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Compressive Property Examination on Poly Lactic Acid-Copper Composite Filament in Fused Deposition Model – A Green Manufacturing Process

[1]M.Venkata Pavan and [2,*]K. Balamurugan

[1]Research Scholar, Department of Mechanical Engineering, VFSTR (Deemed to be University) Guntur, AP, India. E-mail: mvpavan27@gmail.com
[2]Department of Mechanical Engineering, VFSTR (Deemed to be University) Guntur, AP, India. E-mail. kbalan2000@gmail.com.

Abstract

To build complicated and instinct shape 3D printing technology which can also called as green technology has been widely used among them Fused Deposition Model (FDM) has its advantages. To have improved properties, composite filaments are fabricated with metal as reinforcement in the PLA matrix. Composite filament with 12% of copper as reinforcement was successfully fabricated through the hot extrusion process. To measure the compressive strength of the fabricated filament, it is printed to the ASTM D695-15 at different machining conditions. The effect of each printing parameters on density and compression strength are evaluated to understand the effect of compressive load at different printing conditions. The high-density samples are obtained at a low-level layer height. Increment on building temperatures import brittle property and give raise to have high compressive load withstanding capacity. Displacement to compressive load is in the range of 6 mm to 10 mm.

Keywords: Fused deposition model, Composite Filament, PLA-CU, Printing Parameters, Compressive Strength

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1 Introduction

Today in the modern world the development of manufacturing process with least environmental degradation can be called as green technology in this regards, 3D printing technology, a green technology was classified as an additive manufacturing process that allows the material to built layer by layer to create a model. Poly Lactic Acid (PLA) was the most commonly used material in 3D printing technology. Fang et al [1] stated the importance of Fused Deposition Model (FDM), as the FDM techniques were proven to be a suitable technique to fabricate complicated components and find the applications in several engineering areas such as Xin et al [2], electrical chemical storage systems, Nenad et al [3] wood industry, etc. Tuan et al [4] listed the advantages of FDM in various engineering areas likely as Design freedom, mass optimization, waste reduction and to print any complex structures, build of prototype models, etc. Song et al [5] comparative studies of FDM and Injection molding revealed that FDM printed component exhibits better toughness property.

Modernized technologies made a revolution to the development of new methods and equipment to fabricate the composite filament. For example, Carola et al [6] prepared hydroxyapatite polymer-based filament for medical applications, Xiaojun et al [7] printed using Graphene Composite thermal applications, Gnanasekaran [8] prepared CNT and graphene-based conductive polymer nanocomposites for the electrical application using FDM, etc., a likely number of research works are being carried out to meet the engineering trends. Najera et al [9] used ceramic elements was filler elements with PLA to form a composite filament and a porous structure was built using FDM for a typical bone replacement in medical application. Miguel et al [10] confirmed that the orthotropic characteristics will be observed in additive manufacturing based FDM techniques was due to fused filament fabrication and this results in a change of mechanical behavior on the sample. Hence proper studies on the 3D printed samples are to be done before defining the applications.

According to Sheikh et al [11] reinforcement of metal powders with the PLA as the matrix has been gain interest because of capable of any instinct and complicated shapes. Manoj et al [12] stated that nano copper particles were found abundant on earth as natural materials and it can be easily synthesized through the chemical route also, its property makes it a suitable material for various engineering applications. Ahamad et al [13] prepared 3D printed samples with copper as reinforcement and conducted sintering to convert copper into copper oxide semiconductor to produce a 3D semiconductor that was sensitive to light, pressure, and temperature.

Tianyun et al [14] studies on the effect of the raster angle concluded that 45^o printer samples exhibit the even distribution of load irrespective of the applied load and had yielded the excess load withstanding capacity. Shilpesh and Harshit [15] through the experimental study on fused filament fabricated PLA components confirmed that the layer height and the raster angle have a significant effect on the mechanical strength of the printed samples. Hui et al [16] projected that in FDM printed layer height predominantly determines the strength of the sample. According to Chacon et al [17], the ductility of the materials will decrease with the increase of layer height and feed rate.

2 Materials and Methods

Systematic experimental arrangements are shown in Figure 1 and are used to fabricate customizable composite filament with 12% copper powder that has a particle size of 30 to 50 µm with the PLA matrix. Commercially available PLA pellets and copper powder are procured from Coimbatore metal and polymers supplier, Coimbatore, India. PLA pallets are grounded to a fine powder and 12% weight percentage of copper was blended for 24 hours. The powders are allowed into the Hopper where they are heated to 190 degrees Celsius and moved through screw conveyor. The filament of 1 mm is rejected through a special design die. The film is water cold and rolled on a circular disc and now the filament is ready for printing. Initial investigations like density, porosity, and melting of filament are conducted on the sample to evaluate is a property all the available filament.


(a) PLA billet


(b) Copper powder

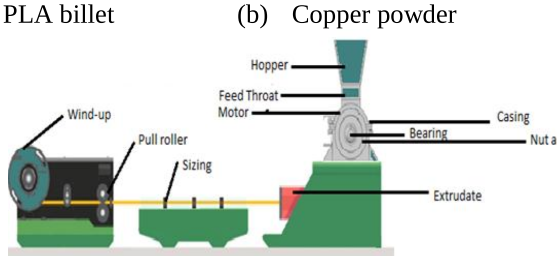

Figure 1 Experimental arrangement for filament preparation

The fabricated filament is printed to the ASTM D695-15 at different printing conditions. Three significant printing parameters such as nozzle temperature, bed temperature, and layer height are taken as the independent parameter. Each parameter has three levels of printing conditions. Considered printing parameters and it's three levels as shown in Table 1.

Table 1 Printing parameters and levels

Exp. No.	Nozzle temperature (Deg)	Bed temperature (Deg)	Layer height (mm)
L1	190	50	0.10
L2	190	60	0.14
L3	190	70	0.18
L4	210	50	0.14
L5	210	60	0.18
L6	210	70	0.10
L7	230	50	0.18
L8	230	60	0.10
L9	230	70	0.14

The fabricated filament is printed according to the table shown and the compressive property of the fabricated filament is examined through universal tensile tester that has the maximum load of 5 tons and the load is applied at the gear rotational speed of 1.25mm/min. the experimental set up with the test samples are shown in Figure 2.

Figure 2 Experimental arrangements for compression test

3 Results and Discussion

3.1 Density Measurements

Density is one of the major factors that have to be considered before compression testing. The density of each sample printed at different operating conditions is measured through the traditional Archimedes principle. From the observation, it is clear to infer that layer height predominantly determines the density of the composite filament. Experiment name L1, L6 and L8 have produced a high density of around 3.5 grams/cc^3.

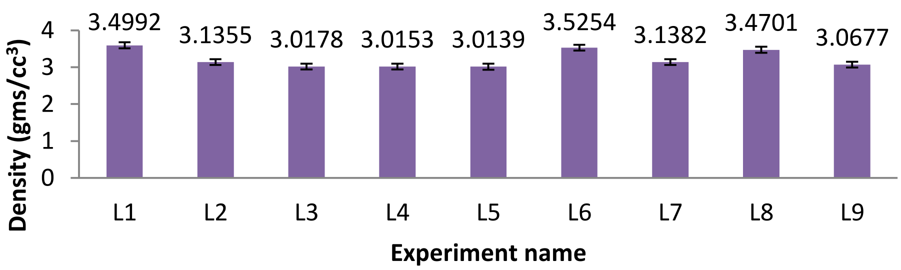

Figure 3 The density of the sample at different printed conditions

The effect of nozzle and bed temperature is significantly low while considering the density study of the fabricated filament. An increase in layer height decreases the bond between the newly formed layer and the layer already built. Due to the poor bonding, some voids are formed between the layer that subjects to have an excellent displacement of PLA elements performing the compression test. Different density obtained at different printer conditions is shown in Figure. 3.

3.2 Evaluation of Compressive Behavior

Compressive strength obtained at different condition printed samples are shown in Figure 4. The variation of compressive strength is found to increase linearly irrespective of layer height. The progression of compressive strength concerning nozzle and bed temperature is found in the incremental range of 15% at each level. The maximum heating temperature preferred to fabricate and also to build the required geometry is less than 200 degrees celsius. Copper can easily withstand the given temperature however; structural change of PLA has to lead to have a variation on the compression strength. Incremental of temperature while building the geometry, PLA elements in the composite filament slightly lose the ductile behavior and import the brittle property and it can be verified through surface topography images.

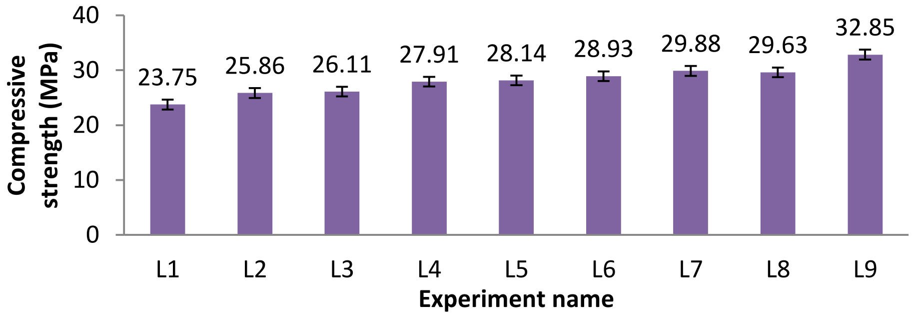

Figure 4 Compressive strength at different printed conditions

3.3 Influence of Machining Parameters

Nozzle temperature, bed temperature and layer height are the key parameters that play a significant role in 3D printing technology. Each parameter has its influence on the output condition. The load-displacement curve for the nine observations as shown in Figure 5. The influence of machining temperature has been greatly witnessed.

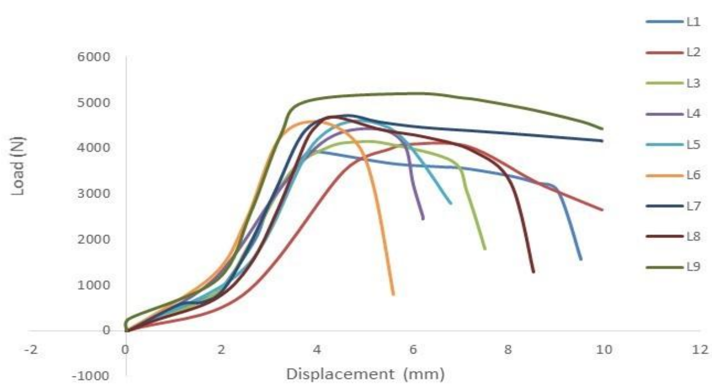

Figure 5 Load Vs Displacement curve of compressive test

Increasing printing temperature reduces the ductile property of PLA-copper filament and it leads to sudden failure. However, the displacement is not greatly affected because of the slippery nature of the copper particle in the PLA matrix. High-temperature level printing condition with the least layer height produces enough deformation than a high level of layer height. Minimum displacement is observed at the L6 condition is because of high bed temperature, as it provides enough time to settle the high-density copper particles at the base of each layer. Increment in bed temperature produces irregular deposition of copper particles over the printed layer. This action leads to having the least load withstanding conditions with displacement.

From the study, it is clear to infer that high bed and nozzle temperature at the layer height of 0.14 yield an optimum printing condition because at this condition L9, load withstanding capacity gets improved considerably followed by the displacement. The enhancement of brittle property leads to sudden failure. On fracture surface analysis, it is understandable that the copper particles can slide on the PLA due to the application of load. Though with the increase in brittle property material particle sliding provides the ductile type of failure.

4 Conclusion

PLA-Cu composite filament successfully fabricated through a hot extrusion process with reinforcement of 12% of copper. The fabricated filament was built to the ASTM D695-15 using a green technology process, FDM for compression test and the following conclusions are drawn

- At higher levels of nozzle and bed temperature, with 0.14 mm as layer height, a maximum of 32.85 MPa loads withstanding capacity samples can be printed.
- An increment of 15 % was observed at the incremental rate of nozzle and bed temperature.
- Increasing layer height creates an excess void region that helps in the formation of a slippery plane at low load working conditions.
- A decrease in ductile property with the increment of bed and nozzle temperature has the least significant effect on the compressive load.
- An increase in bed temperature allows copper particles to deposit at the bottom of each layer and it greatly signifies the dispersion rate.

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Biographies

M. Venkata Pavan, pursing the Ph.D degree in the Department of Mechanical Engineering, Vignan university, AP, India. He had completed the M.Tech. program from Aurora's Scientific Technological and Research Academy, Bandlaguda, Hyderabad, India specialized in Machine Design. Currently he is actively involved in the development of new composite 3D filament for mechanical engineering application.

K. Balamurugan, affiliated to the Department of Mechanical Engineering, Vignan University, Andhra Pradesh, India, since June 2017. He completed

M.E. program in Production Engineering and started his career at Kalasalingam University, Tamil Nadu and subsequently earned a doctoral degree from the same University. His area of research is on advanced machining of composite materials. Currently, he is actively participating in the area of machining and machinable properties of advanced composite materials. His other areas of interest include preparation, characterization of composite materials, Composite filament on 3D printing, Experimentation on the Cryogenic environment.