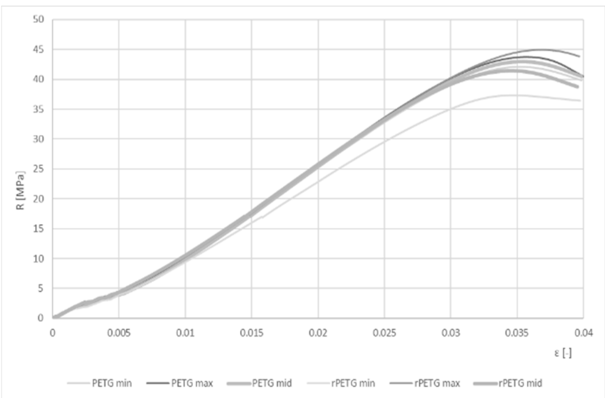

Fig. 5 *Tensile diagram of samples PETG and rPETG*

From the evaluated results and the box plot, it can be seen that there are significant differences between the tested samples made from virgin polymers and recycled polymers. The box plot shows that there is a significant difference between virgin material PLA and recycled material rPLA. For the recycled rPETG material, a large scatter in the measured tensile strength values was found. The virgin PETG material has similar strength limits to the recycled rPETG polymer (see **Fig. 6** Box plot of measured values).

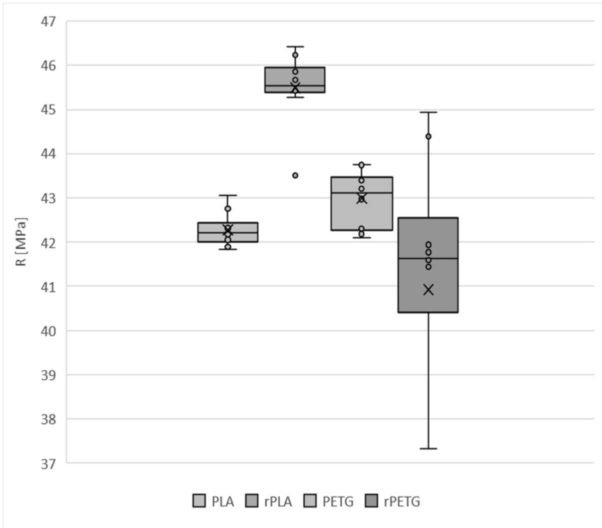

Fig. 6 *Box plot of measured values*

4 Conclusion

A comparison of virgin polymer materials and recycled polymer materials for 3D printing yielded interesting results. From the measurement results, it is not possible to determine uniformly in general terms whether recycled or virgin polymer is preferable from a strength point of view. The two groups of materials tested yielded different results. From the tensile testing it was found that the recycled material rPLA has a higher tensile strength than the virgin polymer PLA. It is possible that these results are related to the processing technology of the selected materials. It will therefore be appropriate to further investigate the possible causes of the mechanical and material properties in more depth. A large group of the tested samples consisted of rPETG and PETG materials. The samples made from recycled rPETG polymer were found to have similar tensile strengths to the virgin PETG polymers. The samples made from virgin PETG polymer had less variance in the observed tensile strengths. Therefore, it can be predicted that they will be more suitable for production due to the more stable mechanical properties of the components produced.

Acknowledgement

The research has been supported by the project TACR GAMA, Proof of Concept 2, TP01010018.

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