An Experimental Investigation on Mechanical Properties of Fibre Reinforced Thermoplastics produced by Rapid Prototyping

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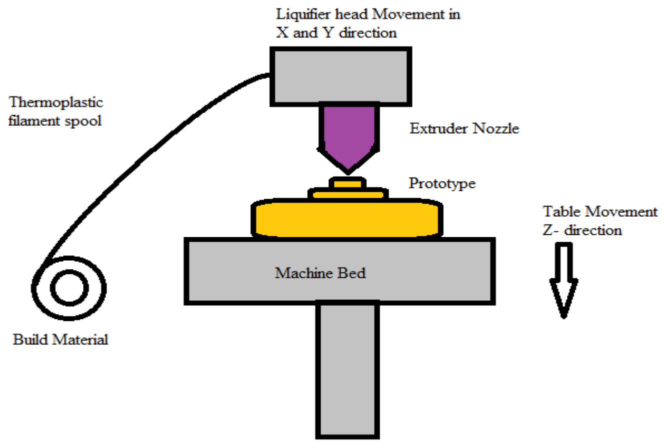
Abstract: Manufacturing of large number of mechanical components and prototypes is taken place by rapid prototyping technology. It is the method of Additive manufacturing in which components are manufactured in layer by layer form. It is observed from past research that mechanical properties of rapid prototyping products are very poor. Mechanical properties can be improved by glass fibre reinforcement with multiple layers of fibre. Bonding between glass fibres and matrix material can be improved by post heating. In this research Poly Lactic Acid (PLA) is taken as matrix material and glass fibre for external reinforcement. Experiment was conducted to investigate mechanical properties of thermoplastic reinforced with multiple layers of fibres and post heated reinforced printed composites by rapid prototyping. Tensile test was carried out to check mechanical strength of specimens.

Index Terms FDM, Fibre reinforcement, PLA, S type of glass fibre, Annealing

I. INTRODUCTION

Thermoplastic material is made in the form of filament and wounded in spool.

Thermoplastic filament is feeded in temperature chamber (liquefier) continuously with the help of stepper motor. This filament is first melted in liquefier and then filled over cross section of part. As material is deposited over previous layer it is solidified again. Basic diagram for fused deposition modelling is shown in figure. X and Y movement is given to nozzle to get desired shape. After producing one layer base moves in Z direction for next layer. For producing hollow structure support material is provided with other nozzle. Generally this support material is given with different colours to separate easily from base material. After producing complete job support material is removed and parts are joined with the help of glue where required. Material mainly used in FDM is ABS, PLA, Nylon, Wax etc.



Although the deposition lines can be integrated into adjacent deposition lines a bit by its own gravity and the force of stepping motor, there exist significant voids between deposition lines, which impairs the mechanical properties of fabricated parts to a great degree. Also the extruded material cools quickly from melting temperature to chamber temperature, resulting in development of inner stresses responsible for weak bond between two deposition lines, which leads to inter- and intra-layer deformation in the form of cracking, delamination or even part fabrication failure. Due to which mechanical strength of parts fabricated with rapid prototyping is less. One of the possible solutions to improve mechanical properties is making composites with fibre reinforcement.

Composite making by FDM

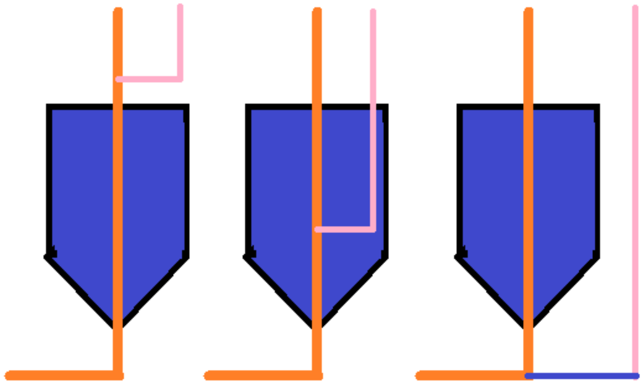
There are three methods to make fibre reinforced thermoplastic composite

1. Composite filament

   In this method already implanted fibre in thermoplastic is used for reinforcement.
2. Nozzle impregnation

   In this method fibre is implanted in nozzle after melting of thermoplastics.
3. After nozzle

   In this method fibre is implanted after the nozzle.



Carbon fibre and glass is implemented externally after half printing fibre is reinforced by three different concepts i.e. direct implementation, hypodermic needle, solvent. In direct implementation fibre is placed directly over half printed part. In hypodermic needle fibre is placed using hypodermic needle. In last method fibre is bonded with printed half part by using solvent i.e. acetone. Best adhesion between fibres and matrix material is achieved by using solvent. Printed part is damaged by hypodermic needle so it is not reasonable choice. Glass fibre is more brittle than carbon fibre. The highest tensile strength and young modulus is achieved by direct implementation with glass fibre. By this method tensile strength and young's modulus is increased by 17% and 21% respectively.[5] Static strength is doubled after thermal bonding (Post heating in Oven). Fatigue strength is higher for reinforced parts. Static tensile strength is increased when carbon fibre is included in plastic wire from nozzle.[1] . Filaments with different carbon contents are used i.e. 5%,10%,7.5% [2]. Tensile strength, young's modulus and yield strength is higher for carbon fibre reinforced composites than pure plastic parts[2]. Tensile strength is maximum with 5% carbon content which is 22.5% higher than pure plastic part and young's modulus is maximum for 7.5% carbon content which is 30.5% higher than pure plastic part[2]. Toughness and ductility is lower for carbon fibre reinforced composites. Tensile strength and young's modulus is higher for 150µm fibre length than 100µm fibre length. Yield strength is same for both lengths [2]. Flexural tests for 5% carbon content filament with 150µm fibre length gives results for flexural stress, flexural modulus and flexural toughness are 11.82%, 16.82% and 21.86% higher for carbon fibre reinforced composites[2]. Porosity becomes severest at 10% carbon fibre content.[2]

Carbon fibre composite has largest increase in mechanical strength which is 6.3 times more than Nylon fibre composite. Its tensile strength was superior to aluminum.[6] carbon fibre reinforced parts are having more strength compared to conventional parts the only limitation in faster production is Nozzle speed.[12].

Annealing process has significant impact over mechanical strength of the specimens. Annealing of 3d printed parts is done at Tg+20˚C for one hour and then cooled with rate of 6-30˚C/hr. up to room temperature. It is seen from tensile tests that mechanical strength of specimens increases 30.25% approximately and young's modulus is increases about 19.65%. This research also checked for effects on mechanical properties with printing orientation. Comparison of the results shows that the specimens printed edge up are 45.53% (49.25 MPa) stronger than face-up printed specimens (33.8 MPa) and almost 4 times stronger than up-right 3d printed specimens.[13]

. He concluded that PLA with 27% carbon content gives best mechanical properties. The best result achieved is 335Mpa flexural strength. [4]

From past research it is found that the best mechanical properties in thermoplastic composites can be achieved by fibre reinforcement. Moreover s-type of glass fibre can also be used for reinforcement purpose because of its good mechanical properties and good bonding properties with PLA. So it is taken for reinforcement and PLA as Matrix material. Multiple layers of fibre can give improvement in its mechanical properties. It is also observed that Annealing of 3D printed parts improves mechanical properties. Thus investigation is performed for annealing of 3D printed specimens according to ASTM D638.

II. EXPERIMENTAL PROCEDURE

Manufacturing of composite part is done in three steps

1. Half or required layer of part is printed and machine is dropped to halt.
2. Fibre is set over the specimen with the help of pitch attachments.
3. Further specimen is manufactured. If multiple layer of fibre is required to be anufactured than it is manufactured with multiple halts.

Figure 2 fibre setup

Figure 1 prepared sample

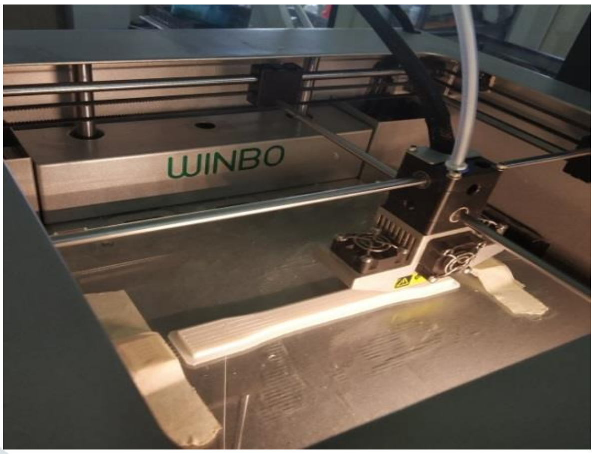
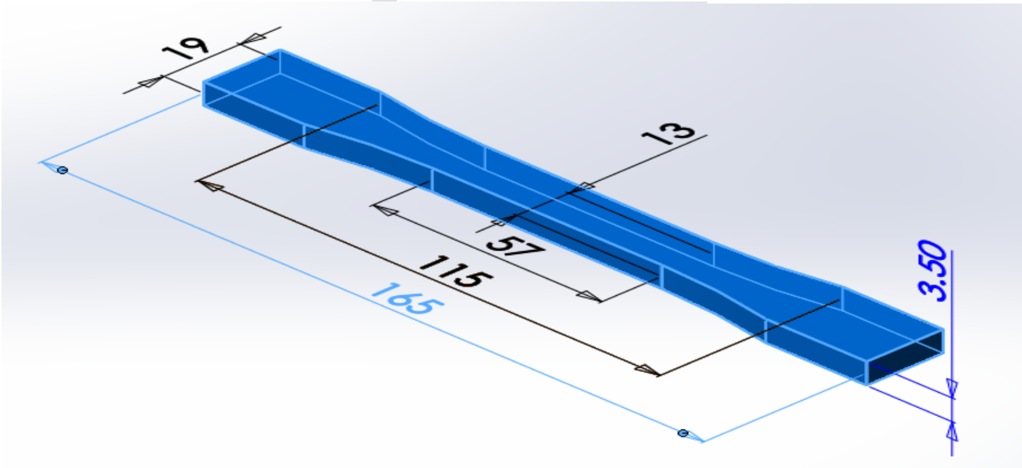


Figure 4 Pitch attachment of 2mm

Figure 3 Printing of specimen

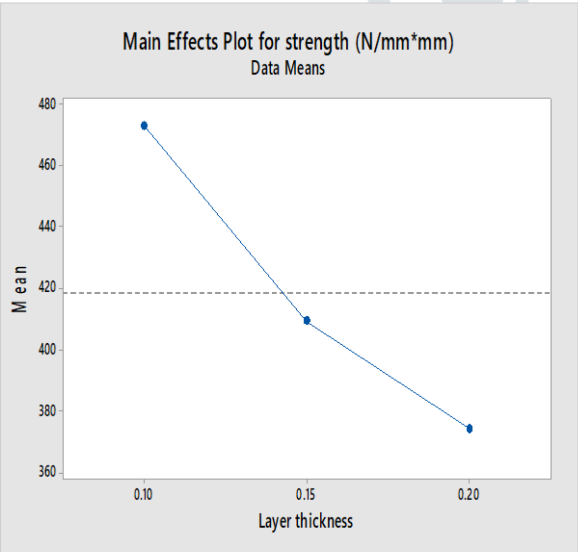


It is reviewed from past research that to avoid air presented between plastics and for increasing bonding between plastic materials it is post heated to saturated temperature for some duration and followed by furnace cooling. So for PLA its glass transition temperature is about 65-70C. For saturated condition it must be heated to 90 C for one hour and followed by cooling with 30 C/hr rate.

Figure 6 Annealing Oven 1

Figure 7 annealing oven 2

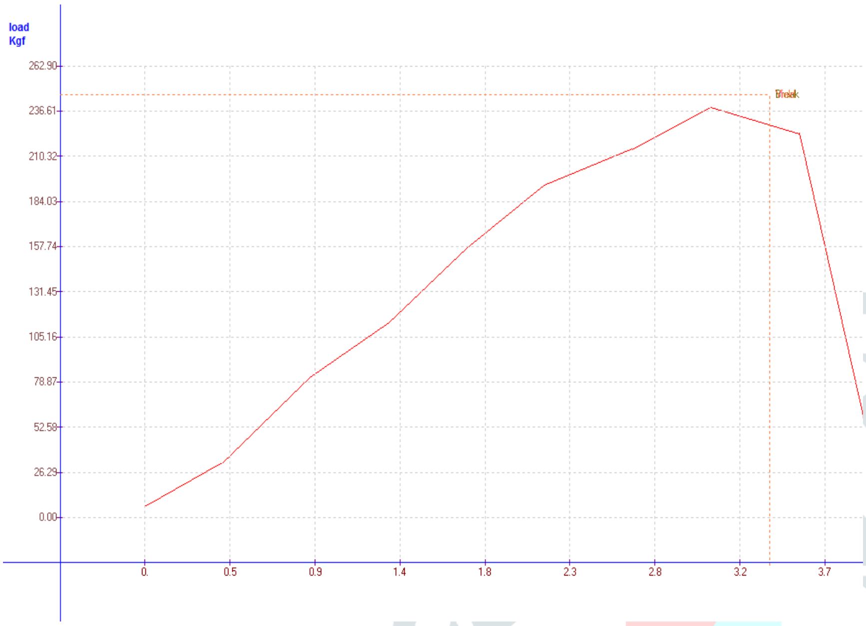
No.	Layer thickness	Multiple layers of fibre	Post heating (Annealing)
1	0.10	0	w
2	0.10	1	w
3	0.10	2	w
4	0.10	0	w/o
5	0.10	1	w/o
6	0.10	2	w/o
7	0.15	0	w
8	0.15	1	w
9	0.15	2	w
10	0.15	0	w/o
11	0.15	1	w/o
12	0.15	2	w/o
13	0.20	0	w
14	0.20	1	w
15	0.20	2	\w
16	0.20	0	w/o
17	0.20	1	w/o
18	0.20	2	w/o

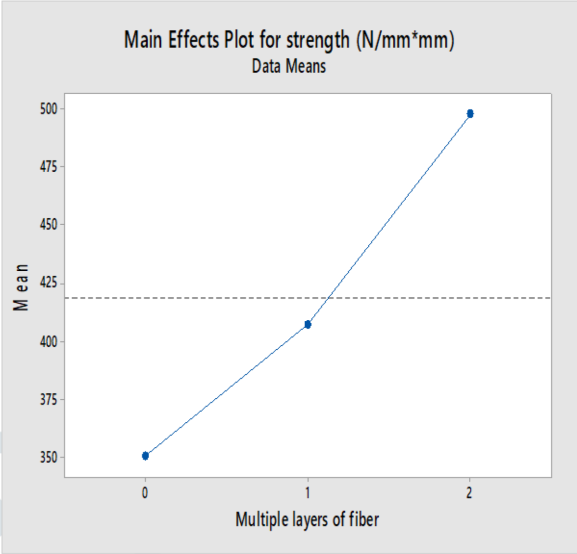


III.RESULTS AND DISCUSSION

From Experimentation and Testing it is found that best parameters for maximum strength is 0.10mm layer thickness, 2 layers of thickness and with post heating 538.46 N/cm^2 , Ductility is 6.98% and maximum load of 253.07Kg. *Least strength which ls available is 0.20mm layer thickness and without fibre without post heating 297.01N/cm^2 and ductility value is 5.38%.*

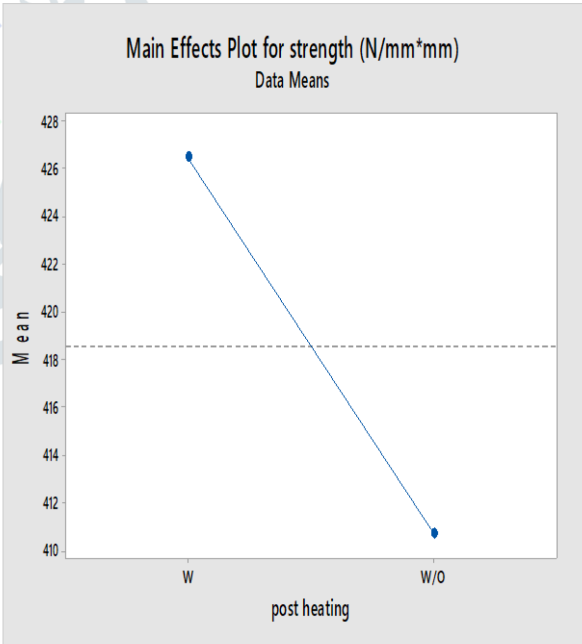
- From experimentations it is found that after implanting fibre, ductility and strength of specimens increases. Layer thickness has significant effect with fibres reinforcement. It is investigated from experiments .





- It is observed from layer thickness vs ductility diagram that with change in layer thickness ductility is remains unchanged and for 0.15mm layer thickness value it deviates but this deviation is very nominal can be neglected. Hence Ductility of the specimens is independent on layer thickness
- It is observed from layer thickness vs strength diagram that strength is continuously decreases as layer thickness is increases. It is seen that force required to break specimens is decreases as layer thickness increases. Hence strength is also decreases.

It is observed that as no. of layers of fibres are increases strength of specimens are increases. And with multiple layers of fibre and decrements in layer thickness best strength can be obtained. It is observed from experiments and testing with increase in layers of fibres strength of specimens' increases with large amounts and ductility is increases marginally. With increase in layers of fibre its amount of force to break the specimen increases. Hence the strength of specimen increase



Check of post heating for further increase in temperature

It is observed after experimentations that after increase temperature to more than 90 ˚C its shape gets distorted and after cooling warping of object takes place so it is concluded that best suited temperature for post heating is 90˚C for PLA as a matrix material.

Figure 5 warped specimen

IV. CONCLUSIONS

- Fibre reinforced thermoplastic polymer shows better mechanical properties than purely printed specimen. As the no. of layers of fibre is increases ductility and strength both increases linearly. The highest value of strength is 538Kg/cm^2, while highest value of Ductility is 6.98%. Ductility is independent of layer thickness. Post heating shows nominal increment in ductility. Post heating is the least significant factor affecting the tensile strength and breaking load and ductility. Sample specimens for Post heating at different temperature are also produced. It is found that for PLA as a matrix material 90˚C is best suited temperature for Annealing (Post heating). Temperature more than 90˚C warping in specimens takes place.

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