Assessment of the tensile characteristics of 3D printed PLA specimens wrapped in carbon fibre fabric

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ABSTRACT
The purpose of this work is to assess the mechanical reaction of Polylactic Acid (PLA) pieces produced using fused deposition modelling and wrapped in carbon fibre fabric using resin. Layers of materials are fused together in a pattern during the additive manufacturing process known as FDM 3D Printing to form an item. In order to build an item layer by layer, the PLA material is typically heated slightly above its glass transition temperature and then extruded in a pattern adjacent to or on top of prior extrusions. For tensile and wear tests, ASTM specimens with precise dimensions are 3D printed using PLA and wrapped in carbon fibre fabric using resin. The results are then evaluated by comparing the mechanical properties of the specimen wrapped with carbon fiber matte and without the wrapping of carbon fiber matte. Finally, we are determining the percentage improvement in the strength and mechanical properties compared to the traditional material.
Keywords: FDM 3D Printing; Polylactic acid (PLA); Carbon fiber; mechanical properties.

INTRODUCTION
A modeling technique known as fused deposition modeling belongs to the 3D printing technology's material extrusion subcategory. Three-dimensional items are produced using FDM printers using filament made of a thermoplastic polymer. In FDM printers, the filament is forced into a heated extruder. In order to create the finished thing, the filament is heated first and then deposited through the nozzle onto a created platform. Layers of materials are fused together in a pattern during the additive manufacturing process known as "Fused Deposition Modeling," or FDM 3D Printing, to produce an item. In order to create an object layer by layer, the material is typically heated slightly above its glass transition temperature and then extruded in a pattern adjacent to or on top of earlier extrusions. One of the biggest advantages of FDM 3D printing is scalability- It can be easily scaled to any size. This is because the only constraint in the size of a build area is the movement of each gantry– make the gantry rails longer and the build area can be made larger, but no other printer design is capable of being scaled as easily with as few issues as FDM. One of the more obvious benefits of having an easily-scalable design is the cost-to-size ratio. FDM printers are continually being made bigger and less expensive, due to low part costs and the simple designs involved. Another advantage is material flexibility. On any FDM printer, a wide variety of thermoplastic materials and exotic filaments can be printed with relatively few upgrades and modifications, something that cannot be said of other styles where a material must be a resin or fine powder.

Polylactic Acid, commonly known as PLA, is one of the most popular materials used in 3D printing. It is the default filament of choice for most extrusion-based 3D printers because it can be printed at a low temperature and does not require a heated bed. PLA is hard, strong and biodegradable but is brittle, being based on plant starch rather than crude oil. PLA delivers aesthetics and strength over toughness. When it comes to the features of PLA, it is naturally transparent and can be colored to various degrees of translucency and opacity. It is strong and more rigid than other materials used in 3D printing. It comprises of less warping and shrinking issues unlike other materials which makes it ideal for small parts. Printed objects usually have a glossier look and feel to them, and as a result it cannot stand too much heat, as standard PLA becomes soft around 50°C. However, one may consider this as an advantage in order to easily repair, bend or weld printed parts. There are many applications for PLA materials as follows; PLA is used in food packaging, bags, disposable tableware, upholstery, disposable garments, hygiene products and even diapers. PLA is also used for example in medical suturing as well as surgical implants, mainly it possesses the ability to degrade directly into inoffensive lactic acid in the body. Surgically implanted screws, pins, artistic prints, rods or mesh simply break down in the body within 6 months to 2 years Carbon Fiber is a polymer and is sometimes known as graphite fiber. It is a very strong material that is also very lightweight. Carbon fiber is five-times stronger than steel and twice as stiff. Though carbon fiber is stronger and stiffer than steel, it is lighter than steel; making it the ideal manufacturing material for many parts. These are just a few reasons why carbon fiber is favored by engineers and designers for manufacturing.

Method & Material

The Specimens for the static Tensile test and Wear test are designed according to American Society for Testing and Materials (ASTM) standards using Autodesk Fusion 360 software. The Tensile test specimen used is ASTM D638 which are dumbbell-shaped with a length of 166mm and thickness of 3.18mm. ASTM D638 specifies methods for testing the tensile strength of plastics and other resin materials and for calculating their mechanical properties.

The wear test specimen is designed in the shape of a cylinder using dimensional parameters according to ASTM G99-04 standards with specimen dimensions of height 40mm and diameter 12mm.

For 3D Printing of specimens, the Designed model is converted to STL (Stereo lithography) file and Slicing of the model is done with the help of Ultimaker Cura software which is used for conversion of a 3D object model to specific instructions for the 3D printer. Parameters like infill density of 30% and layer height of 0.25mm. In particular, the STL format file is converted to g-code format for Fused Deposition modelling.

ASTM Specimens for Tensile test and wear test are 3D Printed using FDM (Fused Deposition Modelling) method with PLA (Polylactic acid) and is printed according to the parameters given during slicing of the model.

Research Methodology

The PLA Specimen is wrapped with carbon fiber fabric manually and coated with resin and hardener. It is kept in a vacuum for about 15minutes to remove air bubbles from coated PLA and dried. The dimensions are measured for Tensile tests like gauge length, length of specimen after wrapping, and thickness of specimens. The dumbbell shaped ASTM D638 specimen for Tensile test is tested in UTM Machine and the cylindrical shaped ASTM G99-04 is tested for wear test is done in Pin on disc Testing machine.

3D-printed PLA specimens conditioned as per ASTM D638 Type I are tested and compared with carbon fiber-wrapped experimentally for Tensile strength on a universal testing machine (UTM).

Results and Discussion

Fracture of PLA specimen and PLA wrapped with carbon fiber fabric

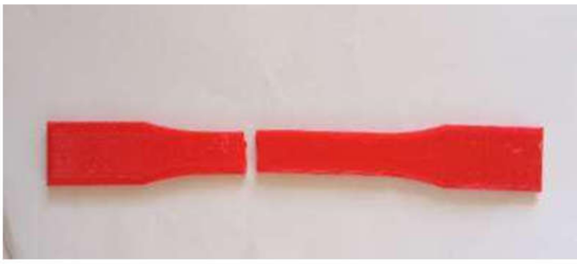

Figure No.1: Fracture of PLA Specimen after Tensile test

Figure No.2: PLA wrapped with carbon fiber fabric after the tensile test

For the Tensile testing 4 specimens of PLA were 3D Printed and 3 Specimens was wrapped with carbon fiber fabric with the application of resin and hardener. The PLA was first Tested in the UTM Machine which had a brittle-ductile fracture as shown in Figure No.1. The PLA Specimens wrapped with carbon fiber fabric was tested (Figure No. 2) which also had the similar type of fracture as PLA.

Table No.1: Tensile Test Results

Parameters	Values	
	Without wrap	With wrap
Peak Stress	20.981 Mpa	88.12 Mpa
Peak Load	0.78 kN	4.514 kN
Yield Load	0.707 kN	2.724 kN
Modulus	1.739 Gpa	4.602 Gpa
Upper Yield Point	19.008 Mpa	55.778 Mpa
Lower Yield Point	20.594 Mpa	34.733 Mpa
Stiffness	0.658 kN/mm	2.552 kN/mm

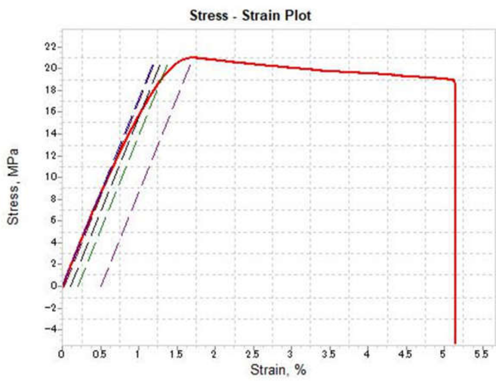

Figure No.3: Plot for stress vs strain, PLA specimen

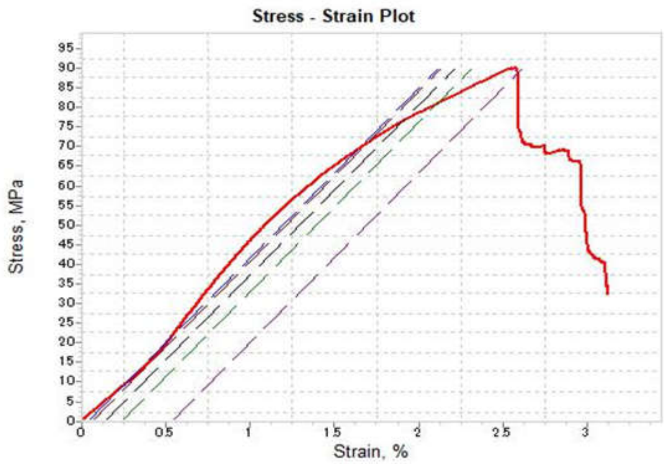

Figure No.4: Plot for stress vs strain, PLA specimen

From the above graphs 3.1 and 3.2 Carbon fiber wrapped specimen withstands more elastic limit before it gets permanently deformed. There is no sudden fracture of the material which means the plastics are ductile nature and as compared to PLA without wrapping of carbon fiber fabric the specimen with carbon fiber fabric possess better ductility property due to the wrapping of carbon fiber fabric of 200 GSM is a woven fabric and the application of resin makes it more ductile.

The PLA material can withstand a 0.707kN load, but the PLA wrapped with carbon fibre matt can withstand a 2.724 kN load. The PLA wrapped with carbon fibre matt with resin and hardener coated one has a higher yield point, stiffness, ductility, and modulus than the PLA material. When we coat with resin and hardener on the carbon fiber wrapped specimen, it increases the strength of the specimen.

Table No. 2: Comparison of PLA specimen and PLA with carbon fiber wrapped specimen

SI no.	Parameters	PLA specimen	PLA wrapped with carbon fiber matt
1	Yield Load	Less	High
2	Stiffness	Less	High
3	Ductility	Less	High
4	Brittle	High	Less

CONCLUSION

The strength of the material increases when wrapped with carbon fibre fabric with the application of resin and hardener, the mixture of the resin and hardener gives a glossy finish making the specimen water resistant. These results in a significant change in the mechanical properties of the PLA and PLA wrapped with carbon fiber fabric. The disadvantage of using PLA to build prostheses makes them unsafe to use, however wrapping the PLA in carbon fiber cloth and using resin and hardener to solidify it makes it stronger. With this change in properties the PLA with the wrapping of Carbon fiber fabric can be used to make prosthetic sockets and the cost of printing with PLA is much less than other 3D Printing materials like polypropelene, TPU (Thermoplastic Polyurethane). Further tests to check the strength of the material has to be done.

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