A review on bonding of Polyamide reinforced carbon fibre via additive manufacturing

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Abstract. Continuous carbon fibre offers a huge potential which is a lightweight, high strength, low density, a low coefficient of thermal expansion, and high thermal conductivity and stiffness. In addition, polyamide-6 (PA6) has good mechanical and physical properties thus, it makes PA6 as effectiveness between matrix and reinforcement of continuous carbon fibre. 3D printing as a cost effective in additive manufacturing was covered in a complex part building using CAD software based on CAD model makes fisible finish the elements. The main objectives of this paper are to review on interlayer bonding of polyamide reinforced carbon fibre by using 3D printing method on their mechanical properties. This paper scope was a review on the bonding of polymeric composites which is polyamide reinforced carbon fibre as the material used and their printing parameter which is important for their orientation during printing. The printing parameter in 3D printing was set to vary the quality and mechanical behavior of the sample. The sample was reviewed on their bead orientation consist of 0°, 45°, and 90° directional angle of the sample in form of their bonding. Mechanical properties of the samples were tests using tensile test and resulted at 0° it achieves higher tensile strength and modulus when tensile loading direction is parallel to deposition direction. At 90° direction, the fibre was perpendicular with the tensile loading direction and resulted in a decreased tensile property.

Keywords: Continuous Carbon Fibre; 3D Printing; Bonding; Orientation.

1. Introduction
The complex part building, cost-effectiveness, and sustainability have shown that additive manufacturing (AM) technologies have a huge potential. Subsequently, AM gets quite possibly in most encouraging fields in manufacturing components and gains considerable attention. AM technologies have numerous methods [1]. One of the AM technologies is layer manufacturing or commonly referred to as 3D printing in additive manufacturing is a very dynamically developing direction in manufacturing technology. The article presents considerations on the possibilities of using 3D printing in the development of manufacturing technology by using a polymer composite [2]. Carbon fibre strengthened polymer composites (CFRP) offer huge preferences over metals in which it gives a lightweight, high strength and stiffness, and they offer to resists corrosion and fatigue. Thermosetting epoxy matrices which are widely used in CFRPs have a stiffness to weight ratio and high in strength which can be used in aviation applications. Surface treatment in carbon fibre and
sizing technologies in materials have been created aviation in the past of years which resulted in achieving high interfacial fibre-matrix bond strength and favorable mechanical properties [3].

The superiority of continuous carbon fibre can be fabricated using these printing methods such as 3D printed continuous fibre reinforced parts awake researchers’ attention. Traditional manufacturing uses the same method which needs a large number of printing parameters to be all considered in AM process. Impact of printing parameters of 3D-printing composites using continuous carbon fibres on mechanical properties was studied. In addition, the literature on polyamide (PA) based composites reinforced with continuous carbon fibres in 3D printing on mechanical properties was also explored. The mechanical behaviors of 3D printed parts with various build orientations which are horizontal and vertical were additionally evaluated [4]. It shows with the use of 3D printing makes it feasible to finish the elements. It has using ready-made metal elements. The specific features in 3D printing which have been created by CAM software based in CAD model have been brought out to adapts to the capabilities of this method [2].

3D printing technology in fused deposition modeling (FDM) which is widely used for utilized low-cost was utilized adhesive properties of thermoplastic materials and hot melt. Polyamide (PA) in engineering thermoplastic polymer materials is important because it has an excellent comprehensive performance. FDM technique is used in 3D printing as it exponentially evolved manufacturing technology covering a process of joining materials to make objects from 3D model data, usually layer-by-layer, which has received significant attention in recent years by offering numerous advantages over traditional subtractive methods since it was first described in 1986 by Charles Hull [3]. The 3DP technology provides the ability to directly create objects with intricate geometrical features in a cost-effective way, which requires no mold tool and offers near-net-shape manufacturing in a relatively short period of time[5]. Moreover, the 3DP is generally advantageous in products and fabrication of customized parts with custom-fitted design and complex while being equipped for harnessing digital information for the realization of a robust and decentralized 3D manufacturing system. A major factor that will limit the performance of PACF in 3D printing is interlayer delamination and is exacerbated owing to the introduction of continuous fibres in this process [6].

2. Polymer composite feeder
In engineering thermoplastic, polyamide 6 (PA6) has mostly used in the automotive industry, electronic components, and mechanical parts [7]. In recent studies, the crystalline polyamide 6 (PA6) was modified by introducing amorphous polymer to prevent severe warpage so that it could be applied to FDM technology. Polyamide-6 (PA6) or can be called polycaprolactam have good mechanical and physical properties with it is a biodegradable and synthetic polymeric substance [8]. The effectiveness between matrix and reinforcement of continuous carbon fibre (CCF) reinforced polyamide was chosen in this study due to their superior mechanical properties. From previous studies, CCF tows were not a pure cluster of continuous carbon fibres. Specifically, CCF tows were found in continuous carbon fibre reinforced polyamide, contains 48 wt % pure continuous carbon fibres. Also, 3D printed were manufacture based on CCF with the temperature of the fibre and matrix nozzle was 270°C, while the printing speeds of the continuous carbon fibre reinforced polyamide (CCFRPA) was 15.8 mm/s. Besides that, the average CCF width was 1.2 mm [1].

2.1. Design compaction of PACF using CAD software
The process starts with a 3D model created with CAD (Computer Aided-Design) programs [9]. The designed part is exported to STL (Surface Tessellation Language) format. The sliced model was sent to a 3D-Printer and created as a physical part as Figure 1 below.
Figure 1. Schematic representation of the 3D printing process [10].

Fused Deposition Modeling (FDM) sometimes also called 3D printing technologies were used as a method in this study. A wide range of polymeric materials using this technology can be produced. Currently, fibre reinforced thermoplastic composites have become more important in this technique. The technologies consist of driving polymers of low melting point into a semi-liquid state and extruding them in a controlled way through the nozzle until the desired layers are deposited. Various printing parameters which includes of the height of the layer, printing pattern, placement of the part in the build plate, nozzle diameter, and infill density can be set in order to vary the quality, appearance, and mechanical behavior of the sample [10]. Figure 2 shows rectangular plates were produced in the xy plane which contains three printing architectures that differ in terms of bead orientation within the stacked layers. The samples were fabricated according to the printing parameters [11].

Figure 2. (a) Conceptual sketch of the FDM manufacturing process and (b) schematic representation of 3D-printed specimens with different printing architectures [6].

3. Characterization
Mechanical test of FDM-printed specimens on the tensile property was tested by using GT-7001-HC6, GOTECH TESTING MACHINE INC, Taiwan China at speed 2mm/min. A further test was observed on fracture surface by field-emission scanning electron microscope FESEM, QUANTA 450, FEI. Test specimens dimension of 250 × 15 × 1 mm (length × width × thickness) for the tensile test was followed ISO 527-5 [12]. In addition, the re-entrant honeycomb structure is subsequently manufactured, and the in-plane compression test is conducted at a constant strain rate of 2 mm/min [13].
Table 1. FDM printing parameter for PACF specimens [13].

| Parameter               | Value                  |
|-------------------------|------------------------|
| Printing speed          | 30 mm/s                |
| Infill density          | 100%                   |
| Nozzle diameter         | 0.4 mm                 |
| Printing raster angle   | 0°, 45°/-45°, 90°      |
| Layer thickness         | 0.15 mm                |
| Nozzle temperature      | 260 °C                 |
| Environment temperature | 22 °C                  |
| Built-plate temperature | 30°C, 55°C, 80°C, 105°C |

Since fiber orientation is directly related to the molten polymer of polyamide fluid during the printing, three-directional angles consist of 0°, 45°/-45°, and 90° are adopted as illustrated in Figure 3. Figure 3 shows the specimen was been produced according to the printing parameter of Table 1 and the build-plate temperature was 105 °C. It shows all three kinds of specimens have exhibit a flat surface. Less material agglomerates were observed due to a tendency of fewer flow rate fluctuations, and carbon fibre is well infiltrated in PA6 matrix. Along the printing direction, fibres tend to be distributed to the orientation, which may influence the tensile property. To acquire good mechanical properties in PACF composites, the effect of deposition path during 3D printing on tensile strength was investigated [13].

![Figure 3. PACF specimen with different directional angles [13].](image)

The interface adhesion between carbon fibre and polyamide was improved, which are beneficial for stress transfer from the matrix to fiber. In addition, a tensile strength of fiber-reinforced thermoplastics is also connected to distribution of fiber orientations [14]. When the tensile loading direction is parallel to the deposition direction, fibers can bear more loadings, achieving higher tensile strength and modulus [13]. When the printing direction along 90°, although fibers are still oriented along printing direction, they are perpendicular with tensile loading direction, which fails in carrying a load and thus result in decreased tensile property.

Polyamide-6 was characterized by Fourier-transform infrared spectroscopy (FTIR). Fourier-transform infrared (FTIR) spectroscopy is the most well-knowns methodology currently used for the identification and quantification of microplastics. Focal plane array–based μ-FTIR imaging gave a considerable decrease in analysis time and rise the accuracy of the results by impartial measurement of the entire filter surfaces [15]. FTIR was resulted on PA6 have a weak peak at 3060 cm⁻¹ on which represents a stretching vibration of crystalline hydrogen-bonded -N-H [16]. Flexural behaviors of 3DP-CCFRPA with different raster angles and stacking sequences, in different loading directions (parallel or perpendicular to the thickness directions of specimens) or namely as horizontal and
vertical were reviews. Note that 3DP-CCFRPA had three mutually perpendicular planes of symmetry. The intersection of these planes defines three axes that coincide with the 0° continuous fibre raster direction (X axis), the thickness direction (Z axis), and the width direction (Y axis) perpendicular to the other two [17]. 0° angle exhibit a higher flexural strength but compared to 45° and 90°. At 90° angle, flexural strength has lower flexural strength and lowest energy absorption among the other specimen [1].

4. Conclusion
In conclusion, the mechanical properties of polyamide reinforced carbon fibre (PACF) composite used in 3D printing method were review. Interlayer bonding on the specimen was influence by the printing parameter through the manufacturing process which affected their mechanical properties on the sample. Orientation and interlayer bonding are found to own a close relationship with the tensile properties of interlayer adhesion. In orientation, continuous fibers with 0° raster angle could effectively improve the bear-loading capability of composites. Besides, 0° to have a higher tensile strength according to their tensile property parallel to deposition direction. The flexural strength at 0° angle also shown have higher energy absorption among the other angles. Can be concluded, the bonding of polyamide reinforced carbon fibre at 0° angle have higher mechanical properties among the other raster angle of 45° and 90°.

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