3D printing of continuous kevlar reinforced polymer composite through coextrusion method

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Abstract: The major drawbacks of 3D printed thermoplastic using fused deposition method (FDM) are exhibit weak mechanical properties. This reduces the usability of the printed part as the functional structure for part replacement in a real-world application. Therefore, in this study a co-extrusion of a continuous fibre of twisted Kevlar using FDM is conducted to examine the improvement of mechanical strength of the 3D printed part with reinforcement of continuous fibre. The coextruded reinforced plastic (CRP) parts consisting of polylactic acid (PLA) as matrix and twisted Kevlar as core fibre. The mechanical performance of printed parts was evaluated in a tensile test under ASTM D638 standard. The results of both CRPs were compared against unreinforced PLA which. It has been demonstrated that CRPs with twisted Kevlar was able to achieve significant increment in Ultimate tensile strength (+179.7%, 104.64MPa), maximum tensile strain (+257%, 5.384%) and relative similar Young’s modules (3.29GPa) compared to unreinforced PLA. As a result, this study created a unique material print which CRP with twisted Kevlar which offer high stiffness and high strength structure.

Keywords: 3D printing, Kevlar fibre, Coextruded reinforced plastic

1. Introduction

Additive manufacturing (AM) or 3D printing has gain significant popularity in the recent years. It has several advantages such as material saving, ability to reuse waste material and capability in fabricating complex geometries products [1-3]. In general, AM includes many methods such as digital lighting processing (DLP), fused deposition modelling (FDM), selective laser melting (SLM), stereolithography (SLA) and others [4 - 6]. Among these methods, FDM is the most commonly known 3D printing technology among the end-users. However, it still has its own limitation when comes to industrial use. For instance, FDM is a layer by layer process, material continuity in a printed part only occurs when neck growth and diffusion happen between two paths [7]. In other words, strength and stiffness of a printed part strongly depend on the inter-road bond strength, air gaps and voids [8]. Therefore, a new printing method is proposed for improving the strength of FDM products to increase the potential of this technology in the industry used.

One of the possibilities includes adding fibre reinforcement into conventional FDM to enhance the mechanical strength of the printed part [9, 10]. Nowadays, the use of fibre reinforcement in FDM can be characterized into two groups: short fibre reinforcement and continuous fibre reinforcement. Most studies report a 65 % increase of strength and stiffness of printed part simply by mixing ~0.1 mm short carbon fibres into thermoplastic filament [11]. However, this is not sufficient as compared to continuous fibre reinforced plastic (CFRP) products made from conventional composite manufacturing methods.
Therefore, CFRP 3D printing is presented in this project to examine the mechanical strength of CFRP printed parts.

In this study, twisted Kevlar was co-extruded with the PLA matrix to fabricate a CFRP part. These material combinations are new in the study of co-extrusion 3D printing. In addition, CFRP parts were fabricated and tested under the ASTM D638 standard to examine the influence of core fibre on the mechanical strength of 3D printed parts.

2. Experimental

2.1. Materials

Twisted Kevlar fibres were co-extruded with PLA matrix in this study namely, a 0.4 mm diameter twisted Kevlar thread. The volume fraction of fibre in 3D part is determined to be 6.54%. Each CFRP specimens consists of 4 layers, each layer was printed with 4 concentric perimeters.

2.2. Experiment set-up procedures

Three sets of specimens were printed according to ASTM D638 standard to determine their mechanical strength with respect to their core reinforcement. These two groups are twisted Kevlar-reinforced PLA (K-PLA) and plain PLA; each group consists of 3 specimens. The geometry of ASTM D638 Type I specimen is as shown in Figure . All CFRP parts were printed with 2 mm nozzle and layer height of 0.8mm.

![Figure 1. Dimension of ASTM D638 Type I specimen (unit: mm)](image)

3. Results & discussion

Stress-strain curve and tensile properties of specimens were recorded in Figure 2 and Error! Reference source not found.. Stress-strain curve for base PLA parts is a typical curve for ductile material with clear strain hardening region and necking region. However, with additional continuous fibre K-PLA specimens, the mechanical properties of the composite behave differently. The ultimate tensile strength of K-PLA had extended far beyond the based PLA part (+179.7%). In contrast, the fracture of K-PLA occurred immediately after the ultimate tensile stress (UTS) without any sign of necking. The K-PLA had achieved an ultimate tensile strength of 104.64 MPa as compared to based PLA part 37.41 MPa. Whereas, both base PLA and K-PLA have about similar elastic modulus i.e. 3.28 GPa and 3.29 GPa respectively. Based on the twisted Kevlar technical datasheet and other literature, the twist multiplier can adversely affect the modulus of yarn [12]. Thus, the resulting low elastic modulus in K-PLA specimens could be attributed to the twisting effect of Kevlar fibre. To compensate with the lack of enhancement in elastic modulus, breaking strain of K-PLA specimens (5.384%) was significantly higher than base PLA part specimens. This indicates that coextruded reinforced plastic (CRP) parts can behave differently depending on the properties of the fibre. These improvement in CRP in mechanical performances had made it comparable to Aluminum 1000 series. Additionally, the density of the CRP is only half of the aluminum density, i.e. 1.24 g/cm³ vs 2.7g/cm³. It can serve as alternative solution to rapid prototyping industry product design challenges where strength to weight ratio is critical.
4. Conclusion
CFRP parts were fabricated by FDM 3D printer through the co-extrusion method. A customized co-extrusion extruder was designed to feed core fibre and thermoplastic filament simultaneously into heat block and co-extruded as CFRP. A new composite was fabricated in this study i.e. tough twisted Kevlar-reinforced PLA composite. The composite was found to exhibit superior tensile strength to that of pure PLA printed part. Moreover, with only 6.5% volume fraction of fibre twisted Kevlar-reinforced PLA composite could reach +179.7% in ultimate tensile strength and +5.384% in breaking strain. This increment of strength is however come along with limitation such as breaking without necking and sudden. As additive manufacturing technology is advancing and becoming important, further improvement in terms printing of flawless CFRP parts shall be explored.

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References
[1] Tempelman E, Shercliff H and Van Eyben B N 2014 Manufacturing and design: understanding the principles of how things are made (Elsevier)
[2] Ford S and Despeisse M 2016 J. Clean. Prod. 137 1573
[3] Abdulhameed O, Al-Ahmari A, Ameen W and Mian S H 2019 Adv. Mech. Eng. 11 1
[4] Ngo T D, Kashani A, Imbalzano G, Nguyen K T and Hui D 2018 Compos Part-B Eng. 143 172
[5] Jasveer S and Jianbin X 2018 International Journal of Scientific and Research Publications 8 1
[6] Komarnicki P 2016 Proceedings of the 13th International Scientific Conference (Springer) p 241
[7] Tymrak B, Kreiger M and Pearce J M 2014 Mater. Des. 58 242
[8] Turner B N, Strong R and Gold S A 2014 Rapid Prototyping Journal 20 192
[9] Liu W, Song H, Wang Z, Wang J and Huang C 2019 Mater. Des. 181 108065
[10] Chen L and Zhang X 2019 Appl. Surf. Sci. 492 765
[11] Blok L G, Longana M L, Yu H and Woods B K. 2018 Addit. Manuf. 22 176
[12] Pal S and Gandhi R 1988 Indian Journal of Textile Research 13 184