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Reinforcement of 3D Printed Part

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[1, 2, 3, 4]B. Tech Production

Abstract: ***The use of 3D printing for rapid tooling and manufacturing has promised to produce components with complex geometries according to computer designs. Due to the limited mechanical properties and functionalities of printed pure polymer parts, there is a critical need to develop technique for increasing mechanical strength of 3D printed parts. In this study, we present a technique for increasing the strength of thermoplastic fused deposition manufactured printed parts while retaining the benefits of the process such as ease, speed of implementation, and complex part geometries. By carefully placing voids in the printed parts and filling them with high-strength resins and fiber composites, we can improve the overall part hardness by keeping the appropriate infill pattern and pressure withstanding strength respectively. We discuss the process parameters necessary to use this strengthening technique. Then the study shows hardness testing and theoretical pressure data comparing solid printed PLA samples with those strengthened through the fill compositing process. The theoretical values were compared after proper mathematical calculations.***

1. Introduction

3D Printing is a process for making a physical object from a three-dimensional digital model, typically by laying down many successive thin layers of a material. It brings a digital object (its CAD representation) into its physical form by adding layer by layer of materials. There are several different techniques to 3D Print an object. We will go in further details later in the Guide. 3D Printing brings two fundamental innovations: the manipulation of objects in their digital format and the manufacturing of new shapes by addition of material. The most basic, differentiating principle behind 3D printing is that it is an additive manufacturing process. And this is indeed the key because 3D printing is a radically different manufacturing method based on advanced technology that builds up parts, additively, in layers at the sub mm scale. This is fundamentally different from any other existing traditional manufacturing techniques. There are a number of limitations to traditional manufacturing, which has widely been based on human labour and made by hand ideology rooting back to the etymological origins of the French word for manufacturing itself. However, the world of manufacturing has changed, and automated processes such as machining, casting, forming and moulding are all (relatively) new, complex processes that require machines, computers and robot technology. Thermoplastic polymer materials such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), polyamide (PA) and polycarbonate (PC) as well as thermosetting polymer materials like epoxy resins could be processed by 3D printing technology. However, most of 3D printed polymer products are still now used as conceptual prototypes rather than functional components, since pure polymer products built by 3D printing are lack of strength and functionality as fully functional and load-bearing parts. Such drawbacks restrict the wide industrial application of 3D printed polymers. 3D printing of polymer composites solves these problems by combining the matrix and reinforcements to achieve a system with more useful structural or functional properties nonattainable by any of the constituent alone. Incorporation of particle, fiber or nanomaterial reinforcements into polymers permits the fabrication of polymer matrix composites, which are characterized by high mechanical performance and excellent functionality.3D printing is able to fabricate complex composite structures without the typical waste. The size and geometry of composites can be precisely controlled with the help of computer aided design.

2. 3D Printing Technologies

3D printing is a methodology that produces 3D physical models' layer by layer based on CAD models. Various printing techniques have been employed to fabricate polymer composites. From these techniques some techniques are well-established, such as fused deposition modeling, selective laser sintering, inkjet 3D printing, stereolithography and 3D plotting while others are still in development. The selection of specific 3D printing technique for fabrication depends on the materials to be used, requirements of processing speed and resolution, costs and performance requirements of final products. Fused deposition modeling (FDM) fused deposition modeling (FDM), is a 3D printing process that uses a continuous filament of a thermoplastic material. Filament is fed from a large coil through a moving, heated printer extruder head. Molten thermoplastic is forced out of the print head's nozzle and is deposited on the growing work. The print head is moved under computer control to define the printed shape. Usually the head moves in two dimensions to deposit one horizontal plane, or layer, at a time; the work or the print head is then moved vertically by a small amount to begin a new layer. The speed of the extruder head may also be controlled to stop and start deposition and form an interrupted plane without stringing or dribbling between sections. "Fused filament fabrication" was coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use, given patents covering "fused deposition modeling" It is difficult to homogeneously disperse reinforcements and remove the void formed during the manufacturing of composite filaments. Another disadvantage of FDM printers is that the usable material is limited to thermoplastic polymers with suitable melt viscosity. Powder bed and inkjet head 3D printing (3DP) This technology is based on powder processing, Powders are first spread on the build platform and then selectively joined into a patterned layer by depositing a liquid binder through inkjet print head, which is able to move in X-Y direction. After a desired 2D pattern is formed, the platform lowers and the next layer of powder is spread.

This process is repeated and finally unbounded powder should be removed to get final products. Factors that determine the quality of final products are powder size, binder viscosity, interaction between binder and powder, and the binder deposition speed. The key advantages of this technology are the flexibility of material selections and room temperature processing environment.

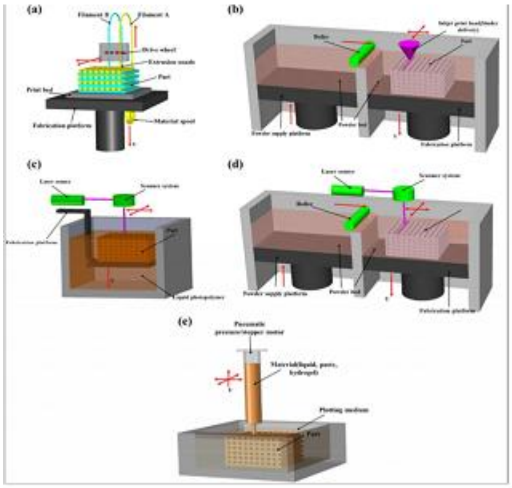

Figure 1: Schematic representation of a typical (a) FDM setup (b) 3DP setup (c) SLA setup (d) SLS setup (e) 3D plotting setup.

3. Processes

Stereolithography (SLA) Stereolithography uses photopolymers that can be cured by UV laser. An UV-laser is controlled in a desired path to shoot in the resin reservoir, and the photocurable resin will polymerize into a 2D patterned layer. After each layer is cured, the platform lowers and another layer of uncured resin is ready to be patterned, as shown in Fig. 1(c). Typical polymer materials used in SLA are acrylic and epoxy resins. The main advantage of SLA printing technology is the ability to print parts with high resolution. Additionally, because SLA is a nozzle-free technique, the problem of nozzle clogging can be avoided. Despite these advantages, the high cost of this system is a main concern for industrial application. Selective laser sintering (SLS) Selective laser sintering technique is similar to previously mentioned 3DP technique and they are both based on powder processing. Instead of using a liquid binder, in SLS, a laser beam with a controlled path scans the powders to sinter them by heating, as shown in Fig. 1(d). Under high power lasers, neighboring powders are fused together through molecular diffusion and then processing of next layer starts. Unbounded powder should be removed to get final products. 3D plotting/direct-write 3D plotting is based on extruding a viscous material from a pressurized syringe to create 3D shape of materials, as shown in Fig. 1(e). The syringe head can move in three dimensions, while the platform keeps stationary where extruded materials are joint together layer by layer. Curing reactions can be performed by dispensing two reactive components using mixing nozzles or be induced either by heat or UV light. The key advantage of this technique is material flexibility. Other techniques Recently, several new techniques are developed for 3D printing of composites, such as PolyJet which works by polymerization of deposited droplets of photopolymer ink, digital light processing (DLP) which is based on selective polymerization of an entire surface of photopolymer by a projector light, liquid deposition modelling (LDM) which consists in the additive deposition of material layers directly from a solution in a volatile solvent, and fiber encapsulation additive manufacturing (FEAM) which involves directly encapsulate fiber within an extruded flowable polymer matrix. Compared to traditional 3D printing techniques, these methods have either more material selections or less processing time. However, due to their high cost and complexity, there are only a few researches adopting these new techniques.

4. Process used for Experimentation

Composites Manufactured by Fused deposition modeling (FDM) method 3D printed parts have low heat resistance and mechanical strength hence it is difficult to use as a structural part for supporting heavy loads. To address this issue, filaments using short fiber-reinforced plastics are used in 3D printing. Masao Yamawaki and Yousuke Kouno has developed the 3D printer's nozzle structure with feature that supplies additional matrix resin in addition to the C-CFRTP filament and controls the supply of C-CFRTP. Two extruders are used to separately provide the additional matrix resin and the C-CFRTP filament. Introduction to Fused deposition modeling (FDM) 3D printing Fused deposition modeling (FDM) is a 3D printing process that uses a continuous filament of a thermoplastic material. This is fed from a large coil, through a moving, heated printer extruder head. Molten material is forced out of the print head's nozzle and is deposited on the growing workpiece. The head is moved, under computer control, to define the printed shape. Usually the head moves in layers, moving in two dimensions to deposit one horizontal plane at a time, before moving slightly upwards to begin a new slice. The speed of the extruder head may also be controlled, to stop and start deposition. The cold end is part of an extruder system that pulls and feed the material from the spool, and pushes it towards the hot end . The cold end is mostly gear- or roller-based supplying torque to the material and controlling the feed rate by means of a stepper motor. By this means the process rate is controlled. The hot end is the active part which also hosts the liquefier of the 3D printer that melts the filament. It allows the molten plastic to exit from the small nozzle to form a thin and tacky bead of plastic that will adhere to the material it is laid on the hot end consists of a heating chamber and a nozzle. The hole in the tip (nozzle) has a diameter of between 0.3 mm and 1.0 mm. Different types of nozzles and heating methods are used depending upon the material to be printed.FDM 3D Printing.

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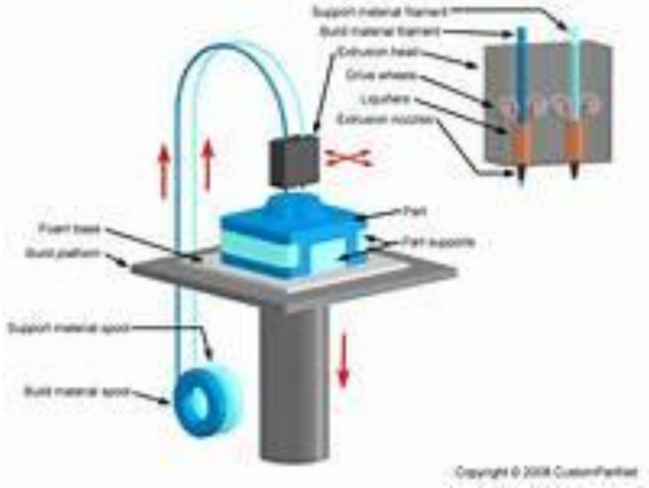

Figure 2: FDM setup

FDM 3D Printing Materials

PLA: - Polylactic acid (PLA) is a relatively new polymer plastic, made from biological• materials like cornstarch or sugarcane. PLA is melts at between 180 and 200˚C. PLA is generally the preferred option for low-cost 3D printers, because it is easier to print with than ABS, as it sticks to other surfaces and itself better. ABS: - Acrylonitrile butadiene styrene (ABS) is a commonly used plastic material that• melts at about 220˚C, then quickly re-forms into a tough, glossy, impact-resistant material. A print using ABS will be very tough; also the print will be water and chemical-resistant. PVA: - Polyvinyl alcohol (PVA) is one of a new class of 3D printing materials that are used to make supports. A synthetic polymer, PVA is used in biodegradable products, such as fishing lures and medical devices that need to work, but then dissolve away. It melts at about 200˚C Nylon: - Nylon is a tough material that has a very high tensile strength. It melts at about 250˚C and is nontoxic. Nylon's use as relatively a 3D printing material is relatively new, but the material is becoming popular because the prints it produces are very tough and resistant to damage. HDPE: - High-density polyethylene is used in pipes and recyclable packaging such as plastic bottles and packages. It melts at about 230˚C, but releases unpleasant fumes if accidentally heated to higher temperatures. In 3D printing, HDPE is often used instead of ABS, as comparable prints turn out lighter and stronger than with ABS. Wood Filament: - The name is a little confusing here: these filaments are not made out of wood, but instead contain very fine wood particles combined with PLA and a polymer that binds them together. This means that, when printed and polished, the finished material can look a lot like wood. Carbon Fiber Mix: -If we take one of the printing materials listed above, a bit of glue and particles of carbon fiber and mix them all up, then we get this type of filament. This gives us excellent rigidity and strength at very low weight. Carbon fiber is a very abrasive material that can wear away the hot end of the extruder very quickly, so you'll need to get a reinforced extruder or replace it after a few prints. nGen: - It is made from Eastman Amphora AM3300 3D polymer. nGen is a low-odour, styrene free material with excellent functional properties that are suited to a wide range of applications, from home appliances to electronics to medical prosthetics. With a glass temperature of over 85˚C, it has over double the heat resistance of PLA and at the same time, it maintains good flow properties through the printer nozzle even when printing a lower temperature than some other polymer required.

Figure 3: Kossel 3d printer

Machine Parameters

- Make: anycubic kossel 3d printer.
- Print Area: 280mm x 280mm.
- Top Print Speed: 20 -60 mm/sec Maximum Tool Head Temperature: 260°C
- Maximum Heated Bed Temperature:100°C
- Layer Thickness: 0.050mm to 0.5mm
- Software Used: Cura LulzBot Edition

Strength of Materials as Printed

In this study, we discuss one method for greatly improving the mechanical strength of 3D printed components, via compositing with higher-strength resins along with fiber reinforcement filled into channel printed within the structure. The approach retains 3D printing’s benefits of fast and easy construction and the ability to make complex geometries, while only requiring a few straight-forward and easy to implement post-processing steps. Using FDM as a platform, we examine a number of different options for printing parts that can be filled with resins along with fiber reinforcement after printing, including hollow parts, sparse-filled prints, and prints with hollow channels oriented to maximize strength to weight ratio, and experimentally evaluate the changes in strength and stiffness. FDM based 3D printing relies on fusing sequential layers of material extruded from a small nozzle to form the overall part geometry. Due to this process, the available materials are currently limited to thermoplastics. To verify the mechanical properties of FDM printed parts, we calculated the theoritical pressure and density and tested hardness using shore hardness test. All tested samples were printed from PLA material, on a anycubic kossel 3d printer. Using the same generic sample geometry, we used the CURA software to print in various build characteristics. Other options can be selected that allow the internal sections of the part to be printed in a sparse/less dense packing of extrusion paths.

Sample Preparation

The dimensions of the samples to be tested are fed into the software. The CAD model of the specimen is prepared in CATIA software. To start the print (.stl) file of the part to be printed is loaded in the CURA software.

Standard printing procedure:

A summarized standard procedure for printing parts on a Lulzbot 3D printer is as follows:

1) Generate an STL file from a CAD program.
2) Upload the STL file into CURA software.
3) Set temperature and other parameters according to filament used as stated in Table2 and quality of part required.
4) Start the 3D print and wait until it finishes.
5) Remove the part at corresponding removal temperature of filament.

Parameters(units)	value
Bed temperature	60 degree cel.
Printing temperature	200 degree cel
Bottom layer thickness	0.8 mm
Speed	60 mm/sec
Layer thickness	0.2 mm

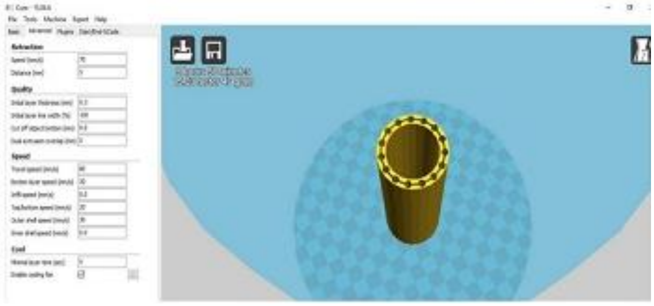

Figure 4: Kura Software Interface

Resin Material and Reinforcement

Kevlar is a heat-resistant and strong synthetic fiber, related to other aramids such as Nomex and Technora. This high-strength material was first commercially used in the early 1970s as a replacement for steel in racing tires. Typically it is spun into ropes or fabric sheets that can be used as such or as an ingredient in composite material components. Kevlar has many applications, ranging from bicycle tires and racing sails to bulletproof vests, because of its high tensile strength-to-weight ratio; by this measure it is 5 times stronger than steel. It is also used to make modern marching drumheads that withstand high impact. When used as a woven material, it is suitable for mooring lines and other underwater applications. A similar fiber called Twaron with the same chemical structure was developed by Akzo in the 1970s; commercial production started in 1986, and Twaron is now manufactured by Teijin

Qualities of Kevlar

It is strong but relatively light. Unlike most plastics it does not melt: it's reasonably good at withstanding temperatures and decomposes only at ~450°C (850°F). Kevlar can be ignited but burning usually stops when the heat source is removed. Very low temperatures have no effect on Kevlar. There is no appreciable embrittlement or degradation down to -196°C (-320°F), which makes it excellent for Arctic conditions. Like other plastics, long exposure to ultraviolet light (in sunlight, for example) causes discoloration and some degradation of the fibres. Kevlar can resist attacks from many different chemicals, though long exposure to strong acids or bases will degrade it over time. Kevlar remains virtually unchanged after exposure to hot water for more than 200 days and its properties are virtually unaffected by moisture.

Kevlar Applications

Kevlar Military Body Armor & Jackets, Protection Vests, Military Helmets, Automotive Uses Kevlar as a Composite, Ropes and Cables Page 46 Although there are numerous resins that could be used to fill into the hollow voids in the printed parts, epoxy resin is used which is readily available at a relatively low-cost. In addition to the stronger resins, reinforcements were also investigated that improve resin strength and stiffness. Carbon zfiber and Kevlar fiber were tested in the epoxy. Epoxy used is Araldite which acts as binder and also provide mechanical strength. Matrix material (Epoxy+Hardener) Matrix materials were room temperature cured epoxy resin. As reinforcement, unidirectional kevlar was used because it has outstanding properties of light weight, high strength and rigidity. First resin and hardener were mixed with 1:1 ratio and matrix are prepared. Then unidirectional kevlar fibers are placed in hollow voids created in the PLA Hollow Cylinder and resin is applied on kevlar fiber. Test samples are then kept at room temperature for curing.

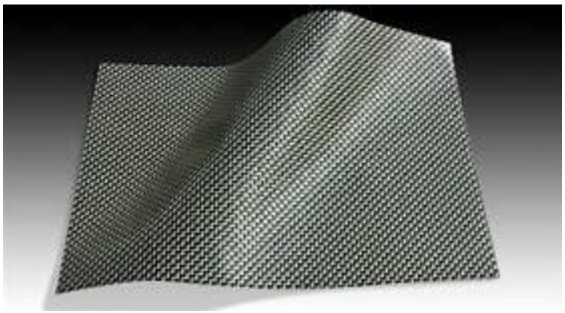

Figure 5: Kevlar material (sheet)

Figure 6: Part 3d printed with whole PLA (left)
Part with reinforcements (right)

Mechanical Testing

As we have to find hardness of polymer, we can't use brinell hardness test, rockwell hardness test or micro hardness test In above processes the material whose hardness is to be calculated requires reflectuve and highly polish surface hence we have to use Shore hardness test because it is widely used for polymers.

Figure 7: Theorotical Pressure Calculation

For Theorotical Calculations of Pressure

We have used barlows formula for busting pressure Barlow's Formula is a calculation used to show the relationship between internal pressure, allowable stress (also known as hoop stress), nominal thickness, and diameter. It is helpful in determining the maximum pressure capacity a pipe can safely withstand.

The formula is expressed as **P=2St/D**, where: P = pressure, t = nominal wall thickness D = outside Diameter in inches S = allowable stress in psi, which depends on the pressure being determined utilizing Yield or Tensile depending on what is trying to be determined

For PLA• S = 41.83 MPa For composite (kevlar + epoxy + PLA)

We have used law of mixture of tensile stresses which is = S1 V1 + S2 V2 + S3 V3 ……... Where S1, S2, S3 are allowable stresses of different materials in mixture And V1, V2, V3 their coressponding percentage volumes For composite S is 175.14 MPa

Density is the ratio of mass to volume.

The mass of PLA component is more but still have low mechanical strength then composite cylinder

Density = mass/volume

5. Results and Discussions

S. No	Sample identification	Hardness Shore D
1.	PLA	81-82 shores
2.	composite	82-83 shores

We have use Shore Hardness tester Durometer Type 'D'

- We can not use Rockwell and Brinel Hardness tester because it requires reflective and
- highly polish surface The difference between PLA and PLA composites hardness is not distictive because
- depth of indentation of type D is 0 – 2.5mm So, we couldn't penetrate the indentator enough to get the difference

Result Pressure (Theoretical)

Sr.no	Sample identification	pressure
1.	PLA	20.915MPa
2.	Composite	87.57 Mpa

The obtain theoretical pressure of PLA is 20.915MPa

- PLA composite is 87.57MPa

6. Conclusions

- So, by introducing kevlar and epoxy in PLA we get 4 times greater pressure value
- The t/d ratio is very high in case of our specimen
- So, the required pressure to break the component is very high so we cannot practically
- Perform the process The practical approach needs to be performed with high quality equipment and with
- Extra precautions

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