A brief note on the mechanical properties and printing process parameter of bio-composites filament fused deposition modeling 3D printing

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ABSTRACT – The bio-composite filament of fused deposition modeling exhibits unique characteristics and behavior depending on its constituents. Hence, different composites with other fibers would have different mechanical properties and require different printing processes set up to produce acceptable printing qualities. In this study, a review of the different types of composites will be performed by focusing on their mechanical properties and printing quality. A review will be focused on the bio-composites filament prepared for fused deposition modeling. Several factors that influenced the mechanical properties of the bio-composites filament are dis-cussed. At the end of this review, the influence of printing process parameters on the mechanical properties of bio-composite printed parts will be discussed.

1. MECHANICAL PROPERTIES OF BIO-COMPOSITES FUSED DEPOSITION MODELING

Fused deposition modeling (FDM) is also referred to as fused filament fabrication (FFF), is a 3D printing technology that uses a long and continuous thermoplastic filament as a feedstock. The filament is fed from a big spindle through a moving, heated extrusion head and deposited on the growing work. The extrusion head moves in X, Y and Z-direction by following the tool path defined by the CAD file. The head usually travels in two dimensions to produce a horizontal plane or layer, and at one time, the printing work or head is moved vertically to establish a new layer. Printing process parameters such as printing temperature, printing speed, raster angle, infill density, and platform temperature can be controlled and set up based on the printability characteristics of the filament. Due to this flexibility, FDM is the most frequently utilized and rising rapidly fast prototyping in additive production technology [1]

The working principle of FDM includes the heat treatment on the filament due to the thermal extrusion process. Bio-composites that dominantly found from natural fiber-based composites. This type of composite has a limitation in processing the materials under high temperatures. The natural fiber could cause degradation and would shrink due to low thermal stability. Therefore, a good printing setup is required to avoid poor mechanical properties and affect the printing quality. Past researchers have conducted a few studies on the mechanical and printing quality of natural fiber-based composites. It has been found that the volume fraction of the fibers influences the mechanical properties of the bio-composites filament. Milosevic et al. [2] have found that hemp and harakeke reinforced filaments at 30 wt.% both gave tensile strengths of 34 MPa, an increase of over 51% compared with the 22 MPa ultimate tensile strength of unfilled polypropylene. Song et al. [3] have presented a work on treated macadamia composites filament where the composites showed good mechanical properties and were comparable with the pure PLA filament. Therefore, Sachini Wickramasinghe et al. [4] have suggested performing the material treatment in the preparation process of FDM filament as it will influence the mechanical properties of the FDM filament. Moreover, Le Duigou et al. [5] have innovatively developed continuous flax fiber composites that exhibit better tensile modulus and strength. The values are in the same range as those for glass fiber composite filament. The continuous composite was made from twisted flax yarn with better mechanical properties than short fiber composite filament. Hence, the mechanical properties of a bio-composites filament of FDM are also influenced by the shape of the fibers. On the other hand, Xiao et al. [6] have compared the mechanical properties of the hemp composites that are prepared through FDM and injection molding. They concluded that FDM printed hemp composites exhibited better mechanical properties than those prepared through injection molding.

2. PRINTING PROCESS PARAMETERS OF BIO-COMPOSITES FDM

The printing quality of the FDM printed parts is greatly influenced by the parameters and material characteristics of the printing process. Therefore, understanding the material characteristics and desirable mechanical properties of the printed parts is compulsory at the initial stage of the printing process. It can meet the design requirements and avoid any damages regarding material consumption, cost, time, and energy. Garzon-Hernandez et al. [7] have conducted a study to predict mechanical properties of FDM printed parts by using an experimental modeling approach. They found that to obtain good mechanical properties and quality of the printed parts, they suggested reducing the layer heights and set up longitudinal raster orientation. It is also agreed
by Tymrak et al. [8] where the \(0^\circ\)C raster could produce the highest tensile strength of the printed part. Therefore, a similar setup could be used in printing the bio-composite-based printed parts. Moreover, the infill pattern that set up before the printing process is significantly influenced the mechanical properties of the FDM printed parts. Ćwikla et al. [9] have suggested applying a honeycomb pattern to accelerate the printing time and increase the strength of the printed parts. In processing fiber-reinforced polymer filament through an FDM machine, there is a possibility to face agglomeration in the nozzle head and cause irregularities during the printing process. This situation significantly affects the quality and mechanical properties of the bio-composites printed parts. Therefore, in their study, Ping Cheng et al. [10] have suggested setting the parameter temperature as 220 \(^\circ\)C with 0.3 mm of layer thickness and 100 mm/min of printing speed to have optimum strength and good bonding between the layers of printed ramie/PLA composite. Le Duigou et al. [11] have performed a study on the continuous flax composites FDM. They found that the slicing parameters also have significantly influenced the mechanical properties of the bio-composites printed parts. They concluded that the reduction of layer height would reduce the layer thickness and decrease the percentage of porosity. The presence of porosity should be avoided. Therefore, the printing process and slicing parameters that set up for the bio-composites should produce lower porosity as it would exhibits better mechanical properties.

3. CONCLUSIONS

In conclusion, several factors have been identified in influencing the mechanical properties of the bio-composites filament and their printed parts. Bio-composites exhibited mechanical properties based on their constituents. Therefore, the fibers' volume fraction, treatment process, and shape possess a different range of strength and modulus of FDM filament. Suggestions have been made by past researchers where the optimum volume fraction is up to 30%. Chemical treatment is required to have good mechanical properties of the natural fibers. Moreover, continuous fiber composites prepared from twisted yarn fibers have excellent mechanical properties compared with the short fiber composites filament. On the other hand, the printing process parameter significantly influenced the mechanical and quality of the bio-composites printed parts. Adequate printing parameters, such as printing temperature, printing speed, infill pattern, raster angle, layer height, and thickness, could exhibit good mechanical properties and printing quality.

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