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Improve the surface roughness of PETG products in FDM 3D printing process with addition of Carbon Fiber

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Abstract: The aim of this study is to improve the surface properties of PETG material in 3D printer products by adding Carbon-Fiber (CF). Carbon-Fiber is a material that can be added to PETG, PLA, ABS, Nylon and Polycarbonate PC filaments to increase their strength and stiffness. The main contribution of this study is to provide a comprehensive evaluation of the surface roughness of PETG and PETG/carbon-Fiber filaments printed by fused deposition modeling (FDM) technique. The surface roughness is measured using surface roughness PCE-RT20000 tester. By adding 15% weight of Carbon-Fiber to PETG material, the surface roughness value was reduced by 32.7% in the final 3D printed product. This resulted from Carbon-Fiber's capacity to improve the material's flexibility and strength as well as its capacity to close gaps between PETG material threads by enhancing flow and adhesion. The chemical interaction between Carbon-Fiber and PETG contributed to increased flow and adhesion of the material. This interaction plays a role in obtaining good surface properties.

Keywords: (3 D printing, materials, surface roughness, PETG, PETG/Carbon-Fiber)

Introduction

The increasing popularity of 3D printing, also known as additive manufacturing (AM), rapid prototyping (RP), or solid free-form technology (SFF), in a variety of applications has led the modern manufacturing industry to seek to replace conventional techniques with this innovative technology where suitable. This is due to the numerous advantages that 3D printing offers in comparison to conventional, energy-intensive techniques, such as the ability to fabricate complex geometries as a single unit with no joints, reduced material and labor costs, improved surface finish, decreased energy demand, single-step processing temperature, simplified processing (CAD model-Print-Install), near-net shape finish, quick production time, short lead time, and lower overall cost [1]. One of the main benefits of 3D printing is the capability to produce near-net shape products without the need for physical molding to achieve the desired shape of the product. Designs can be created as 3D objects using software such as AutoCAD and SolidWorks, which are commonly used for designing prototypes for 3D printing applications. Once created, the 3D soft files can then be converted into the stereolithography (STL) format, a format that can be interpreted by a 3D printer [2]. The main advantages of this technology are the ability to develop complex shapes without geometric limitations and the conversion from the 3D solid model to the manufactured part with only a few parameters. The generic term AM encompasses several technologies such as fused filament fabrication (FFF), selective laser sintering (SLS), electron beam melting (EBM), and stereolithography (SLA). FFF is by far the most extensively used technology due to its ability to manufacture complex parts with a broad range of thermoplastic polymers at relatively low production costs. FFF accounts for 69% of all AM processes [3]. Surface roughness is a critical parameter that affects the mechanical and physical properties of materials, such as friction, wear, corrosion, adhesion, and reflectivity. In 3D printing, surface roughness also determines the accuracy, quality, and appearance of the printed parts. Therefore, it is essential to understand and control the surface roughness of 3D printed materials for enhancing their performance and functionality [4]. Among the various 3D printing materials, polyethylene terephthalate glycol (PETG) is a thermoplastic polymer that exhibits high strength, toughness, and chemical resistance. However, PETG may have high surface roughness due to its low viscosity and high shrinkage during printing. To overcome this limitation, PETG can be blended with carbon fiber reinforced filament (carbon Fil), which can improve the stiffness, dimensional stability, and thermal conductivity of PETG [5]. The main contribution of this study is to provide a comprehensive evaluation of the surface roughness of PETG and PETG/carbon Fil filaments printed by FDM technique. This study can help in selecting the appropriate materials for different 3D printing applications that require high surface quality. This research aims to improve the mechanical properties of PETG by adding carbon fibers to it. It is expected that this research will lead to the development of polymer materials based on PETG with improved mechanical properties, which can be used in various applications, including the automotive industry, aviation, and 3D printing**.**

2. Methodology

2.1. Materials

In this study the PETG and PETG\CF materials commercially available industrially common 3D printing material was used: Polyethylene Terephthalate Glycol - Carbon Fiber (PETG - CF). This filament of 1.75 mm in diameter.

Carbon fibers are added to materials in different ratios and are commonly available in 3D printers and other products. In this study, PETG material was chosen with 15% carbon fiber added to it.

2.2. Experimental procedures

2.2.1 Specimen preparation

Samples were printed using the ENDER 3D printer. Figure 1, shows the 3D printer used in this study.

Fig:1, 3D printer (FDM)

And the printer settings are given in the following table1:

Table 1: shows the printer settings Parameter.

printer settings		
1-	Infill	100%
2-	Printing temperature	240C⁰
3-	Build plate temperature	80C⁰
4-	Print speed	55 mm/s
5-	Fan speed	100 mm/s
6-	Layer height (mm)	0.2 mm

The samples were designed using SolidWorks software 2023 and converted into stereolithography (STL) format. The printer's operating program (G-Codes) was then produced to control the printer's operation and execute the models. Six samples were prepared, three of which were made of PETG material and the other three were made of PETG material with 15% Carbon-Fiber added to them. The surface roughness of each sample was measured and the average value was taken for the sake of accuracy. The surface roughness is measured using a roughness tester. The following figure shows the PCE-RT 2000 Roughness Tester.

Fig.2. Surface Roughness Tester

RESULTS:

The surface roughness test results for PETG and PETG-CF materials are:

PETG are: (6.853 , 6.339 , 7.236) μm, $Ra = 6.886\mu m$ and PETG+15% carbon-Fiber are: (5.144 , 4.765 , 4.010) μm, $Ra = 4.639\mu m$. The improvement percentage in surface roughness is: 32.7%.

The appearance of the 3D printed surface roughness test PETG and PETG-CF specimens are shown in Fig3(a,b):

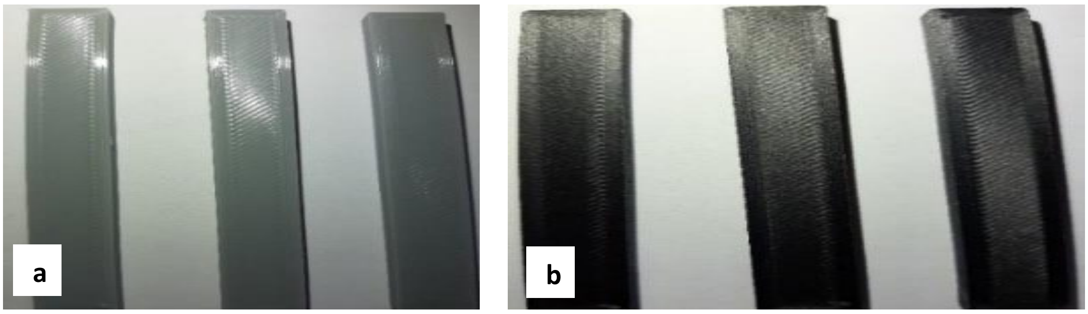

Fig. 3 (a) the surface of PETG sample, and (b) the surface of PETG-CF sample

Discussions

By adding 15% carbon-Fiber to PETG material, surface roughness was reduced by 32.7% during the 3D printing process. This was due to carbon-Fiber's ability to reinforce the strength and flexibility of the material, as well as fill gaps between PETG material threads by increasing flow and adhesion. This corresponds to references [6,7]. This resulted in improved surface smoothness and regularity. Carbon-Fiber has different functional groups than PETG material, which contributed to the formation of new bonds and breaking old bonds between polymer chains. These properties also contributed to the flow and adhesion of the material to the surface, thus leveling the surface or filling gaps between threads. This is consistent with what (Eunseob Kim et al) [8] found that Carbon-Fiber is more viscous than PETG at temperatures close to 3D printing temperature. This makes Carbon-Fiber flow better from the nozzle and form better on the surface, leading to improved surface smoothness. However, material viscosity may also be affected by other factors such as particle shape and composition in the material due to their manufacturing method and their physical and chemical properties This corresponds to references [6].

Conclusion

1- Addition of carbon Fil into_to PETG material made it stronger and more rigid, thus making it less prone to deformation or breakage during 3D printing. This may lead to improved surface smoothness and regularity.

2- The surface properties of PETG material improved by 32.7% when 15% carbon-Fiber was added to PETG.

3- One of the most important factors that contributed to improving surface roughness is that carbon-Fiber has higher viscosity than PETG.

4- The small particle size of carbon-Fiber filled the gaps and voids in PETG material.

5- Good mixing between the two materials contributed to forming a smoother and more regular surface.

6- The printer's Settings calibration was very compatible with the printed material, which effectively contributed to obtaining good results.

7- Increased surface leveling and filling gaps between threads due to increased flow and adhesion of the material by carbon-Fiber.

8- The chemical interaction between carbon-Fiber and PETG contributed to increased flow and adhesion. This interaction played a role in obtaining good surface properties.

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