International Journal of Research Publication and Reviews

Journal homepage: www.ijrpr.com ISSN 2582-7421

A Review on the Mechanical Characteristics of Synthetic Fiber-Reinforced Thermoplastic Composites

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A B S T R A C T

Additive manufacturing is a flexible processing technique for producing complex part geometries using a layer-by-layer approach. Fused deposition modeling (FDM) is one such additive manufacturing method used to produce thermoplastic 3D-printed structures or parts. Various materials, including ABS, PLA, nylon, and others, are utilized in this process to create 3D components. Research in this area has focused on improving the properties of thermoplastic, leading to the development of numerous combinations of these materials with fiber reinforcements. The objective of this short review paper is to summarize significant research on thermoplastic composites reinforced with various fibers.

Keywords: Additive Manufacturing, Fused Deposition Modeling, 3D Print, Thermoplastic Materials, Fibers.

1. Introduction

Additive manufacturing is the process of assembling successive layers of materials to produce a desired three-dimensional product. Compared to other traditional subtractive manufacturing methods, additive manufacturing techniques may easily produce prototypes with complex geometry. The automotive, aerospace, and medical industries, among others, will adopt additive manufacturing technology. Thermoplastic prototype products are made using a variety of techniques, including stereo lithography (SL), selective laser sintering (SLS), fused deposition modeling (FDM), 3D printing, and laminated object manufacture (LOM).

2. Material based analyzing Processes

[1] Antonio Lanzotti et al (2019) aimed to gain deeper insights investigating the mechanical characteristics of items created through 3D printing using recycled and virgin polylactic acid (PLA). Initially, using virgin PLA filament, a collection of specimens was 3D printed and put through mechanical testing. These samples were then crushed into little pieces and put through another extrusion process using a handmade extruder to produce filament. The newly produced string was utilized to making a second set of samples, the second set of samples are also analyzed. A different recycling procedure was used in this study in order to evaluate how they affected the printed products' mechanical characteristics. The findings imply that using recycled PLA for 3D printing could be a practical and sustainable solution.

[2] Lin sang et al (2019) aimed to Create a polylactide (PLA) composite reinforced with basalt fiber (KBF) treated with KH550 as a feasible feedstock for 3D printing. In these investigations covered a range of physical properties, including thermal, mechanical, and rheological aspects, along with an assessment of feasibility of utilizing Poly Lactic Acid /KBF in 3D printing applications. One interesting discovery was that, in contrast to their casting counterparts, the KBF distribution in the 3D printed specimens was oriented-dispersed. The impact of complex viscosity on interlayer adhesion, PLA/KBF exhibited improved flexural capabilities and equivalent tensile properties when compared to carbon fiber reinforced composites with the similar weight portion. This highlights PLA/KBF's mechanical benefits. It is noteworthy, therefore, that an increase in the weight percentage and fiber length of KBF had a discernible effect on micro-defects and infill, leading to a decline in mechanical performance. The current study demonstrates that PLA/KBF is a mechanically improved, economically viable, and attractive feedstock for 3D printing applications, especially when dealing with intricate designs and variable size.

[3] Wenli ye et al (2019) discussed comes to 3D printing using thermoplastic polyimide (TPI), issues including low strength, foaming, and excessive printing temperatures can all be caused by TPI's high viscosity and water absorption properties. In order to get above these obstacles, an analysis was conducted on the water absorption of short-fiber TPI composites and pure TPI 3D printed filaments. A study was conducted to examine the correlation

between the tensile strength of 3D printed objects and the drying time of pure TPI filaments. Impacts of 3D printing factors, such as printing speed, layer thickness, and filling rates, on the tensile strength of 3D printed objects are also investigated in this research. The three types of TPI that were studied were separated continuous carbon fiber-reinforced TPI, original continuous carbon fiber-reinforced TPI (OCC), and pure TPI, both with and without continuous fiber reinforcement. The mechanical properties of TPI reinforced with continuous carbon fiber, both with and without continuous fiber reinforcement, were evaluated through research. The study found that SCC strengthened the interfacial bonding between the continuous carbon fiber and the TPI matrix and considerably increased the success rate of continuous carbon fiber-reinforced TPI 3D printing. Specifically, it was discovered that TPI reinforced with continuous carbon fiber had a higher tensile strength than OCC. When compared to pure TPI, the tensile and bending strength of the continuous carbon fiber and the TPI plastic matrix bonded strongly, yielding an impressive improvement.

[4] Xiaoyong Tian et al (2017) has been proposed Reprocessing and reusing of continuous carbon fiber reinforced PLA composites produced using 3D printing. Based on the 3D printing procedure, a fully recyclable continuous carbon fiber reinforced thermoplastic composite pattern was created and examined in this study. In addition to studying the mechanical performance of recycling and remanufacturing continuous carbon fiber reinforced thermoplastic composite patterns, the printed composite's microstructure and interfacial properties were examined. Because of its superior interfacial qualities, the recycled continuous carbon fiber filament has a higher tensile force than the filament that was initially produced. Remanufacturing composites are made from pure PLA and recycled carbon fiber impregnated filament as source materials. Comparing the remanufactured composite specimens to the original 3D printed composites, the flexural strength increased by 25%.

[5] Nanya Li et al (2016) continuous carbon fiber reinforced polylactic acid composite was created using 3D printing's rapid prototyping method. The printed samples either have carbon fiber pre-processed with PLA resin or not. Printed samples are carbon fiber and 98% of Polylactic acid resin prepared by continuous extrusion process. Without pre-processing of carbon fiber and PLA thermoplastic materials gets weak bonding between the interfaces and the pre-processing of carbon fiber gets strong bonding between the PLA resins. Methylene dichloride is used to pre-processing the carbon fibers. The electronic testing equipment and dynamic mechanical analyzer were utilized to measure the mechanical and thermodynamic properties of the printed specimen. The results of the experiment and analysis demonstrate that the bonding capacity of the carbon fiber and resin may be successfully increased by pre-processing the carbon fiber with a polylactic sizing agent. Tensile and flexural strengths of the modified or pre processed carbon fiber reinforced composites are greater than those of the original carbon fiber reinforced samples. The bonding contact between resin and carbon fiber is measured using a scanning electron microscope.

3. Process or Printing Parameters:

[6] Tianyun Yao et al (2019) focused on the ultimate tensile strength of FDM PLA materials at various printing orientations both theoretically and practically. The ultimate tensile strength of materials generated by Fused Deposition Modelling (FDM) in 3D printing has been studied in a range of technical and scientific applications, from biomedicine to aerospace. On the other hand, nothing is known about the mechanical characteristics of materials used in 3D printing. to make the design and mechanical analysis of 3D printed structures easier. First, a theoretical model based on the transverse isotropic hypothesis, classical lamination theory, and the Hill-Tsai anisotropic yield criterion was created to forecast the final tensile strength of FDM PLA materials. Tensile measurements were then used to validate this theoretical concept. Interestingly, this model provided two different in-plane shear modulus calculation techniques, which improved the accuracy of the results. Specimens for the experimental portion were created using the ISO 527-2-2012 standard for test specimens with several purposes made of plastic. These samples were 3D printed with three distinct layer thicknesses (0.1 mm, 0.2 mm, and 0.3 mm) at seven different angles (0°, 15°, 30°, 45°, 60°, 75°, and 90°). The model's capacity to predict the ultimate tensile strength of FDM materials for different angles and thicknesses was confirmed by comparing the theoretical and experimental results, which showed a near alignment. Moreover, it was shown that the ultimate tensile strength dropped with increasing layer thickness or decreasing printing angle. This experimental methodology and theoretical model can also be used to other 3D printing materials made with FDM or Stereolithography (SLA) processes.

[7] Aboma Wagari Gebisa0F et al (2019) has explored the impact of FDM process parameters on the tensile properties of ULTEM 9085 material. A new digital manufacturing method called 3D printing creates things layer by layer. The process of creating components using fused deposition modeling (FDM), a popular 3D printing technology, involves heating, extruding, and depositing thermoplastic polymer filaments. Processing factors have a substantial impact on the qualities of parts generated by FDM; these parameters have trade-offs that should be investigated. Examine how process variables affect the tensile characteristics of FDM-produced components in this research, with an emphasis on high-performance ULTEM 9085 polymeric materials. This study examines the effects of five important parameters, including air gap, raster angle, contour number, and contour width, using a full factorial design of experiments. Interestingly, the raster angle showed the biggest impact. A limited tensile strength was recorded at lower levels of this parameter, whereas a tensile strength was observed at the greatest level of this parameter.

[8] M.Heidari-Rarani et al (2019) have studied Mechanical evaluation of continuous carbon fiber reinforced PLA composites printed using FDM technology. Fiber-reinforced composite additive manufacturing is significant for a variety of industrial applications. This paper reports on the development of a novel extruder for continuous fiber-reinforced thermoplastic composites that is specifically suited for Fused Deposition Modelling (FDM) 3D printers. In order to produce high-quality composite parts, the project faces a number of difficulties, such as achieving the right fiber tension, prepping the fibers surfaces, calibrating the printing temperature, and adjusting the feed rate. These difficulties are thoroughly examined. This extruder's ability to work with current FDM 3D printers eliminates the need for a thorough redesign of the printer's chassis, which is one of its main advantages. Standard tensile and three-point bending specimens made of both pure poly lactic acid (PLA) and PLA reinforced with carbon fiber are printed and put through quasi-static mechanical testing in order to assess the quality of the created goods. The efficiency of the technique is demonstrated by the experimental results, which show significant improvements in the tensile and bending properties of the PLA. Additionally, morphological examination is performed to examine the

bonding between PLA and carbon fiber. This new method creates continuous carbon fiber-reinforced Poly Lactic Acid composites by integrating a newly designed extruder into a traditional FDM 3D printer. By using the "Embedding Component" technology, the extruder makes it possible to extrude long fiber reinforcement and a thermoplastic matrix at the same time. A great deal of experimental testing is done to optimize important parameters such as the optimal carbon roving diameter, the simultaneous injection of molten polymer and fibers, quick post-deposition cooling with a cooling fan, and improving fiber-to-matrix adhesion using a Poly vinyl alcohol solution. The results of the experiments show that continuous carbon fiber-reinforced Poly Lactic Acid composites have tensile and bending strengths that are up to 35% and 108% higher, respectively, than pure PLA. The efficiency of using poly vinyl alcohol for fiber surface preparation is supported by morphological study. In continuous carbon fiber-reinforced Poly Lactic Acid composites, de-lamination and de-lamination-induced matrix cracking are the most common failure mechanisms found.

[9] Shuting Liu et al (2018) have studied A new free-hanging 3D printing technique for thermoplastic lattice truss core constructions reinforced with carbon fiber that is continuous. This printing that hangs freely path generation strategy, enabling the fabrication of intricate truss structures with overhangs and undercuts without the need for external supports. Lattice truss core structures composed of continuous fiber reinforced thermoplastic (CFRTP) hold significant promise in aerospace engineering due to their expectation weight reduction efficiency and multifunctional applications. The authors effectively create a variety of lattice topologies, including intricate structures like integrated variable-thickness wings, by expanding on the hangs freely printing technique. A thorough analysis is conducted of the cross-sectional morphology of the samples made with this technique. To clarify the relationship between these process factors and the out-of-plane compressive qualities of the constructions, the analysis is expanded to include parameters such relative density, fiber volume content, and truss angle. When compared to the theoretical geometry, the experimental results show an impressive degree of precision, with an average structural error of about 1.89%. Moreover, the specific compressive strength of the free-hanging printed samples exhibits competitive performance when compared to existing CFRTP lattice structures documented in the literature. Notably, the compression strength of the printed samples significantly exceeds that of their counterparts made of pure thermoplastic resin, recording a 224% increase.

[10] L.G.Blok et al (2018) have investigated Fiber-reinforced thermoplastic composites printed in three dimensions. With Fused Filament Fabrication (FFF), thermoplastic material is deposited through a nozzle throughout the 3D printing process, allowing items to be constructed gradually, layer by layer. This technique allows for a degree of design freedom that is superior to that of typical manufacturing procedures, enabling the development of complex and distinctively formed products. However, the intrinsic mechanical characteristics of the thermoplastic materials used in FFF frequently don't match those of typical engineering materials. In order to improve the strength and stiffness of the material, carbon fibers are incorporated into a thermoplastic matrix to create composite printing feed stocks for FFF, which are the subject of this study. The study begins with an overview of the basic processing parameters for FFF, elucidating how the addition of fibers affects the dynamics of printing by changing the viscosity of the material and the heat profiles. Presenting the state-of-the-art in composite 3D printing, the study differentiates between feed stocks with short fibers and feed stocks with continuous fibers. An experimental investigation was carried out to assess these techniques. The findings show that compared to unreinforced thermoplastics, printing continuous carbon fibers with the Mark One printer produces noticeably better performance. The mechanical characteristics attained are comparable to those found in ordinary unidirectional epoxy matrix composites.

4. Conclusion

The collective review studies demonstrate substantial progress in enhancing the mechanical performance, structural integrity, and application potential of thermoplastic composites in 3D printing through advancements in material selection, reinforcement strategies, recycling processes, and manufacturing innovations. Research on recycled and virgin PLA (Lanzotti et al., Tian et al.) confirms that recycling can preserve or even improve mechanical properties, promoting sustainability in additive manufacturing. Basalt fiber reinforcement (Lin Sang et al.) offers a cost-effective alternative to carbon fiber, with significant flexural gains when optimally processed. Improvements in thermoplastic polyimide (Wenli Ye et al.) and pre-processed carbon fiber composites (Li et al.) reveal that careful fiber treatment and interfacial bonding optimization yield notable tensile and flexural strength enhancements. Studies on FDM process optimization (Yao et al., Gebisa et al.) show that parameters such as layer thickness, raster angle, and print orientation significantly influence tensile performance, enabling predictive modeling for design efficiency. Continuous carbon fiber integration via custom extruders (Heidari-Rarani et al.) and innovative printing strategies like free-hanging lattice fabrication (Liu et al.) expand structural capabilities, producing lightweight, high-strength components suitable for aerospace and automotive sectors. Investigations into fiber-reinforced thermoplastic feed-stocks (Blok et al.) confirm that continuous fiber-reinforced thermoplastics can match or exceed the performance of conventional composites, though some design limitations remain. Overall, the synergy of optimized materials, reinforcement methods, recycling, process parameter control, and advanced printing techniques positions fiber-reinforced thermoplastic composites as high-performance, economically viable, and environmentally sustainable solutions for demanding engineering applications in diverse industries.

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