Review on fiber reinforcement in parts manufactured by fused deposition modeling

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Abstract: The aim to present this paper is to give a review about the fiber reinforcement in Fused Deposition Modeling (FDM) 3D Printer. This paper offers a comprehensive review of the existing literature on fiber reinforcement and dual matrix materials, the objective of the paper is aimed at providing guidance on different types of fibers and different types of fiber inclusion methods that can be used to improve strength. This research targets to find new paths that can be used for further development of fiber reinforcement in different materials.

***IndexTerms* - fiber reinforcement, dual material, fused deposition modeling**

I. INTRODUCTION

Additive manufacturing is one type of widely used technology to produce plastic parts ranging from prototype to final products. Additive manufacturing is classified as stereo-lithography, laser sintering, laminated object manufacturing and fused deposition modeling according to matrix material used i.e. powder, liquid, filament. Fused deposition modeling (FDM), first developed by Stratasys Inc., is one of the most commonly used techniques among AM technologies due to its relative low cost, low material wastage and ease of use. in fused deposition modeling, before fabricating parts STL file of part model is created using CAD software. This STL file is sliced into thin horizontal layers of definite thickness using 3D printing software i.e. Repetier Host, Cura.

In FDM process feed stock filament is fed to the extruder by using gear and roller mechanism. Plastic parts can be manufactured layer by layer by extruding filament from extrusion nozzle at constant temperature called glass transition temperature. First layer is printed by giving motion to the extruder in XY plane in desired trajectory from part design. After first layer is printed printing bed is moved down by layer thickness. Part is manufactured layer by layer in the same way. Acrylonitrile butadiene styrene (ABS), poly- carbonate (PC), polylactide (PLA), polyamide (PA), Nylon, and High Impact Polystyrene (HIPS) are the materials used as matrix material in fused deposition modeling. Sometimes the mixtures of any two types of thermoplastic materials are used. ABS and PLA are most commonly used material in FDM.

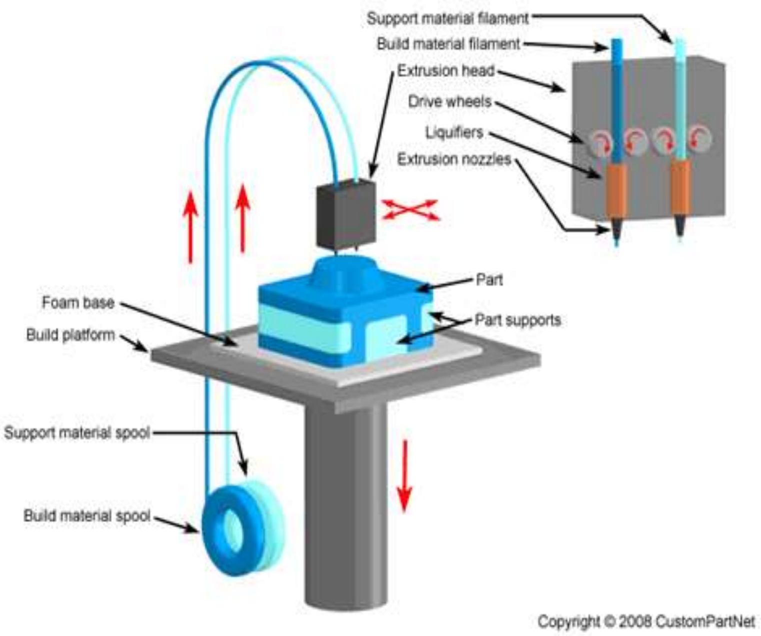

Fig. Schematic of the FDM process

Sometimes multiple nozzle 3D printers are used to print dual material part or part with support material can also be printed by dual nozzle 3D printer. The support material can be removed mechanically or chemically (by using solvent).

FDM fabricated parts has poor mechanical strength. This limitation restricts wide applications of FDM technology. Therefore there is critical need to improve mechanical strength of FDM fabricated parts. One of the possible solutions is fiber reinforcement in matrix material. Different types of reinforcement materials available are carbon fibers, glass fibers, natural fibers, kelvar fibers and nano fibers.

Fibers can be reinforced by three different techniques.
(1)Prior to nozzle - fiber is reinforced in filament material and fiber reinforced filament is fed to the extruder.
(2)Inside the nozzle – fiber is reinforced inside the nozzle. Various fiber and matrix material combination can be achieved by this reinforcement technique.
(3)After the nozzle – continuous fiber is reinforced in matrix material after it is extruded from nozzle while part is being manufactured.

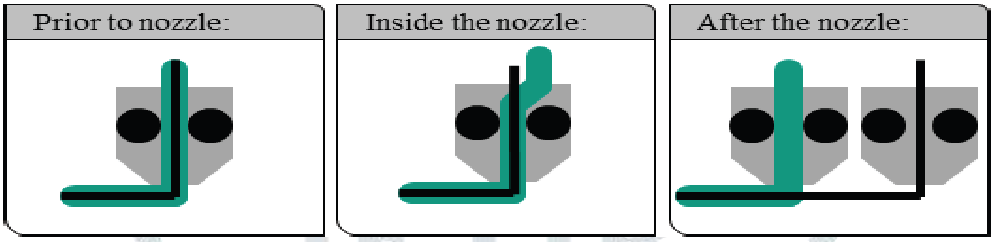

Fig. Concepts for implanting fiber

II. LITERATURE REVIEW

Ning et al studies about effects of carbon fiber content and length on fused deposition composites using carbon fiber reinforced filament. Filaments with different carbon contents are used. Carbon fiber with 150µm and 100µm is used. Tensile strength, young's modulus and yield strength is higher for carbon fiber reinforced composites than pure plastic parts. 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. Toughness and ductility is lower for carbon fiber reinforced composites. Tensile strength and young's modulus is higher for 150µm fiber length than 100µm fiber length. Yield strength is same for both lengths. He also conducted flexural tests for 5% carbon content filament with 150µm fiber length. Flexural stress, flexural modulus and flexural toughness are 11.82%, 16.82% and 21.86% higher for carbon fiber reinforced composites. Porosity becomes severest at 10% carbon fiber content.

Ning et al. also studies effects of various process parameters on carbon fiber reinforced composites. He used 5% carbon content reinforced filament. infill speed(15,20,25,30,35mm/s) nozzle temperature(210, 220, 230, 240 ° C)and layer thickness(0.15,0.20,0.25,0.30,0.35) is taken as variable process parameters. Tensile properties are investigated for 100% scale and 50% scale specimens. All tensile properties are highest at infill speed 25mm/s and nozzle temperature 220ºC. For layer thickness tensile strength, young modulus and yield strength is higher at 0.15mm while toughness and ductility is higher for 0.25mm layer thickness.

In another study Ning et al. compare chopped carbon fiber reinforcement and graphite particle reinforcement in ABS as a matrix material. Tensile properties and porosity are tested for both CF/ABS and GR/ABS. It is shown that addition of fiber does not affect glass transition temperature T_g. Porosity of GR/ABS parts is less than CF/ABS parts. Tensile properties are superior in CF/ABS parts than GR/ABS parts. Porosity is higher for (-45, 45) than (0, 90) raster angle. Tensile strength, Young's modulus and Yield strength for (0, 90) raster angle is more than (-45, 45) raster angle. Toughness and ductility is maximum for (-45, 45) raster angle.

Baumann et al. compare carbon fiber reinforcement and glass fiber reinforcement in ABS. Fiber is implemented externally after half printing fiber is reinforced by three different concepts i.e. direct implementation, hypodermic needle, solvent. In direct implementation fiber is placed directly over half printed part. In hypodermic needle fiber is placed using hypodermic needle. In last method fiber is bonded with printed half part by using solvent i.e. acetone. Best adhesion between fibers and matrix material is achieved by using solvent. Printed part is damaged by hypodermic needle so it is not reasonable choice. Glass fiber is more brittle than carbon fiber. The highest tensile strength and young modulus is achieved by direct implementation with glass fiber. By this method tensile strength and young's modulus is increased by 17% and 21% respectively.

Kim et al. studied mechanical properties of 3D printed single and dual material products. Effect of different parameters like infill rate material type and orientation is tested for printed parts. The higher strength is achieved by PLA with 100% infill rate and X-direction. Mechanical strength is checked with 100% infill and X-direction orientation for different material ratio of PLA and ABS. From this it is concluded that pure PLA printed part is stronger than others. Then mechanical strength is investigated for different structural arrangement with 50-50 material ration of PLA and ABS. When structure arrangement is increased from 3 or 4 lines to 6 or 8 lines mechanical strength increased. There is not much different in tensile strength of 3 lines and 4 lines structural arrangement. It is showed that adhesion between horizontal layers is stronger than vertical layers.

Dickson used special printer to print continuous fiber called mark forged mark one printer. He used Nylon as a matrix material and compare carbon, glass, and kelvar fiber reinforcement fiber orientation and fiber type is taken as variable parameter. Parts are printed with multiple layers of fibers and matrix material by using concentric and isotropic fiber orientation for carbon, kelvar and glass fiber. Tensile and Flexural test are conducted for printed parts. Carbon fiber has largest increase in mechanical strength which is 6.3 times more than Nylon. Its tensile strength was superior to aluminum. Glass fiber reinforced part is tested for different volume fraction. For different volume fraction maximum efficiency is achieved at 18% fiber content.

F. Roger examined thermoplastic structures fabricated by FDM with heterogeneous infill and multi materials topological optimization is used for designing external geometry of part. In higher stress region material with higher strength and high infill density or fiber reinforced material is used while in low stress region virgin material or material with low strength and low infill density is used.

Block et al. compared short carbon fiber and continuous carbon fiber reinforcement in nylon as matrix material. Tensile, flexural and shear strength is computed for both short and continuous fiber reinforcement. Continuous carbon fiber reinforced parts has higher strength and modulus than short fiber reinforced parts. Small radius and sharp angles can not be printed by continuous carbon fiber because it is brittle material. Part quality is better for short fiber than continuous fiber. A gap between printed tracks is much larger in continuous fiber filament.

Uddin et al. conducted tensile and compressive tests for ABS parts with various parameters and compare it with injunction molded parts. Layer thickness (0.09, 0.19, 0.39), Printing plane (XY, YZ, ZX), Printing orientation (H, D, V) are taken as variable parameter. YZ-H part with 0.09 layer thickness has highest young modulus of 1524GPa among all printed parts. Stiffness of injection molded part is 1.22 times higher than that of stiffest printed part. Printing plane orientation has negligible effect when layer thickness is 0.19mm or higher.YZ-H and YZ-D parts with 0.09 mm layer thickness has higher yield strength of 39MPa among all printed parts. Yield strength of injection molded part is higher than printed parts. Ductility of printed parts is 1.45 times more than injection molded parts. YZ-V part with 0.19mm layer thickness has highest failure strength of 30MPa which is 2 times than injection molded parts. Printed specimen shows larger plastic deformation or elongation before reaching failure.

Mori et al. reinforced carbon fiber in ABS. Fiber is implemented directly over half printed part. Completed part is heated is oven. Static tensile test and dynamic tensile and bending test is conducted. Static strength is doubled after thermal bonding. Fatigue strength is higher for reinforced parts. Static tensile strength is increased when carbon fiber is included in plastic wire from nozzle.

Nanyali et al. compare carbon fiber reinforced parts with modified carbon fiber reinforced parts. Carbon fiber is modified chemically by using solvents. Mechanical properties (tensile strength, flexural strength) and thermodynamic properties (storage modulus, loss tangent, glass transition temperature (T_g)) is tested for both. Tensile strength and flexural strength of modified carbon fiber is 13.8% and 164% higher than carbon fiber reinforced parts. Strength modulus of modified carbon fiber reinforced parts is 351% higher than carbon fiber reinforced parts. Interfacial strength of PLA with carbon fiber is increased by modification of carbon fiber.

Tian et al. studied 3d printed products with PLA as a matrix material and carbon fiber as reinforcement. He examined parts with different layer thickness, fiber content and hatch spacing for relative flexural properties. He concluded that PLA with 27% carbon content gives best mechanical properties. The best result achieved is 335Mpa flexural strength. Veneker et al. studied Propylene as matrix material and E-type of glass fibers for reinforcement purpose. He examined extrusion temperature, extrusion speed, Air void estimation lower limit and upper limit. It is observed that from increasing void 1% to 19% its flexural strength is decreases by 1.5% to 19%.

Kensella et al. gives manufacturing process for S-type of glass fibers. He compared different glass fibers and gives result for mechanical properties. it is concluded that S-type of glass fibers having superior mechanical properties. Kuldeep Agrawal and G.D.Goh studied Nylon as matrix material and carbon fiber and glass fiber respectively as reinforcement. G.D.Goh gives comparision in CFRTP and GFRTP and microscopic fracture behavior of parts. he gives nozzle speed is limitation for faster production of parts. Kuldeep Agrawal concluded that carbon fiber reinforced parts are having more strength compared to conventional parts.

III. CONCLUSION

Review of literature suggests that 3d printing has a vast area of research for researchers. Fiber reinforcement in 3d printing gives positive results for mechanical properties with cost effectiveness. There are various scopes of research in externally reinforced plastics with 3d printing. The paper includes study on composite dual matrix material, carbon fiber, glass fiber, kelvar fiber reinforced with PLA, ABS and Nylon as a matrix material.

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