PLA Deposition on HDPE Substrates for Hybrid Additive Remanufacturing

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Abstract. *Additive remanufacturing can realize the integrated repair of structures or functions, add new features, or apply to simple or complex geometries. It can significantly reduce use, maintenance, labour, and time costs. Additive remanufacturing can be used to produce discontinued replacement parts or emergency guarantee of spare parts, accelerating the green development of product life cycle. This study investigates the technological feasibility for the remanufacturing of high-density polyethylene (HDPE) components by depositing polylactic acid (PLA) through Fused Deposition Modelling3D printing technique. The resulting shear lap tensile strength was evaluated according to the ASTM D3163 standard to define the adhesive or cohesive failure. The tests were performed on as-cut smooth HDPE samples. The results showed an adhesive failure for all the samples, highlighting a poor joining between HDPE and PLA. However, the best performance of around 200 N was achieved for the joint obtained between PLA and HDPE with a dimples' textured surface with a 1 mm diameter made by CNC machining. This finding can be addressed to the greater dimension of the texture, allowing to accommodate a greater amount of fused PLA within the texture itself.*

Keywords. PLA, HDPE, FDM, hybrid components, remanufacturing

University of Maribor Press

DOI https://doi.org/10.18690/um.4.2023.28
ISBN 978-961-286-783-6

1 Introduction

Additive manufacturing is a production approach based on addition of material allowing manufacturing of customized parts with complex geometry, which are very difficult to be produced by traditional techniques [1]. Components' structures can be also optimized to limit waste production, weight, and costs, while ensuring the proper performance [2].

Among the many solutions, Fused Deposition Modelling (FDM) is the most popular technique thanks to its low cost, high prototyping accuracy, and high printing speed [3]. It is mainly intended for thermoplastic materials, e.g., PLA, ABS, PA, TPU, etc. [4], and it hasbeen successfully applied in many fields, from chemical, to pharmaceutical, food, biomedical, automotive, aeronautics, aerospace, etc. [5].

Recently, the concept of additive remanufacturing/replacement has gained great interestthank to the environmental and economic benefits that can arise by using low-impact additive manufacturing techniques [6]. Moreover, the combination of different materials, aswell as different fabrication technologies, can allow the production of hybrid components with new features and improved performance [7]. But, due to high number of materials andmachines, there is the need of a guideline for parts remanufacturing or replacement.

The present study investigates the technological feasibility for the remanufacturing of high-density polyethylene-based components (HDPE) by depositing PLA through FDM onexisting parts and evaluating their shear strength on the basis of their surface treatment.

2 Materials and Methods

The experimental activity concerned four main steps: (i) preparation of starting plates by CNC cutting; (ii) surface texturing by CNC or laser; (iii) PLA deposition by FDM; (iv) mechanical characterization by shear strength tests. In the following the details.

The selected material to use as substrate is a commercial sheet made of High-Density PolyEthylene (HDPE), by RS, while a commercial PolyLactic Acid (PLA) filament, by SUNLU, was adopted for the FDM processing. The thickness of the sheet is 3.8 mm, whilethe PLA filament has a diameter of 1.75 mm.

The samples were prepared according to the ASTM D3163 standard for shear strength evaluation. The substrates, as well as the FDM counterparts, were designed as plates of 25x70x3.8 mm in dimensions. The HDPE plates were cut by using the Stepcraft D840 CNC,while the PLA plates were fabricated by using the Creality Ender 3 FDM. The CNC operations were designed by using Fusion 360 CAM software by Autodesk, while the 3D fabrication by using Cura slicing software by Ultimaker while adopting the default printingparameters for PLA extrusion. Figure 1 shows the plate geometry with the resulting shear test sample. The thickness depends on the starting material. For the FDM, a support structurewas needed to avoid deflection since the overlapping of the samples was limited to 20 mm.It is worth noting that to guarantee the adhesion of the HDPE on the building plate of the FDM, a sacrificial layer of 0.2 mm was fabricated for the substrate bonding.

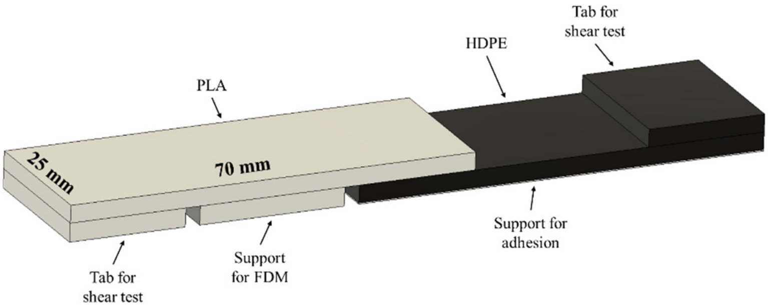

Figure 1. Final geometry of the test samples

The investigation dealt with the evaluation of the shear strength of the joints depending on the surface topography. The samples were tested as built, and after texturing the surfaceby means of the Stepcraft D840 CNC and the 1.6 W Snapmaker Original Laser system. Themodified area is the overlapping one of 20x25 mm. The textures were lines, 90° nets and dimples, with 1 mm and 0.4 mm dimension for the CNC and the laser respectively. Accordingly, the spacing between geometries was set at 1 mm and 0.4 mm as well.

Finally, the shear lap tensile strength tests were carried out by using the 50 kN UniversalMTS Insight Electromechanical Testing System according to the ASTM D3163 standard which provides the procedure and the sample geometry to be adopted. Specifically, the testswere performed with a crosshead speed of 1.27 mm/min while registering the applied load and crosshead displacement.

3 Results and Discussion

The results are listed in Table 1. As shown in the latter, the best strength results are achievedwith the dimple texturing type, for both machining methods. In particular, the realization ofthe texture by means of the CNC allows reaching a maximum load of around 199 N before failure, against 62 N obtained for the laser texturing. This can be due to the dimension of thegrooves, which is greater for the CNC and therefore able to accommodate a greater amountof fused PLA during deposition, which is extruded through a nozzle of 0.4 mm in diameter.It is worth noting that without any surface treatment, no adhesion is obtained due to the smoothness of the substrate. Among the texturing geometries, the dimples ensured the best performances. This result can be addressed to the more homogeneous deposition of PLA between dimples. In fact, with lines and nets there is a greater empty area underneath, thus compromising an appropriate and smooth deposition of PLA. In any case, the observed failures were all of the adhesive type, underlying therefore a poor joining between the adopted materials.

Table 1. Experimental results

Texturing	None	CNC			Laser		
		Lines	90° Net	Dimples	Lines	90° Net	Dimples
Max. Load, N	-	36	122	199	-	42	62

4 Conclusions

This study was aimed at verifying the joining between HDPE and PLA by means of Fused Deposition Modelling for hybrid components remanufacturing. After successfully fabricating new plates on existing substrates to obtain shear lap testing sample geometry according to the ASTM D3163 standard, the samples were tested to evaluate the shear strength depending on the surface treatment, i.e., none, lines, 90° nets or dimples, obtained with CNC or laser. In general, adhesive type failure between the materials was observed, thus proving a poor joining. In spite of this, the best results were obtained for the dimple texturing through CNC up to around 199 N. This can be due to the greater size of grooves that can accommodate more material during deposition and the shape of can allow a more homogeneous deposition since the empty areas are less extensive. Future developments willaim to test new texturing geometries and deposition condition to promote a stronger adhesion between the materials.

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