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3D printing application of PLA thermoplastic bio composites-A brief review

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ABSTRACT

One of the renewable thermoplastic polymers is polylactic acid (PLA)-based composites, which are preferred over non-biodegradable plastics due to their biodegradability. PLA must find a home in a variety of applications such as polymer composites, biomedical, automobile, electrical, agriculture, and so on. Polymer composites based on PLA have desired properties such as mechanical strength, flexibility, endurance, and high durability. Several natural fibre and filler-based PLA composite combinations have been created and tested for physical and mechanical properties. The PLA composites and production that would be employed in additive manufacturing (AM) applications in many industries. AM processes like stereolithography (SLA), powder-liquid 3D printing (PLP), fused deposition modelling (FDM), electron beam melting digital light processing (DLP), and selective laser sintering (SLS) are fabricating the thermoplastic product. The most common AM process is FDM, which has gained popularity recently for producing unique parts with complex shapes, particularly thermoplastic products. It is well accepted that due to its crucial advantages, it can replace hazardous synthetic materials. Bio-based polymer composite matrices have garnered more attention recently than typical thermoplastics. Current advancements in biomaterials-based FDM printing are highlighted in this review in this context. The exploration and presentation of existing bio-based composites, which are composed of either bio-derived filler or polymer matrices, have been performed in an effort to make 3D printing sustainable. All of the effects of fillers on FDM-based products and filaments, the development of novel bio composites properties, the printability of the developed composites, and their various industrial applications were examined and summarised.

KEYWORDS:3D printing, biodegradable, PLA, Filler, Reinforcement, biocomposite, thermoplastics

1. INTRODUCTION

In the last few decades, additive manufacturing (three-dimensional printing) has developed in the design and fabrication industries due to its versatility and low operating costs for speedy prototyping. Using the direct digital manufacturing process, it can successfully build a wide range of 3D products with complex geometries [1-4]. The key benefits of AM process include the ability to create customised, complex, and prototype models without the use of tooling, less production time, less material wastes, and reduced prices [5-7]. As a result, the huge demand for functional items motivates researchers to develop novel materials ideal for FDM. ecause of its biodegradability and environmental friendliness, PLA is the most often used raw material in the FDM-based 3D printing technology. However, the use of pure PLA polymer in the FDM technique is limited due to drawbacks such as mechanical weakness, less thermal conductivity, and water solubility rate. On the other hand, PLA composites made with the right AM process have been suggested as a way to improve the quality of PLA parts made with the FDM process [8, 9].

Numerous researches on the applications of the FDM technique, as well as the usage of pure PLA polymer in 3D printing, have been published [10-14]. However, there is a shortage of a review article on the use of innovative natural reinforced PLA polymer composite filaments in 3D printing process. Moreover, the primary preparation methods for obtaining the PLA composite filaments that will be utilised as a raw material in 3D printers. Also, there has never been a review of how the use of filler and bio filler PLA composites in the various industry has improved the properties of 3D-printed product. This review will fill that gap.

In this research, we will focus on the fabrication methods for PLA composites and investigate their mechanical and thermal properties. The future raw material of filler reinforced PLA composite filaments that will be utilised in FDM-based 3D printers will be introduced. Finally, the important uses of the novel PLA composites developed with extrusion-based 3D printing technique will be presented.

2. 3D PRINTING ADDITIVE MANUFACTURING PROCESS AND PLA COMPOSITES

FDM PROCESS

Fused deposition process, is a material production process that is formed via single layer by layer contour superposition. The solidified material will then circulate through the two-dimensional filling and layer-by-layer superposition to generate 3D entities. It uses a nozzle to squeeze molten wire into the layered model deposited [15, 16]. FDM process technique has the following advantages over other 3D printing technologies: it is low cost and to melt the raw material, the FDM moulding method employs a resistive heater. Figure 1 shows the typical schematic view of FDM process. When compared to laser-powered equipment, it causes no damage to the structure. The equipment and maintenance are simple, and the technical operation costs are low. FDM technology is widely used in the field of mould creation and manufacturing because to its low cost and easy and quick operation performance. 2) Materials with specified bonding qualities that can melt through this equipment can meet the application requirements. At the moment, majority of plastic materials with low melting points, such as PLA, ABS, PC, PCL, PETS and nylon, are widely used in the production of plastic parts [17-21]. It can be designed by below-mentioned method showing how filament biocomposite material will be developed, as shown in Figures 2.

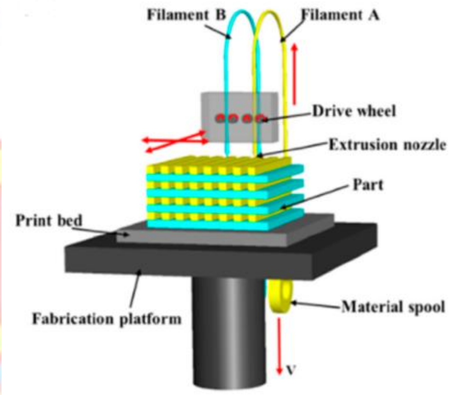

Figure 1 Typical schematic view of FDM process [1]

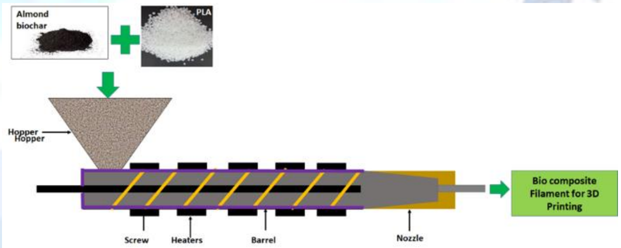

Figure 2 Fabrication of biocompositefilament by the extruder

3. 3D PRINTING PROCESS-BASED PLA BIO POLYMER COMPOSITES

The primary natural-based raw material for 3D printing is polylactic acid, a thermoplastic aliphatic polyester. It's a biodegradable thermoplastic polymer made from renewable basic ingredients [22, 23]. The fundamental advantage of PLA over ABS is that it does not require a heated substrate while printing; thus, PLA may be manufactured at low temperatures ranging from 190 to 230 degrees Celsius [24]. PLA does not require substantial post-processing because it may be acetone-treated or sanded as needed, and the supports are typically easily detachable. PLA is one of the most widely used materials in additive printing. It is also one of the most commonly utilised materials in 3D printing. PLA has the advantage of being one of the easiest materials to print, despite the fact that it tends to shrink slightly after 3D printing [25]. Figure 2 shows that typical 3D printing bio composite fabrication process.

Fiber-reinforced PLA polymer composites were fabricated using fused deposition moulding and die casting moulding to investigate the mechanical and structural properties of the polymer composites. Despite their larger porosity, FDM printed composites offer higher tensile strength and modulus than typical die-cast composites, which are determined by the orientation and dispersion of PLA fibres. Also, the found that FDM products' tensile strength and elastic modulus were improved, and the FDM fibres in the composites were more aligned. Chizari [26]. A PLA nanocomposite containing 40% by weight of carbon nanotubes (CNT) was manufactured. The study concentrated on the application of 3D printed conductive materials in smart sensors for textile or electronic applications. Y Tao [27] fabricated PLA reinforced wood floor polymer composite through FDM process and physical and thermal study was examined. From that analysis, it was determined that PLA composites bending resistance was enhanced, the initial thermal degradation temperature was marginally reduced, and the melting temperature remained same.

Torres et al. [28] investigated the effect of manufacturing factors on the mechanical characteristics of PLA specimens created with FDM. High density and high layer thickness were revealed to be the two most important characteristics that determine tensile strength. It was also discovered that higher temperatures increase strength by improving layer cohesion. The result revealed that in order to save material by using low density or infill settings, the perimeter layers can be increased to boost the overall strength of the component.

The electrical, thermal, and electromagnetic properties of different weight percentages of 3D-printed PLA-MWCNTGNP nanocomposites were examined. Shielding efficiency was shown to be higher (26-37 GHz) compared to the neat PLA. Furthermore, PLA with GNP (12 wt.%) was shown to have much greater thermal conductivity than plain PLA. Also, the thermal conductivity of the MWCNTs and the PLA matrix loaded with both fillers and polymer composites was found to get a little bit better [29]. Another study on the mechanical and thermal properties of microwave-heated PLA composites used SiC-coated PLA filaments. When compared to clean PLA, PLA-SiC composites demonstrated better temperature rise qualities and temperature distribution following microwave heating. The tensile strength and stress increased due to re-melting at the interface of the 3D-printed samples and reinforcing the interface bonding [30].

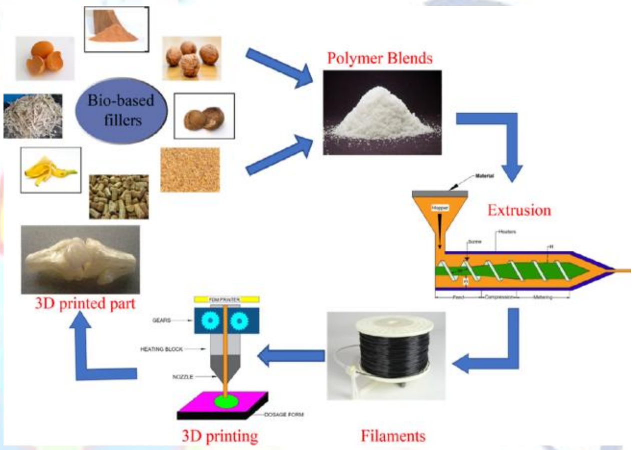

Figure 2 Typical 3D printing bio composite fabrication process [4]

4. Characterization and Various Fabrication Method of PLA Polymer Composite

Various techniques are used to manufacture PLA polymer composites, depending on the nature of the reinforcement and the type of composite to be prepared. For example, if the reinforcement is of the filler type, a twin-screw extruder and injection moulding are employed [31]. Natural fillers such as carbonates, bio waste filler, shell filler, wood flour, and silicates are enhanced in this technique. A compression moulding machine is used in the production of fibre mat. Hemp, kenaf, sisal, coir, wood, carbon, and other natural and synthetic fibres can be reinforced with PLA through compression processes. Both techniques include the provision of a heating element to melt the PLA pallets. The temperature range of heating elements is typically maintained between 170-185o C. PLA blends with other biopolymers such as polyethylene glycol (PEG), poly (hydroxy acid) (PHA), thermoplastic dry starch (DTPS), natural rubber (NR), poly (butylene succinate) (PBS), ethylene-vinyl-acetate (EVA), polycaprolactone (PCL), and poly (hydroxy butyrate) have frequently been created to offer stiffness (PHB) [32]. Melt blending, in which polymers are mixed and spun in a beaker, is used to form these mixes. Injection moulding, also known as melt screw moulding, has several advantages over other production processes like as compression moulding, hand lay-up, vacuum bag moulding, resin transfer moulding, and so on. Injection moulding and melt screw moulding, for example, have minimal operating costs, specimens for particular dimensions can be created directly by utilising a die at the exit, and advanced materials are simply fabricated.

5. Filler reinforced PLA polymer composite

Filler particulate acts as a high-impact load absorber, thermal resistance, and high-ductile in the polymer composites. Song [33] fabricated a wood filler/PLA wood-plastic composite using wood filler (WF), a environmentally friendly and biodegradable. When the wood filler concentration was 50% (mass fraction), the tensile strength of the composite rose by 10 MPa when compared to pure PLA. Particle addition improved mechanical properties by a particular percentage, which decreased further as particle content in the samples increased. The sample has a maximum tensile strength for groundnut shell particle reinforcement of 40% by weight [34]. The crystallisation rate and durability of PLA by combining it with polycarbonate while retaining PLA's degradability. The natural filler-reinforced PLA polymer composite is summarised in Table 1.

Most ecommerce companies have their receive to pay process as predominantly manual, leading to non-reliability of payments & delayed visibility for sellers and requirement of additional manpower for scaling up for buyers. For a seller this involves high turn around time to know the money that the buyer is going to acknowledge. This in turn leads to reduction in time to respond to any deductions without impact to payment for the invoice and unpredictability in working capital planning.

Manual invoice processing forces a buyer to scale up in operations which in turn require scale up in manpower. Manual processing ensures that the cost of processing per invoice is high while being error prone.

The system will determine the viability of different image processing techniques to obtain all relevant information from the document and determine their accuracy.

Most ecommerce companies have their receive to pay process as predominantly manual, leading to non-reliability of payments & delayed visibility for sellers and requirement of additional manpower for scaling up for buyers.

6. Bio char filler reinforced PLA polymer composite

Specifically, the biomaterial is a viable option for such harsh environment applications. It can be designed by below-mentioned method showing how biochar composite material will be developed. Fillers used in the proposed project are almond shell, and peanut shell biochar. Biochar filler composite's concentration will vary from 5% to a higher percentage. BC is created by thermochemical cracking of biomasses via three major routes: hydrothermal liquefaction, pyrolysis, and gasification. Hydrothermal liquefaction is a thermochemical process that occurs at temperatures up to 350 degrees Celsius in a water medium under moderate pressure. This method enables advanced depolymerization of biomass, resulting in highly functionalized BC known as hydrochar [45]. Proper pyrolytic processes occur at temperatures greater than 400 degrees Celsius in an oxygen-limited [46] or inert environment. It is possible to achieve a fast and advanced cracking process for each biomass component, such as cellulose, lignin, and hemicellulose, while also producing BC, non-condensable gases, and bio-oils at the same time [47] by using the pyrolytic approach. Poulose et al. [48] Explored the effects of date palm biochar filler on the mechanical, dynamic mechanical, electrical, and thermal properties of polymer composites. They found that adding biochar enhanced tensile strength and electrical conductivity. Qian et al. [49] Studied the characteristics of PLA-based composites that had bamboo biochar added to them. Compared to pure PLA, the biochar-added composites demonstrated improved tensile, ductile, and flexural properties. The author found that when the addition of 30% biochar obtained the maximum tensile strength and tensile modulus. Zhang et al. [50] Examined bamboo biochar filled polymer composites for mechanical properties. The resultant dispersion property and interfacial bonding between filler and matrix were improved. Furthermore, due to the fine biochar filler, it was found that the tensile and impact strength were significantly improved.Sundarakannan et al. [51] Investigated on mechanical properties of cashew nut shell biochar reinforced polyester polymer composite with varying biochar concentrations of 5, 10, and 15 wt%. Compared to unfilled composite, 10% biochar filled composite enhanced the maximum tensile, hardness, flexural, and impact strength.

Table 1 Works on Natural filler reinforced PLA polymer composite

Authors	PLA various natural fillers reinforcement	Fabricating methods	Properties evaluation	Conclusions
Stoof et al. [35]	Pine apple flour cassava flour, and ash filler.	Twin screw extruder	Mechanical properties	Mechanical characteristics of PLA improved up to 30% for both cassava and pine flour reinforcement, but began to decline as reinforcement weightage reached 40%.
Oktay et al. [36]	Nanometric and micrometric cellulose filler	Solvent casting	Tensile strength	Nanometric filled PLA composite has a higher young modulus and tensile strength than micrometric filled PLA composite.
Oktay et al. [37]	Starch, cellulose fiber filler	Hot compression moulding	Tensile strength	When compared to foam without PLA, the foam with 9% PLA demonstrated the greatest improvement in tensile strength, with a 31% increase.
Khan et al. [39]	woven jute fabrics	hot press moulding process	tensile strength, flexural strength, and impact	Mechanical strength increased the when addition of jute fiber
Wang et al. [40]	Benzylated treated rice straw and nano clay filler	Solvent casting		The strong molecular contact between fibre and PLA, the crystallinity of PLA increased slightly.
Zandi et al. [41]	Rice straw filler	Twin screw extruder	Thermal property	The addition of rice straw to PLA resulted in reduced glass transition and melting temperatures. Composite deterioration occurs early on.
Kuciel et al. [42]	Basalt fiber and wood flour filler	Twin screw extruder	mechanical properties	The mechanical properties of PLA did not increase with the addition of basalt fibre, but rather worsened with the addition of wood filler.
Yussuf et al. [43]	Kenaf fiber and rice husk filler	Injection moulding	Flexural and impact properties	Flexural property increased to addition of Kenaf fiber and rice husk filler.
Lee et al. [44]	Wood flour filler	Twin screw extruder	Mechanical and thermal properties	PLA's thermal stability improved while its crystallinity decreased.

Jayabalakrishnan et al. [52] Studied coconut shell biochar filler effects on epoxy resin composites' mechanical, dielectric, and thermal properties. They found that containing 5% biochar has a maximum tensile modulus and strength of 6.7 GPa and 172 MPa, respectively. Furthermore, a composite produced with 7% biochar had the highest dielectric constant and loss factor of 6.2 and 1.6. The addition of particles enhanced the mechanical characteristics by a certain percentage, which reduced further as particle content in the samples rose. The sample has a maximum tensile strength for 40 weight percent groundnut shell particle reinforcement [53].

7. PLA COMPOSITES 3D PRINTING APPLICATIONS

This section will present 3D printing applications of PLA composites in nine sections to help readers determine their options. Biomedical, tissue engineering, biodegradability, and bio-printing applications are all part of the health business. Electrical, electromagnetic, sensor, battery, and photocatalytic cell applications are all part of the electromechanical system industry. Mechanical engineering is significantly used in automotive and space applications.

Automotive applications

It has been argued that the use of 3D printing technology in the automotive and aviation industries will significantly cut the time necessary for tooling and the cost of producing prototypes. Polyamide is the most commonly utilised polymer in 3D printing in these industries due to its crystallinity's appropriateness to create better functional properties such as mould shrinkage, as well as its chemical, wear, and temperature resistances [54] [8]. However, there have been numerous experiments in which PLA composites have been employed for this purpose. For example, PLA-flax fibre composites with 30% and 40% flax fibre content by weight were created using a twin-screw extruder. The mechanical properties of PLA-flax fibre composites were found to be suitable for usage in car panels, although the inclusion of plasticizers had no influence on the impact strength of the samples [55].

Applications of Electrical Conductivity

The low-cost manufacture of highly conductive micro- or nano-flexible circuits is a critical goal in the electronics industry. For this objective, polymer-graphene and polymer-other carbonaceous material composites were employed. PLA was utilised as the matrix polymer in 3D printing on occasion. Conductive 3D microstructures, for example, were created utilising PLA-multi-walled carbon nanotube (MWCNT) dispersion composites as raw material [56]. PLA was melt-mixed with carbon nanotubes (CNT) and graphite powder after 3D printing to create polymer composites with strong thermal and electric conductivity. But PLA-based CNT polymer composites could be used to change the thermal conductivity of PLA-G composites. Adding a small amount of CNT to PLA-G composites increased the thermal conductivity by at least 40%. [57]. By changing the MWCNT and PLA concentrations, rheological and electrical conductivity behaviour on these nanocomposites were done to identify the printability and ideal processing conditions. Many nanofillers have also been attempted in order to improve their characteristics [58].

Electromagnetic Applications

To make low-cost composite antennas, PLA components can be painted using conductive paints. Highly conductive polymer nanocomposites can help with electromagnetic interference (EMI) shielding, microwave absorption, and antenna applications. For example, 3D printing was utilised to build PLA-ABS composite structures for microwave metamaterials [59]. An all-fiberized and low-cost 3D-printed PLA-graphene composite saturable absorber was designed for the ultra-fast mode locking of a fibre laser operating in the 1.9 wavelength region [60]. A comparable study investigated the electromagnetic absorption capacities of PLA-graphite nanoplatelet (GNP) composites in microwave and terahertz frequency ranges after they were 3D-printed. The complex dielectric permeability of PLA-GNP composites was modelled using Maxwell-Garnett theory. The PLA matrix's combination of conductive and geometric GNP properties allows the composite to absorb THz frequencies below the perforation threshold. [61]. The influence of parameters such as fibre spacing, layer count, and printing patterns on transparency and EMI shielding efficiency was investigated using 3D printing to build conductive scaffold microstructures of PLA-CNT nanocomposites. 3D-printed PLA-CNT nanocomposites were shown to have significantly better EMI shielding efficacy than hot-pressed PLA-CNT samples [62]. Figure 3 shows that typical printing process with poplar/PLA composites. Figure 4. shows the biomedical application of poly lactic acid.

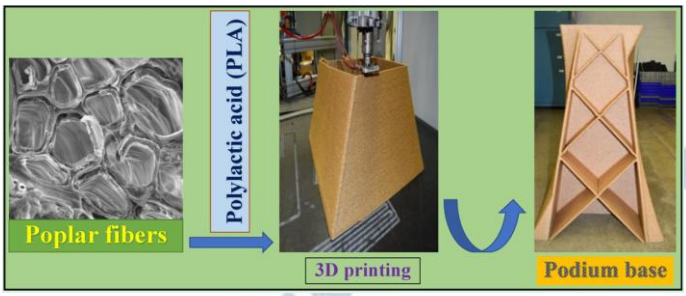

Figure 3 Typical printing process with poplar/PLA composites [63]

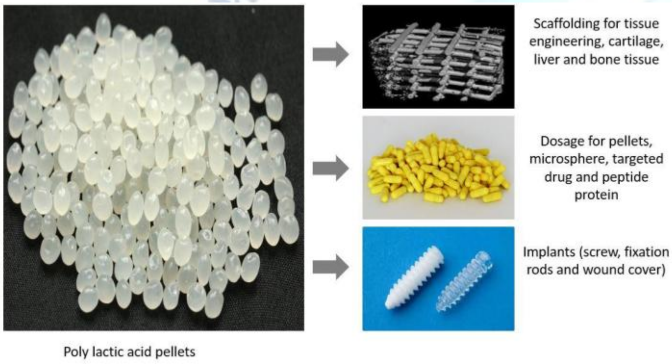

Figure 4. Biomedical application of poly lactic acid [64]

8. Conclusions

Polylactic acid (PLA) is the most extensively used raw material in extrusion-based three-dimensional 3D printing in a number of fields because of it is biodegradable and environmentally acceptable. The requirement for preparing PLA composites for use in 3D printing applications in many industries was investigated, as were PLA composite production processes. 3D-printed PLA composites are typically manufactured in two processes. The first step is to use melt extrusion to make filler and fibre reinforcement for PLA matrix polymer composite feedstock filaments (or solvent precipitation). Second step: filaments or composite filaments are then used in an FDM-based 3D printer under controlled circumstances, such as nozzle temperature, raster angle, layer thickness, raster width, polymer flow rate, and temperature level, to make the desired 3D print. The temperature of the printing nozzle, as well as the history of surface orientation, are critical in defining the adhesion strength between the printed layers, which influences the total mechanical strength of the material.

The biomedical industry was identified to be very important fields for the usage of 3D-printed PLA composites since 3D printing can manufacture biodegradable specific body parts for personal use that will not harm the body. The medical field's utilisation of 3D-printed PLA composites is rapidly developing, and numerous helpful implants and restorations have been developed in the recent decade. Furthermore, 3D-printed PLA composite prototypes are used in the training of surgeons, researchers and medical students. The use of PLA in bioprinting is a novel and essential area of research. However, many issues in the medical industry remain unaddressed. For example, obtaining the appropriate mechanical strength for 3D-printed PLA things in the body is always a difficult challenge. Controlling the rate of degradation and the effective pore size of the scaffolds are also issues, particularly for bone applications.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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