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The Impact Of Carbon Fiber on the surface properties of the 3D Printed PEGT Product

Abraheem Hadeeyah[a], Hana Jamhour[b]*, Ibrahim Emhemed[c], Fouzi Alhadar[a], Neila Masmoudi[d], Monder Wali[d]

[a] Dept. Mechnical Engineering, National Engineering School Sfax, Tunsisia / Higher institute of Technical Siences, Tarhuna, Libya.
[b] Libyan polymer research center, Tripoli, Libya.
[c] Dept . Physics Education Faculty, Azzaytuna university , Tarhuna,Libya
[d] Dept. Mechnical Engineering ,National Engineering School, Sfax, Tunsisia.

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A B S T R A C T

The primary focus of this work is the development of a hybrid composite material for 3D filaments. Polyethylene phthalate glycol (PETG) and (PETG/Carbon) fiber composite materials have their surface properties (surface roughness, Shore hardness, and micro hardness) tested. A ratio of 15% carbon fiber (in the form of carbon filaments) was used as the reinforcing filler. Using FDM (fused deposition modeling material) technology, the surface properties of PETG material used in 3D printed objects were enhanced. An ENDER 3D printer was used to create three PETG and PETG/Carbon fiber samples, using the printer setting 240°C temperature, 80°C build plate temperature, 55mm/s speed, 0.2mm layer height and speed fan 100mm/s. After that, an optical microscope and FT-IR technologies were used to investigate the samples. Results showed that as compared to PETG, the surface roughness of PETG/Carbon was reduced by 32.7%. This allowed carbon fiber to break doubly bonded in the PETG structure and also enhanced sample flow and adhesion. The PETG/Carbon samples had a Shore hardness D that was 2.16% lower than PETG's, but a slightly higher Micro hardness, making them more comparable to 10.4 HV than to 9.6 HV. However, the carbon fiber was reinforced and showed high compatibility with a PETG polymer matrix at the samples' buried structures, demonstrating that a 3D printer is an effective production tool for producing homogenized composite materials. According to claims, these features enhance the carbon fiber's ability to slide in PETG/Carbon samples.

تأثير ألياف الكربون على الخصائص السطحية لمنتج PETG المطبوع ثلاثي الأبعاد

إبراهيم هدية[أ] و *هناء جمهور[ب] و إبراهيم إمحمد[ج] ، فوزي الهدار[أ] و نائلة المصمودي[د] و منذر والي[د]

[أ] الهندسة الميكانيكية، ، المؤسسة الجامعية، المدرسة الوطنية للمهندسين بصفاقس، تونس/المعهد العالي للعلوم و التقنية، ترهونة، ليبيا.
[ب] مركز أبحاث اللدائن، طرابلس، ليبيا.
[ج] قسم الفيزياء،ترهونة، جامعة الزيتونة، ليبيا .
[د] الهندسة الميكانيكية، المؤسسة الجامعية، المدرسة الوطنية للمهندسين بصفاقس، تونس.

الكلمات المفتاحية:
ألياف الكربون
المواد المركبة
الطابعة ثلاثية الابعاد
البولي ايثيلين تيريفثاليت جلايكول
خصائص السطح

الملخص

هذه الدراسة تهدف لتطوير استخدام عملية الإنتاج والتشكيل لخيوط المواد البوليمرية المركبة الهجينة باستخدام الطابعة ثلاثية الأبعاد و حيث تم دراسة الخصائص السطحية (خشونة السطح، صلادة شور، والصلادة الدقيقة) لعينات مادة (PETG) ومقارنتها مع عينات من مادة (PETG/Carbon) المركبة وذلك باستخدام نسبة 15٪ من ألياف الكربون كحشو تقوية على شكل خيوط لمواد مركبة من ألياف الكربون مع البولي إيثيلين فثالات جلايكول (PETG/Carbon) باستخدام تقنية نمذجة الترسيب المنصهر (FDM)، جهزت العينات بحيث كانت درجة حرارة الطابعة 240°م، ودرجة حرارة لوحة التصميم 80°م، سرعة الطابعة 55 مم/ثانية، وسرعة المروحة 100مم/ ثانية، ارتفاع الطبقة 0.2مم . وبعد ذلك تم استخدام المجهر الضوئي وتقنيات (FT-IR) لفحص العينات. وأظهرت النتائج أن خشونة العينات المصنوعة من مادة (PETG/Carbon) المركبة تقل بنسبة 32.7٪عن العينات المصنوعة من مادة (PETG) فقط. ويعود ذلك لأن ألياف الكربون تعمل على كسر الروابط الثنائية في هيكل مادة (PETG) وكذلك

*Corresponding author:
E-mail addresses: hanajamhoer@yahoo.com, (A. Hadeeyah) ibrahem27777@gmail.com, (I. Emhemed) I.emhemed@azu.edu.ly,(F. Alhadar) alhadar7533@gmail.com, (N. Masmoudi) neila.masmodikhabou@enis.tn, (M. Wali) mouali@kku.edu.sa.
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تحسين التدفق والالتصاق. وأن اختبار صلادة شور (Shoer D) لعينات (PETG) أقل بنسبة 2.16٪ من عينات (PETG/Carbon) المركبة، واختبار الصلادة (Micro-hardness) كان أعلى قليلا 10.4HV مقارنة بـ 9.6HV ومع ذلك فان التعزيز بألياف الكربون أظهر توافقًا عاليًا مع بوليمرPETG في الهياكل التركيبية الداخلية في الفحص المجهري، مما يدل على أن الطابعة ثلاثية الأبعاد هي أداة إنتاج فعالة لإنتاج مواد مركبة متجانسة حيث تعزز هذه الميزات بقدرة ألياف الكربون على الانزلاق في عينات (PETG/Carbon).

Introduction

paper To improve the polymers' strength, appearance, conductivity, and temperature resistance, various fillers are added. New composite materials are gradually becoming accessible to expand the possibilities of 3D printing [1]. Since the first patents ultimately expired, several 3D printing techniques have been created and are in use today[1].The modern manufacturing sector is attempting to replace traditional methods with this cutting-edge technology where appropriate as a result of the rising popularity of 3D printing, also known as additive manufacturing (AM)[2], The term "additive manufacturing" (AM) refers to a group of technologies used to create physical objects layer-by-layer adding material from a computer-aided design (CAD) file, in contrast to subtractive manufacturing methods as machining [3]. Although it is often referred to as "3D printing," "layer-based manufacturing," "solid freeform fabrication," and "rapid prototyping" (RP) [3], the term "AM" is standardized by ISO and ASTM [3]. The generic term AM encompasses several technologies such as fused filament fabrication (FFF), Fused deposition modeling (FDM), selective laser sintering (SLS), electron beam melting (EBM), and stereolithography (SLA)[4],[5]. 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 [6] and Fused deposition modeling (FDM) one of various additive manufacturing (AM) technologies, that have revolutionized the manufacturing industry, from the development of concept models to the creation of functional parts. FDM uses a wide variety of materials to create 3D-printed parts. However, most FDM printers in the market use polylactic acid (PLA) and acrylonitrile butadiene styrene (ABS) thermoplastic materials for their good mechanical properties and low cost. Polyethylene terephthalate glycol (PETG) has recently gained considerable attention due to its enhanced properties by FDM technologies [2],[7].

PETG is an amorphous and linear polymer, it is an excellent material for extrusion, injection molding, blow molding and thermoforming [8] but In recent years, PETG has also become popular in 3D printing [9]. PETG is on the contrary easy to print due to the high dimensional stability of the polymer during solidification. Among the various 3D printing materials, polyethylene terephthalate glycol (PETG) is a thermoplastic polymer that exhibits high strength, toughness, and chemical resistance. PETG is non-toxic, which makes it suitable for industries such as food and medicine, particularly dentistry [10]. PETG plastic has a high resistance to alkalis and acids, which makes it much more difficult to post-treat. When considering the use of PETG in additive manufacturing, it should be noted that its properties are affected by the 3D printing mode chosen when implementing the FFF technology[10]. Not much attention has been paid to this issue. There are data on the effect of specimen orientation during 3D printing on mechanical properties [10], on the effect of PET plastic type on mechanical properties [11], and on the effect of long-term exposure to chemicals on the quality of PETG products [12]. It is important to note that often the mechanical properties of the printed specimen are not understood as properties of the material itself, but as properties of the specimen structure, which introduces some confusion in the interpretation of tensile test results[13]. 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[14],[6].

The main contribution of this study is to provide a comprehensive evaluation of the surface roughness and some surface properties of PETG and PETG/Carbon fiber 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.

Methodology

2.1. Materials

PETG Filaments

The material polyethylene terephthalate glycol-modified (PETG) is extremely durable and adaptable with excellent heat resistance. The best material for printing mechanical components is this one. Due to its virtually complete lack of warping, PETG is best for printing huge objects. The temperature requirements for the filament with a specific gravity of 1.27 g/cm^3 are 220-240℃ for the extrude and 50-90℃ for the bed. PETG filament is completely reclaimable but not biodegradable. It is renowned for being crystal clear and excels in bridging. PETG filaments are offered in a variety of colors and diameters of 1.75 mm, 2.85 mm, and 3.0 mm. PETG was provided for this investigation from publicly available, chain-produced stores. This filament is gray in color and has a 1.75 mm diameter.

Carbon Fiber – PETG Filaments

Carbon fiber is used to strengthen 3D printer filaments like PETG, creating a very hard and unyielding material that is comparatively light in weight. Very excellent ductility, high strength, and impact resistance. Carbon Fiber-PETG filaments come in a variety of colors and diameters of 1.75mm, 2.85mm, and 3.0mm. The temperature on the bed and while printing is between 230 and 250℃. Applications include replacing a part in your model vehicle or airplane and mechanical body components. In this investigation, Carbon Fiber-PETG was provided by a chain store under the Formutura product serial number HC39169090. This filament is 1.75 mm in diameter, Black in color, and has bed temperatures between 230 and 265^{o}C. Its viscous softening temperature is 79 ℃ (ISO306).

2.2. Experimental Work

2.3. Specimen Preparation

Samples were printed using the **Endr 3D printer**. **Figure** (1), shows the 3D printer used in this study and the printer settings parameters are given in the following table1:

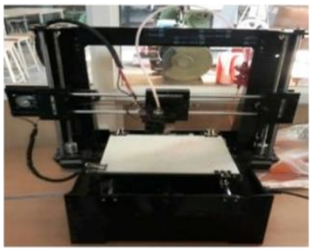

Fig. 1: .3-D Printer

Table 1:Printer Settings Parameter[16]،[15].

Printer Setting	Parameter
Infill	**100%**
Printing temperature	240 ℃
Build plate temperature	80 ℃
Print speed	55 mm/s
Fan speed	100 mm/s
Layer height mm	0.2 mm

The samples were designed using Solid Works software 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 (ISO527-2). Six samples were prepared, three of which were made of PETG material and three of which were made of PETG/ Carbon fiber material with added 15% CorbonFil Filaments.

2.4 .Characterization
2.4.1 Fourier Transform Infrared Spectroscopy

FT-IR test was carried out using Agilent Microla630 to identify the chemical bonds and functional groups in the PEGT and PEGT/Carbon fiber composites. sample which was in cutting to small pieces to analyzed using Attenuated Total Reflection (ATR)method. FT-IR analysis was carried out at wavelength between 400 to 4000 cm^{-1} with step scan 4 and resolution of 4 cm^{-1} to measure the absorption band of the substances.

2.4.2 Optical microscopy
Optical microscopy (HST 402-AW made by Jinan Hensgr and instrument CO.;Ltd) was used to investigate the distribution carbon fiber in PEGT at 100X and 20X magnifications.

2.5. Surface Properties Measurements

2.5.1. Surface Roughness
The surface roughness of PETG and PETG/ Carbon fiber samples were measured using a roughness Tester PCE-RT 2000 at different point of samples see **Figure** and to sake of accuracy the average value was determination.

Fig.2: Surface roughness PCE-RT20000 Tester.

2.5.2. Shore Hardness
The indenter was attached to a digital scale that is graduated from 0 to 100 units, and Shore Hardening D was used to measure the surface hardness. The typical method was to press down firmly and quickly on the indenter and record the maximum reading as the shore D hardness measurement were taken directly from the digital scale reading. According to ASTM D2240 and ISO 868, hardness findings are the average of three samples measured from PEGT and PEGT/ Carbon fiber using a durometer (RAY-RAN MACHINE, Model RR/B550, UK) see **Figure**3[17].

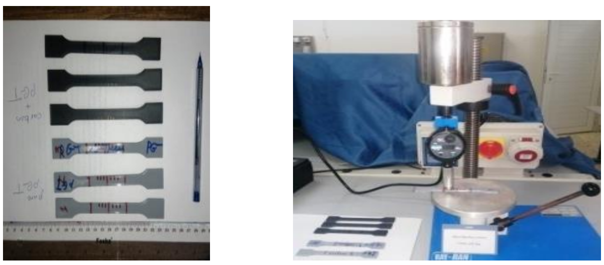

Fig.3: Shore Hardness Testes.

2.5.3 . Micro Hardness test

Vickers (HV)Micro Hardness of PETG and PETG/Carbon fiber samples were measured using a Micro Hardness Tester MVT-100Z at load 100gf and 10s dwell time. For each samples, the HV number was taken as an average of three indentations were randomly selections in point of surface.

Fig.4: Hardness Tester MVT-100Z**.**

Results and Discussions:
Figure (5) Shown of FT-IR band for a **PEGT** and **PEGT/Carbon** fiber where there is no different between the bands but slightly broads and decreased in intensity of UV absorbed band it may suggested the **PEGT/Carbon** is not effected an degradable by light so that is more stable than PEGT as results of carbon fiber.

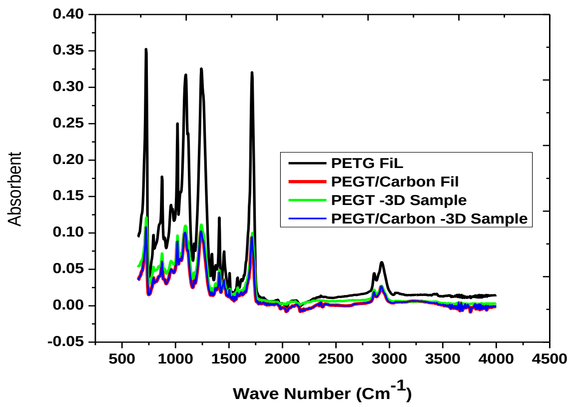

Fig.5: FT-IR Spectrum for PEGT Compared to PEGT/Carbon fiber .

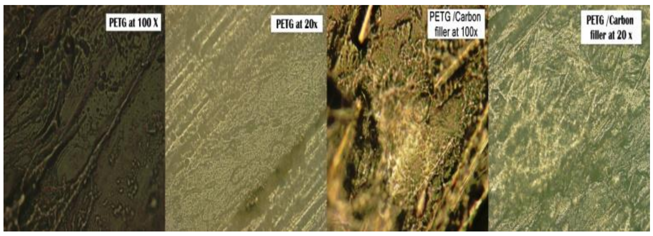

Fig 6: Microscopy photos of PEGT and PEGT /Carbon fiber at 20 - 100 X.

Figure (6) Optical microscopy was used to investigate the distribution particle distributions are relatively uniform structure for both PEGT and PEGT/Carbon fiber There was fine cluster formation by Carbon fiber contents as well as the formation of fine percolation paths of Carbon fiber in the PEGT E matrices .
Figure (7) shown The appearance of the 3D printed by FDM technology for **PETG** and **PETG/Carbon** fiber specimens was improved surface finishing, smoothness surface and regularity of surface at adding 15% Carbon fiber Black and results of measurements in Table 2 shown the surface roughness of **PETG** was reduced by 32.7% at comparatively with **PETG/Carbon** fiber specimens. this fact was due to carbon fiber ability to reinforce the matrix of polymer and giving good flexibility as well as fill gaps between PETG polymer threads by increasing flow and

adhesion[8][14].

Fig 7: Shows the surface roughness of (A) PETG and (B) PETG/Carbon fiber specimens.

Table 2: Results of the Surface Roughness Test.

Sample No:	PETG	PETG/Carbon fiber (15%W)
S1	6.853	4.765
S2	6.339	5.144
S3	7.236	4.010
Average	**Ra = 6.886μm**	**Ra = 4.639μm**

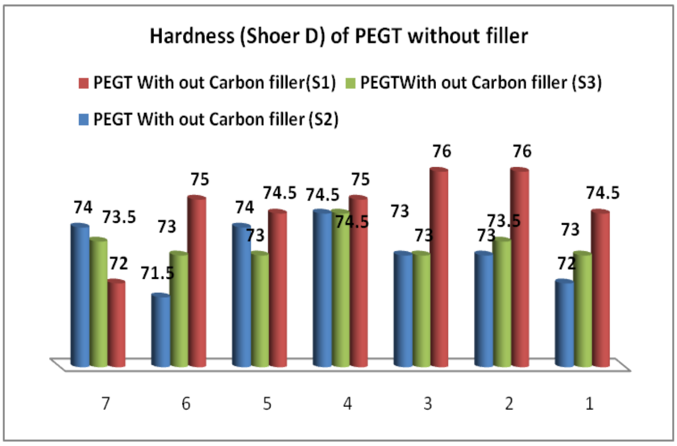

Fig 8: Hardness (Shoer (D)) of PETG Specimens produced by FDM Technology in 3-D printer.

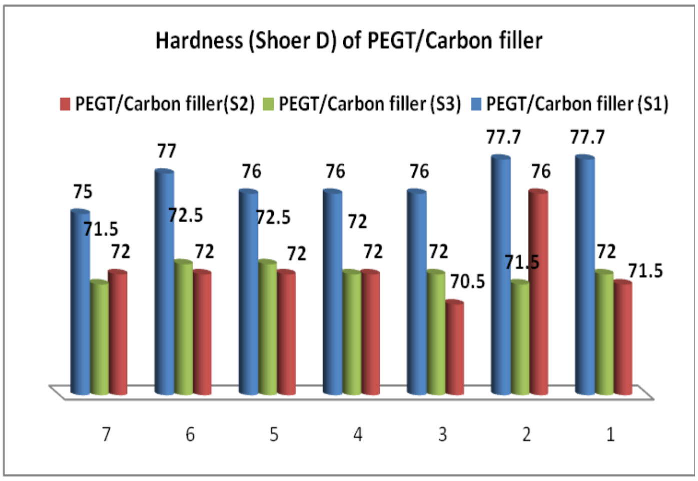

Fig 9: Hardness (Shoer D) of PETG/Carbon fiber specimens produced by FDM Technology in 3-D printer.

Figure (8) and (9) Shown The **PETG/Carbon** samples had a **hardness (Shore D)** that was 2.16% lower than PETG's At produced FDM technology in the 3D printed where the average of **hardness (Shore- D)** equaled **73.74 D**, **72.14D** respectively at added 15% carbon fiber filler and Micro-hardness test was slightly increased of HV hardness of PETG/Carbon samples, where it equaled **10.4 HV** but for PETG equaled **9.6 HV**. These features were stated to improve the sliding properties of carbon fiber in **PETG/Carbon** samples, but at the buried structure of samples, the carbon fiber was made a stronger bond with a matrix of **PETG** polymers and good compatibility with it; suggested that an effective manufacturing technology to generate homogenized composite materials is a 3D printer and this can explicated by the number of stacked layers for **PETG/Carbon** [15],[14].

Conclusion

A Adding 15% carbon Fiber to PETG polymer was decreased the hardness (Shoer D) at a surface by fact increasing the flexibility and higher viscosity of polymer matrix and less prone to deformation or breakage during 3D printing. The surface properties of PETG material improved by 32.7% when 15% carbon Fiber was added to PETG as a results as a small particle size of carbon Fiber filled the porosity PETG matrix and good compatibility between to materials. These fact can be revealed by a microscopy where a matrix have good distributions in polymer matrix and no void occur in photos results as The printer's Settings calibration was very compatible with the printed material, which effectively contributed to obtaining good results. FT-IR reveled the intensity of UV light is decreased by Adding 15% carbon Fiber to PETG which indicated may good adhesion between two material where a Carbon Fiber /PETG was less degradability under this light.

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