Investigation on Composite Feedstock filament for fusion deposition modelling

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Abstract. The purpose of this paper is to present the recent developments occurring in the field of fusion deposition modelling generally known as 3D Printing technology. Widely for the prototyping purposes the fusion deposition modelling is done with plastics and mainly two types of plastics are widely used acrylonitrile butadiene styrene or ABS plastics and polylactide or PLA \cite{1}. The ABS plastics are rigid in nature and its non-biodegradable product while the PLA material is less in strength and it’s a biodegradable product. Natural fibers are widely used in reinforcement of thermoplastic components. Where this 3D printing is a process where material extrusion is done using polymers. There is huge lack of understanding the effect of printing parameters only huge research has been undergone to understand the effect of mechanical properties and micro structural analysis of existing printing technology and existing filaments used in FDM process. The recent developments are undergone in composite material manufacturing in filaments major works concentrates on addition of materials with the existing material to get better results by undertaking mechanical behavioral analysis\cite{2}, this paper will present the recent research undergone on composite filaments and future works that can be carried out in the field of composite filaments used in FDM.

Keywords: FDM, Filament Extrusion, Natural Fibers.

1. Introduction

The 3D printing technology which is a integrating technology adapts a new era in manufacturing where this technology adapts ADDITIVE MANUFACTURING. Md Ali Osman \cite{1} discussed as The term AM defines in addition of materials and this technology have more advantageous things compared to the traditional subtractive manufacturing the conventional manufacturing machining concentrates on material removal process. This additive manufacturing method is described as 3D printing technology and these technology 3D components are printed in layer by layer process and it’s been sliced up and layers are determined by the software. In this methodology the 3D object is designed using a CAD software and then its sliced using a slicing software later the 3D model is converted into a .stl file to fed into the 3D printing device. Depending upon the manufacturing methodology it can be categorized as prototyping, solid free form layered manufacturing and computer automated manufacturing. The application of 3D printing has recently evolved into greater heights including in the fields of food industries, health care where organ printing research also undergone \cite{2-4}. Initially the 3D printing technology was adapted by most engineers to create prototypes and from there it will be developed to mass manufacturing.

The most widely implemented AM technique is fused deposition modelling \cite{5} the main reason for the achievement of this method is by its simplicity, accuracy and its easily affordable. Fusion deposition model allows any kind of complicated geometry to be manufactured easily by its unique feature of layer by layer build up process by successive deposition of material that gets melted in the
nozzle. Mostly the thermoplastics are preferred as filament material even though there are wide verity of materials available which includes ceramics, metals and composite materials which are compatible with FDM.

The raising popularity in newer technologies makes an alarming sense to consider the environmental factors and awareness, this awareness creates a urge to develop a sustainable novel material as filament where these composite natural fibers come into the screen, natural fibers are becoming as a preferred substitute for a reinforced polymer composite. Polyp et.al describes The manufacturing of synthetic fibers takes immense energy in other hand considering the natural fibbers it’s a dual advantage as its biodegradable and renewable also having good tensile properties. The strengths of natural fibers were up to 1830MPa are reported [8].

These are generally present within plants in the form of bundles from which single fibers can be extracted by means of treatment of which alkali treatment is by far the most common. A recent review of natural fiber composites includes their mechanical properties, different treatments, and related composite mechanical performance [9-15].This paper presents the development of natural fiber reinforced polypropylene composites that are compatible with FDM processing. The literature suggests that the inclusion of natural fiber as reinforcement has yet to be investigated in FDM. The research focused on the formulation of constituent materials in order to maximize the tensile properties of composite FDM filaments and ultimately 3D printed parts. In this investigation, two types of natural fiber were used for composite reinforcement, name ly hemp (Cannabis sativa) and harakeke (Phormium tenax). Both species are abundant, relatively inexpensive to procure, and exhibit among the most favorable tensile properties of any natural fibers. Pre consumer recycled polypropylene was selected as the constituent matrix material, due to its affordable cost and minimal moisture absorption. The low processing temperature required for polypropylene also minimizes the lingo cellulose degradation of reinforcing natural fibers.

2. Methods in Additive Manufacturing

Basically, the additive manufacturing done in seven methodologies, they are Fused Deposition Modelling, Stereo lithography, Laminated Object Manufacturing, selective Laser Sintering, Digital Light Processing, and Electron Beam Melting. In STL the parts can be easily manufactured from the CAD model directly, it doesn't need any tooling or fixture this method is a cost-effective way of manufacturing of 3D structures. FDM uses extruder which is temperature controlled to force out the material which uses thermoplastic filament and it deposits semi molten polymer on the bed (platform Ex. Glass or Metal) layer by layer. The filament moves between two rollers which drives the filament into the nozzle, the semi molten material gets on the bed in layer by layer. In LOM the object is manufactured in layer by layer process from a paper roll that are cross hatched and it acts as a use and throw base for the fabricated part. The paper roll is thermally activated and it is adhesive in nature at the lower side, the laminated sheets are heated and accompanied by a stainless-steel roller. SLS is achieved by binding of different powders where metallic powder is molten thoroughly and fabricated into 3D structures. SLS is manufactured by layered process that allows the complex 3D objects by successive layers of powdered material on top of each other. DLP is similar to Stereo lithography which deals with photopolymers. It uses arc lamp which is conventional method with liquid crystal display panel.
3. Fused deposition modeling

FDM process is primarily adopted for the purpose of rapid prototyping of polymer 3D objects, the materials selection is basically depending upon the application of the parts that has to be manufactured. In recent times commonly Poly lactic Acid generally called as PLA have been used as a stiff and environmentally friendly material. Materials like nylon are also used for soft jewelry applications. The FDM is named after the process of fusing the materials into desired shape and size by depositing the materials in a layer by layer process. The primary steps involved in FDM process are as follows.

- Designing a 3D model in a desired CAD software
- Slicing the model into different layers by the use of slicing software
- Position the 3D model appropriately to mineralize the supports creation.
- Convert the 3D CAD data into .stl file
- Feed the data into a 3D printing machine.

This process involves very minimalistic steps to convert a 3D design to a 3D model. In this methodology the spool of material is selected according to the application and fed into the 3D printer the printer will have two rollers to draw the material into the nozzle chamber, the nozzle chamber has a heating column which heats the
material and melts it down and the motor connected to the nozzle will move the nozzle to drop the semi molted material to the bed according to the design parameters.

4. Materials used in FDM

The general application in fusion deposition modeling involves basic materials which is nowadays readily available in market and these materials are depending upon the application of prototyping the parts, certain application requires hard intrusion where ABS materials can be used and many polymers are also used in FDM process like PLA standard material, PLA wood fill, PLA metal fill, Nylon standard, Nylon 11, Nylon 12, Nylon Carbon-Filled, Nylon onyx, PETG standard, PEI ULTEM 9085, ASA standard, standard TPU with shore hardness 60A-95A. These filaments are readily available for manufacturing by many small scale and medium scale companies which is manufacturing in mass numbers commercially. The applicable printers to print these materials also plays an important role in consideration of materials.

In general Fusion Deposition Modeling involves various optimization procedure in selection of materials as there are large possibility is material selection and various combination of materials can be incorporated in manufacturing of objects. Widely the following two materials are used in manufacturing of components using Fused Deposition Modeling they are Acrylonitrile-Butadiene-Styrene (ABS) and Poly Lactic Acid (PLA), of these two material ABS material is non bio degradable and used in industries for high strength to weight ratio material requirements, these ABS materials are considered to be more resilient compared to PLA materials. In the contrary we have PLA materials which are bio degradable and comparatively less strength than ABS materials and used in prototyping of models.
### Table 1. Mechanical properties of ABS Material

| S. No | Property                  | Metric       | Units       |
|-------|---------------------------|--------------|-------------|
| 1     | Yield Strength            | 1.85e7 - 5.1e7 | Pa          |
| 2     | Tensile Strength          | 2.76e7 - 5.52e7 | Pa         |
| 3     | Elongation                | 0.015 - 1    | % strain    |
| 4     | Hardness (Vickers)        | 5.49e7 - 1.5e8 | Pa         |
| 5     | Fracture Toughness        | 1.19e6 - 4.29e6 | Pa/m^0.5 |
| 6     | Young's Modulus           | 1.19e9 - 2.9e9 | Pa         |

### Table 2. Mechanical properties of PLA Material

| S. No | Property                  | Metric | Units |
|-------|---------------------------|--------|-------|
| 1     | Yield Strength            | 70     | MPa   |
| 2     | Tensile Strength          | 59     | MPa   |
| 3     | Elongation                | 7      | %     |
| 4     | Hardness (Rockwell)       | 88     | HR    |
| 5     | Poisson Ratio             | 0.36   | -     |
| 6     | Young's Modulus           | 1280   | MPa   |

5. **Filament Extrusion process**

In FDM process filament plays a important role in the finishing of the final product the plastic resins are taken to the manufacturers in the form of pellets sizing few millimeters. Initially the resin is mixed additive materials like blender or modifier, the next step is important in this extrusion process to bring out a quality filament here the mixture is been dried for about 2 hours between 60\(^\circ\)C to 80\(^\circ\)C skipping of this process will lead to jamming in extrusion. The next process involves a important machine in current trend of manufacturing – The Single Screw extruder. These SSS is basically a heating machine that extrudes filament into long strands. The filaments are extruded from different sized nozzle to obtain difference sized diameters such as 1.75mm, 2.85mm etc the speed at which the filament is pulled out determines the filament diameter.
Figure 4. Steps involved in filament extrusion

The next process in filament extrusion is the complex cooling process where the filaments are cooled under cold air or warm water bed this process is very important in determining the roundness of the material filament if this process goes through in a wrong way the roundness will be disturbed. Finally, the wrapping of the finished filaments into a spool usually vacuum sealing is done by hygroscopic that is they absorb water from air and protect from humidity.

6. Composite filament models

In the fusion deposition modeling, there are various filaments used for various applications, in these filaments very few adaptations are undergone the materials like ABS and PLA are widely adopted materials for FDM process and few other synthetic materials are also used there are few researchers like Osman et.al. touched these areas of filament composite parts,[2] these composite parts are made up of rice straw and PLA and other few researches are carried out in the composite preparations of wood ash combined with other existing synthetic plastics [1]. In these composite filament manufacturing the existing synthetic polymers are finely grained into powder state and the composite material or fiber material that are to be added with the synthetic plastic are also powdered finely and taken as sample A and B these samples are then added in different ratios and added with fusion agents and its extracted from a filament extrusion machine these variation in ratios results in the finishing and strengths of the filaments [3].

7. Conclusions and future proposals

Current investigations on the feedstock filament for Fusion Deposition Modelling accomplishes various findings in which major usages are based on the market available elements such as ABS and PLA few other synthetic plastic based elements are also adopted but not very largely, this creates a global awareness on the environment about the prototyping and decomposing the prototypes or the recycling process where it takes large energy as well as non-environmental friendly process to recycle. To an alternate some few researches are undergone on inclusiveness of bio compatible materials such as rice husk and wood ash composite has been tried as alternate to the existing synthetic materials very few researches has been carried out in the area of bio degradable fiber based filaments and filaments which are recyclable with minimal processes. We find a large scope in the process of developing new verity of filaments with natural fibers into the addition with the existing synthetic fibers, natural fibers like kenaf, coir and additive materials could be a great alternative for the existing synthetic fibers.

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