Feasibility of Metal Spray Reinforced Thermoplastic Composites Manufactured Using Fused Deposition Modeling

Aniket
yadavaniket018@gmail.com
M. Tech Scholar, Department of Mechanical Engineering, BRCM CET, Bahal, (Haryana), India
Suresh Kumar
sureshjangra161086@gmail.com
Assistant Professor, Department of Mechanical Engineering, BRCM CET, Bahal, (Haryana), India

ABSTRACT

Additive manufacturing refers to the process of creating a component from a CAD model using a 3D printer, and fused deposition modelling (FDM) is a technique that falls under both AM and fast manufacturing. Since FDM is utilised in a wide variety of sectors for the fabrication of items, those products must be cost-effective while also possessing desirable mechanical qualities. Through an in depth analysis of the relevant literature, the authors of this study have made an effort to narrow the gap that exists between the current state of the method parameters and the various forms of layering that are used in FDM parts. As a result, the characteristics of an FDM product are highly dependent on the careful adjustment of the manufacturing process's settings, which in turn determines those characteristics. Because the Process factors are primarily responsible for determining the quality of the FDM parts, identifying these factors is extremely important. The process parameters in FDM were improved with the help of a number of different methods, including Tagauchi's, ANNOVA, and the Response Surface approach. An experimental investigation has been carried out as part of this research by altering the parameters of the FDM 3D printing process and applying Taguchi's approach to replicate the repeatability of trials, a total of 11 tensile parts have been printed out using the FDM 3D printer. Every component is made in accordance with the ASTM requirements. After that, the mechanical characteristics of the tensile parts are evaluated using the UTS machine, and the analysis of the findings reveals that the parameters have a influence on the mechanical properties. The cracking or fracture behaviour of the part is also investigated within the scope of this study.

Keywords: FDM, 3D Printing

INTRODUCTION

The 3D Manufacturing Process is advancement in technologies that make possible to move from analog to digital. The AM is a transmuting approach or Way to industrial production that make possible to build lighter parts and stronger parts. The Additive Manufacturing was invented in early 1980's in Japan (Kovalcik et al., 2020). Additive manufacturing is a computer-controlled process in which the model is prepared by using digital data in computer added design software, and then translates the design into layer by layer framework for machine to follow. This was then sent to printer which starts to create the prototype layer by layer and makes a solid prototype. The name Additive Manufacturing was given as it adds up the material layer by layer to manufacture the part(Pelzer et al., 2023). The additive manufacturing is the process of joining the material layer by layer which is completely the opposite of the subtractive manufacturing in which the material was removed to make final part . The subtractive manufacturing was used in traditional manufacturing process in which the material is removed by milling process, grinding etc. to make final part(Yang et al., 2018). The Additive Manufacturing is very easy process and rapid manufacturing technique than traditional manufacturing process which require weeks for set up, designs of molds and tools for part manufacturing. This is the reason why Additive Manufacturing has been proved popular with inventors and engineers. It is time saving, material saving and money saving technique (Goncalves et al., 2018). In other words, we can say that this technique is a group of technologies which makes it practical to manufacture models and prototypes of complex parts, even by not using tool and fixtures and produce complex geometries from3D Computer Aided Design (Yin et al., 2021). In 2010 the ASTM formulated a set of standards to classify the range of additive manufacturing process into 7 categoriesAs, 3D printing is used by many companies, but the aerospace and medical companies are the two companies in which the success and growth of the additive manufacturing was seen. As per the report given by Smart-tech market forecast, “the adoption of 3d printing in aerospace industry rises from 723 million dollar in 2015 to 3.45 billion dollars in 2023 and attain 18.97 % annual growth rate. Additive manufacturing helps companies like EOS, Bell Helicopter to design and produce flight certified parts for their commercial aircrafts(Poljak et al., 2020). As the additive manufacturing can save time and cost in aerospace industries whereas it can save lives in medical field According to the CEO and President of OPM (Oxford Performance Materials), Scott DE Felice says, “there is no region of human Skelton anatomy that was not touched by this technology. According to the report of Smart-tech market the expected growth of additive manufacturing in medical fields was 2.88 billion dollars from 2015 to 2023. The industrial world is just starting to understand the value of AM (additive manufacturing) and there is no distrust that with the improvement in the technology the new application will be continually discovered.

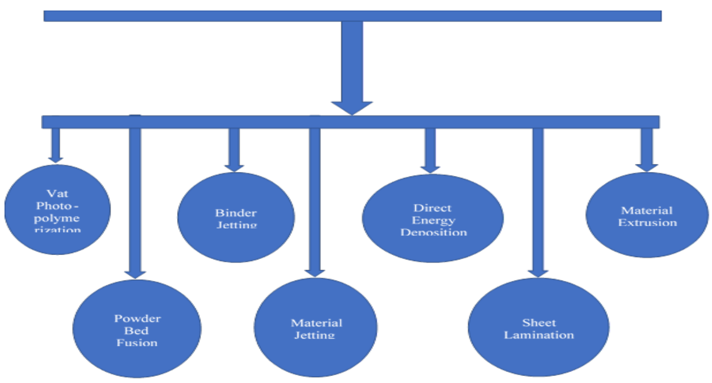

Figure 1 Classification of 3D manufacturing

Literature Review

In this chapter the overall detailed discussion on composites developed by FDM and other 3d printing technologies are presented.

Itcarried out a series of experiments to investigate the effect tha t raster layup has on the characteristics of threedimensional part s printed using FDM. The material used for making the part was poly lactic acid (PLA). (Armillotta& Cavallaro, 2017)The results obtained from the experiment shows when the orientations of layer is changed by 90 degree for standard layup then the strength and stiffness are similar but there is variation in toughness and with this type of layup the material has the capability to change their nature from ductile to brittle depending upon the load directions. it was concluded that, if the fibers are loaded diagonally to raster then the material will have more toughness against parallel or perpendicular loading directions.(Zaki et al., 2020) analyze the dimensional precision, mechanical behavior and overall cost of the part made using FDM. Authors use composite material like glass or Kevlar reinforced polyamide (KRP). The three-parameter selected by them are thickness of layer, temperature of extrusion and speed of printing on the basis of which the parts to be manufactured by using FDM. It was concluded that from all the three factors, the two factors like temperature of extrusion and the thickness of layer has major impact on properties of material compared to speed of printing. The reinforcement of the polyamide (PA) in Kevlar or glass helps to upgrade the mechanical properties of material used for making FDM parts.(Diegel et al., 2011)provide a methodology with which the mechanical properties and intermediate structure of model prepared by FDM can be predicted and worked to provide a computational work with which building parameters and filament specifications of the printing process can be simulated and stress is maximum and if increasing the layer height, it will decrease the mechanical performance.(Klippstein et al., 2018)worked to examine the effect of tensile stability and young's modulus of model made by fused deposition modeling using PLA material. The model prepared on the basis of orthographic material hypothesis. The trial data shows that the tensile stability of model prepared by using PLA material using FDM increases as the angle of printing increases, or with the decrease in the thickness of layer. The Young's modulus is high when the inclination of printing rises from 0-90 degree, or by reducing the thickness of layer from 0.0003 to 0.0001 meter. Relative error between these two models is the criteria to find the accuracy. All the relative errors are small i.e. less than 0.14 which is good in engineering applications.(Weiss et al., 2022)worked on RCAD (reverse cad model) to pre assume the geometrical and mechanical properties of part formed by fused deposition modeling and validate the reverse cad model with cad model prepared by using fused deposition modeling 3D printing. Authors said that manufactured part is not only cloning of original cad model, however it is the clone of the sliced model that depends upon different slicing specifications. It was shown that the reverse cad model provides a precise estimate of geometric properties and mechanical properties of the part to be created using fused deposition modeling 3d printing because the reverse cad model also adding the consequences of slicing parameters. Then made comparative study to validate reverse of cad model with cad model and compare the geometric and properties and mechanical properties of part made by fused deposition modeling 3d printing and shows that reverse cad model is best and gives precise estimator of the properties of the part made using FDM.(Kuipers et al., 2017)worked to investigate impact of the procedure parameters on tensile properties of part built by fused deposition model 3d printing. Authors use FFD (full factorial design) and conduct tensile trails on Ultem 9085 machine to analyses the impact of procedure parameters on tensile properties of part made using FDM 3D printing. The material used by them is polymeric material and the five procedure parameters selected for studying the impact on tensile properties of part are air gap, number of contours, with of raster, width of contour, and angle of raster. It was concluded that from all the five parameters that are selected for studying the impact on tension.(Promakhov et al.,

2016)The findings of the research show that including glass fib re into composites would lead t an increase in the composite's modulus of elasticity as well as its strength; neverthelessthe co mposite's flexibility will decrease as a result of the incorporatio n of the glass fibre.The statistics that were gathered from this i nquiry have been linked to the component that was made using the process of compressionmolding.This demonstratesclearly th at the component that is made by using compression acquires hi gher level of strength, whilst the component that is manufa ctured byutilizing 3Dprinting obtains a better level of flexibility .When compared with 3D printing, the that are retrieved through xray diffraction reveal a greater degree of cry stallinity in the object that was made via compression moulding .

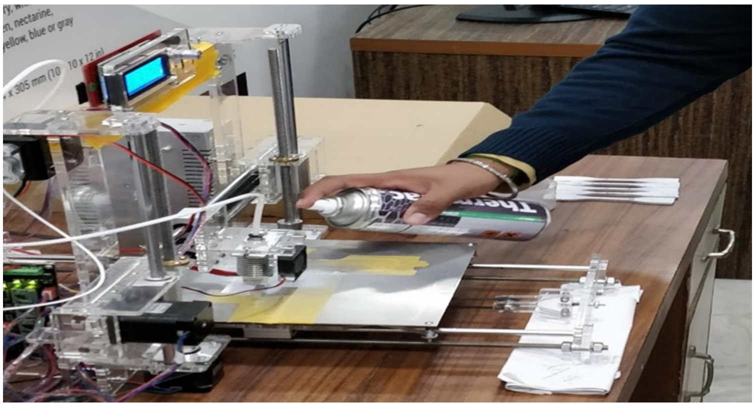

Figure 2. Metal spraying process during FDM printing process

Methodology

We use PLA, or polylactic acid, which is another name for polylactic acid and one of the many materials used by 3D printers. Produced from renewable resources like cornflour and sugarcane, vegetable based plastic is eco-friendly and doesn't harm the environment. Solvents such as benzene, tetrahydrofuran, etc., are used to dissolve the PLA. Tensile strength ranges from 2700 to 16000 MPa, and it remains stable up to 110 degrees Celsius in temperature. Annealing, introducing an interlink structure, and creating a composite with Nanoparticles are all ways to improve the PLA material's mechanical capabilities. Moulding material, screws, plates, microwave betrays, biomedical applications like dentists' equipment, bottles, plastic cups, and so on are all made from PLA. Metal spray (Worth India Ltd, Delhi, India) is used to spray in between the layers that have been deposited, and the thickness of the dried film is 50 mm at a density of 1.15 mm/cm3 (Figure 3.2).The spray's aluminium particles are 99.9% pure, and they're bound together with an acrylate alkyd resin; the recommended maximum spray temperature is 250 degrees Celsius. Al is deposited as a microfilm in the spaces between the layers (the manufacturer reports the dry film thickness to be 50 mm).

SAMPLE PREPARATION

The tensile parts are made as per ASTM D638 class IV standard having dimensions of 115x19x33x6mm and R14 and R25 mm. The processing parameters are number of aluminium layers, infill density or percentage, bed temperature and their impact on tensile strength and young modulus etc. has been studied. A total of 9 tensile parts has been prepared. The metal spraying performed in-between layers of PLA structuresThe density of the aluminium spray utilised is 1.15 m m/cm3, and the dry layer thickness is 0.05 mm.after pausing the FDM process, the spray is done with a single, continuous back-and

forth motion at a constant distance of 150 mm.Metal spray depo sits a layer 0.05mm deep regardless of spraying time or velocity , contrary to vendor claims.With the current experimentation, 3 2 layers were redeposited for a total thickness of 3.2 mm, as the layer height of the extruded filament was held constant at 0.1 mmthroughout the process.In Experiments 1, 2, and 3, after for ming 16 layers of PLA as indicated in Figure 3.4 . For Experim ents 7, 8, and 9, a sample with 5 layers undergoes the first spray after depositing 6 layers of PLA, the second spray after deposit ing 11 layers, the third spray after depositing 16 layers, the four th spray after depositing 26 layers, and the fifth spray after dep ositing 31 layers.The values of the processing parameters that were used to create the tensile parts are represented in table 3.1. The table has a variety of values for each processing parameter. It has been determined what effect a number of different parameters have on the mechanical properties of the pieces. The (UTS) Universal Tensile strength Machine, which has a maximum capacity of 5000 N and a strain rate of 5200, is the instrument that is utilized for the process of determining the tensile qualities.mm/min. The component is then placed in between two tensile grips, as illustrated in figure, and the feeding speed is increased by a computer-controlled machine. After that, the lower beam goes downward at a given constant pace for elongation, and the data is represented according to that machine used to test the universal tensile strength.

Table 1: Input parameters as per Taguchi Design

Exp	Aluminum layers	Percentage infill %	Temperature of bed
1	1	40	80
2	1	70	60
3	1	100	100
4	3	40	60
5	3	70	100
6	3	100	80
7	5	40	100
8	5	70	80
9	5	100	60

RESULT AND DISCUSION

In Table 4.1, you can see how varying tensile parts' characteristics affect their mechanical properties. All composite PLA pieces, with the exception of five layer samples, had stronger strength than virgin PLA. Spraying the final PLA part's top surface yields a sample with a lower tensile strength than composites. There is a negative correlation between the quantity of aluminium layers and the tensile strength of composite components A composite material's tensile strength decreases as the number of its layers increases. Due to aluminium spray breaking the link between PLA layers, tensile strength diminish with increasing layer count. The ability to support weight is thus diminished. Since a maximum S/N ratio is required to minimise noise in the experiment, it has been employed as a response in an ANOVA analysis. In order to maximise the S/N ratio and the mean value, it is advised to keep the infill density high while using only one layer of sprayed aluminium. Part 8 has the lowest strength, measuring in at 452.5N at its peak, 1.9mm at its highest elongation, 407.25N at its break, 23.57MPa at its peak, and 21.21MPa at its break when printed with 5 aluminium layers, 40% infill density, and a bed temperature of 100 degrees Celsius. All the tensile components are identifiable by their own colour codes. Part 1'sbackgroundcolour is brown, Part 2's is green, Part 3's is blue, Part 4's is red, Part 5's is pink, Part 6's is dark blue, Part 7's is light blue, Part 8's is sea green, Part 9's is orange, and Part 10's is purple.

Table 4.1 Tensile strength results obtained from UTS machine

S No.	**Load at peak (N)**	**Elongation at peak (mm)**	**Load at break**	**Elongation at break (mm)**	**Peak strength (MPa)**	**Break strength (MPa)**	**Percentage elongation at peak**	**Percentage elongation at break**
1	703.8	2.87	633.26	2.87	36.63	32.96	6	6
2	789.6	2.30	710.48	2.30	41.13	37.2	5	5
3	939.8	1.7	845.57	1.7	48.95	44.06	4	4
4	592.4	1.4	535.70	1.54	31.2	27.7	4	4

5	681.5	1.7	612.7	1.7	35.49	31.94	4	4
6	1075.5	3.63	967.79	3.63	56.03	50.5	8	8
7	452.7	1.7	407.27	1.7	23.59	21.23	4	4
8	568.6	2.68	511.94	2.68	29.65	26.68	6	6
9	757.8	1.7	681.77	1.7	39.47	35.55	4	4

CONCLUSION

An alternate method of composite development using metal spray and FDM process has been investigated in present study. The aluminium metal spray I performed in between layer of thermoplastic material during FDM printing process. This enables to develop customized composite structures with flexibility of metal spray layers and concentration of reinforcements along with directional control. The tensile properties of metal spray reinforced PLA structures are examined and compared with pure PLA material and surface coated parts. The peak tensile strength was improved thanks to the sprayed aluminium reinforcement layer. The tensile strength of composite PLA specimens increases in a predictable fashion as the density of the constituent pieces rises. The peak strength was lower for the specimen made with a higher number of layers and lower infill density. The peak strength of the specimen produced by fabricating a composite material is barely affected by the bed temperature. High density PLA combined with a single layer of sprayed metal particles is recommended because more layers cannot be accommodated in dense components. Besides maximum strength, additional tensile qualities that are non-linearly affected by the input parameters are also being investigated. Here are some findings related to other properties:

FUTURE OUTLOOK

The industrial 3D printing is being used by wide variety of industries and even companies are gaining the benefits by allotting for more design of freedom, increases product customization and improving costs. 3D printers are used in wide range of applications to make moulds for jewellery in customizable gifts industry such as toys, dolls etc. and products, functional models.

The following are potential research areas:

a) Metal spray of other metals such as copper, iron, nickel, chromium etc. must be used and tested of enhancement of mechanical properties.

b) Electrical and thermal conductivity of metal spray reinforced thermoplastic composites must be ascertained in future

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