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TRIBOLOGICAL CHARACTERIZATION OF FDM COMPONENT USING ARAMID FIBER REINFORCED WITH NYLON

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Abstract

Additive manufacturing technique is one of the modern trend leading manufacturing techniques. This technology is widely used in Aeronautical, Automotive, Manufacturing, Architecture, Bio-Medical applications. The New Product Development team of all the manufacturing industries frequently undergo the phase of design review with the customers. This also has a significant impact on the cost incorporated towards the development of prototypes. Rapid prototype technique uses polymers and Ultraviolet sensitive resins as their raw materials for the production of prototypes. The limitations of these techniques are just the prototypes and not the actual. The primary reason for the limitations is the low characteristics of the raw materials used as compared to the process of producing the actual parts.

In the present investigation Fused Deposition Modelling (FDM) technique was used to print the 3-Dimensional prototype models. The raw materials used were composite material consisting Nylon, Aramid short fibre and Acrylic Resin. Since Aramid fibres are of fabric form, a new technique was adopted to produce the composite spool of 3mm diameter eventually used as raw material. Cura Software was used to control the FDM. The part was printed at a fill density of 80 percentages, printing nozzle temperature of 190°C with the platform temperature of 50°C.

The printed model was subjected to the tribological characteristic evaluation. Pin on disc test was conducted to understand the tribological characteristics after the reinforcement. The printed parts were tested and had exhibited better characteristics as compared to the non reinforced Nylon polymer. This has enhanced the characteristics of the products that are produced by Additive Manufacturing Technique. These results have concluded the characteristics enhancement and to extend the application of these products as per the need of customer for better wear resistance.

Keywords: Fused Deposition Modelling, Nylon-Aramid fibre, Pin on Disc test.

1. Introduction

Rapid prototyping (RP) is a process of producing the components by layer additive method hence it is known as Additive Manufacturing process (AM). The 3D models from the modelling software are transferred to the RP softwares through the .STL format. These models are sliced base on the specified thickness and each layer is filled with desired polymer material. The subsequent layers are built from its previous layer. A prototype is often used as part of the product design process to allow engineers and designers the ability to explore design alternatives, test theories and confirm performance tests prior to starting production of a new product. Engineers use their experience to tailor the prototype according to the specific unknowns still present in the intended design. The method of producing the prototype models, incorporate the following procedure through RP technology [1].

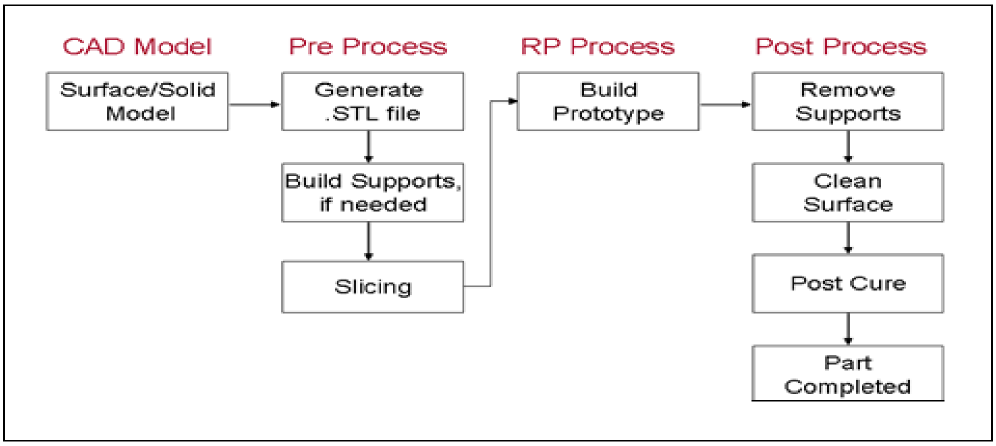


Fig 1. Flow Chart for RP Components

Fused Deposition Modeling (FDM) was developed by Scott Crump, the founder of Stratasys. It was commercialized by Stratasys in 1991. FDM process create component by extruding material (normally a thermoplastic material) through a nozzle that traverses in X and Y to create each two-dimensional layer. Heaters which surround two separated nozzles keep the plastic at a temperature just above its melting point so that it flows through the nozzle and forms the layer according to the tool path. In each layer separate nozzles extrude and deposit material that forms the parts and the support structure. The plastic hardens immediately after flowing from the nozzle and bonds to the layer below. Once a layer is built, the platform lowers, and the extrusion nozzle deposits another layer and the process is repeated until the object is completed. Figure2 show a schematic diagram of FDM process.

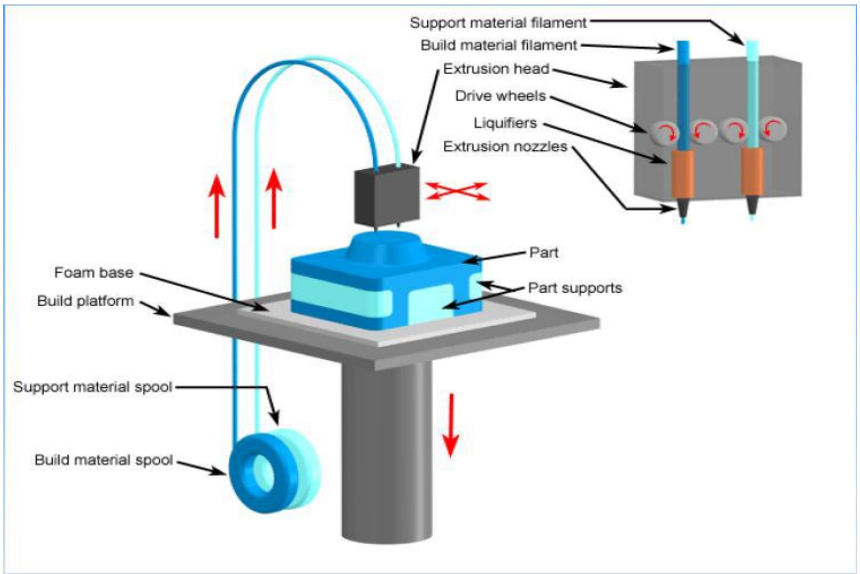


Fig 2. FDM Process

Support structure can be removed manually or, when water soluble supports are employed, they can be simply dissolved by put into particular chemical solution. However, soluble support is only available for building ABS model, other high melting point plastic material such as polycarbonate (PC) and polysulphone (PPSF) are not applicable.

2. Methodology

2.1 Literature Survey

The exploration of the significant literatures has provided an outline of the latest developments in the field of the process and the materials used in the development of the better components. The experimental methodologies and the outcome results from the literature review are cascaded below. J R Meakin et. al.[2] has investigated on the accuracy of an FDM model of a sheep lumbar vertebra using data from a CT scan. The model and the original vertebra were compared by making measurements with vernier callipers and by laser scanning. Visually, the model reproduced the features of the original object; this conclusion was supported by a comparison of the laser scans. Discrepancies in measurements were comparable with those of models produced using other rapid prototyping techniques, demonstrating that FDM is a viable method for making models for clinical use. As per the investigation performed by Prashant K Jain et al [3] the materials used in the Rapid prototyping techniques include the material in powder state, liquid state and solid state. The most commonly used material include wax, cermet, ceramics, nylon composites, glass composites, metal-polymer powders, metals, alloys, steel and polymers. Acrylonitrile-Butadiene-Styrene (ABS), casting wax, Poly carbonates and Nylon family. The author has spoken about the inclusion of additives for the base materials for the enhancement of the desirable properties and the impact of it in the field on Bio-medical engineering towards the making of artificial organs. The evolution of the Additive Manufacturing (AM) techniques from prototype to the production of the actual final component has led to many challenges in the development of the better raw materials. R. D. Goodridge et al [4] has investigated on the consideration towards the selection and processing of the polymers in AM techniques. The author has evaluated the properties of the composite material produced by Laser sintering techniques. The characteristics of the Polyamide 12 through laser sintering process are evaluated. C Ramesh et. al. [5] has conducted a study on the behavior of nylon under variable temperature. The crystallization of nylon-6 from the melt was monitored in situ by X-ray diffraction. The nylon-6 was found to crystallize into a hightemperature α‘-phase as indicated by the two-peak nature of the diffractogram. On cooling from the crystallization temperature to room temperature, nylon-6 retained the two-peak nature. However, data analysis indicates a change from high temperature (HT) α‘-phase to low-temperature α-phase at 180 °C. On heating, the α-phase transformed into the α‘-phase at about 190 °C and melted in the α‘-phase. The transition took place over a temperature range where both phases coexisted. However, samples crystallized from the melt at temperatures 140 and 180 °C showed the α-phase at room temperature, but on heating the α-phase first transformed into a pseudohexagonal phase and before melting the pseudohexagonal phase further transformed into the α‘-phase. The α-phase was transformed into the γ-phase, by potassium iodide−iodine treatment, and the behavior of the γ-phase with temperature had been studied for the first time. The γ-phase was very stable and did not show any crystalline transition below the melting point. Kyriaki Kalaitzidou et. al. [6] has evaluated the characteristics regarding the tensile, flexural properties by following the standards ASTM D638, ASTM D790. The impact strength of the component is evaluated as per the ASTM D256. The crystalline characteristics are assessed through X-ray diffraction patterns. The investigated component has the combination of nylon-12 reinforced with Carbon black. The electrical conductivity is analyzed for the prepared sample. The fabric form of the aramid material is widely used as the reinforcing agent for the body armor because of its high resistance properties and better mechanical properties. Ting-Ting Li. et. al. [7] has conducted an investigation on the static and dynamic puncture behaviour of compound fabrics with high performance Kevlar fiber. It was possible to produce an highly economical reinforced fabric with the combination of glass fibers and Kevlar fiber so as to with stand the impact load. The effect of layers had an significant resistance in the puncture.

2.2 Materials used in FDM

Nylon pellets and Aramid fibres are used as the raw material in the form of an extruded spool of 3mm diameter. Acrylic resin is used as the binding agent in the present study.

Table 1. Materials used for fabrication

Materials	Designation	Nylon %wt	Aramid %wt
Nylon	N	100	-
Nylon+Aramid	N-A	98	2
Nylon+Aramid	N-A1	96	4

2.3 Fabrication

2.3.1 Preparation of Nylon Pellets

The commercially available nylon-6 spool purchased from the market and chopped into 4 mm long pellets manually.

2.3.2 Hardening of Aramid Fabric by Epoxy Resin

The commercially available epoxy and hardener used to harden the aramid fabric. The epoxy and hardener (Huntsman) mixed in 1:10 ratio and then the fabric is dipped into the solution and allowed to get dry in room temperature. The resin applied aramid fabric will get dry in 24 hours and then it is chopped into 4 mm long pellets manually by using seizer as shown in below figure 3

Fig 3. Image of Aramid Pellets

2.3.3 Mixture of Fibre and Reinforcement Based On Weight

After preparing the Nylon-6 (Fibre) and Aramid (Reinforcement) Pellets both are mixed in terms of weight ratio as the minimum quantity is required for the extrusion of wire spool. In this investigation we have mixed as 2% and 4% by weight ratio.

2.3.4 Extrusion of Composite

The above mixed fibre and reinforcement i.e. the mixture of Nylon and Aramid pellets are fed into the hopper of twin screw extruder to get the wire spool. In the extrusion of polymers, raw compound material in the form of nurdles (small Pellets) is gravity fed from a top mounted hopper into the barrel of the extruder. The process has much in common with plastic injection molding from the point of the extruder technology though it differs in that it is usually a continuous process. The material enters through the feed throat (an opening near the rear of the barrel) and comes into contact with the screw. The rotating screw (normally turning at up to 120 rpm) forces the polymer pellets forward into the heated barrel. The desired extrusion temperature is rarely equal to the set temperature of the barrel due to viscous heating and other effects. In most processes, a heating profile is set for the barrel in which three or more independent proportional integral derivative controlled heater zones gradually increase the temperature of the barrel from the rear (where the plastic enters) to the front. This allows the polymer pellets to melt gradually as they are pushed through the barrel which comes in a 3mm Dia wire after that the wire is wounded into spool. As Shown in figure 4.

Fig 4. Nylon – aramid composite spool

2.3.5 Composite Spool Fed through FDM

The 3D model is converted into .STL (Standard Tessellation Language) format and then imported to FDM software called CURA, the process parameters are entered manually into the software then raw material in the form of 3mm Dia wire spool is fed into the FDM machine. The required part is printed layer by layer without any disturbance.

2.3.6 Sample Preparation

As per ASTM G99 standards the specimens (Pin on Disc test Specimens) are modeled using UG NX7.5 software and converted into .stl format then imported to Cura software for 3D printing [8].

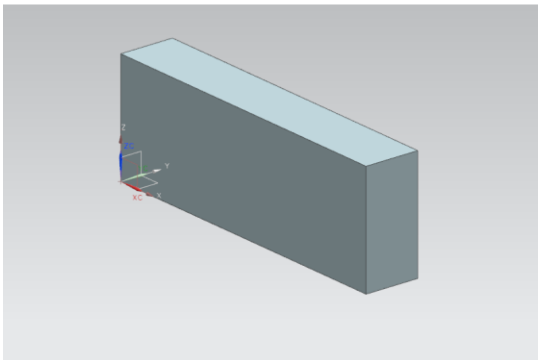


Fig 5. Flexural test specimen

Fig.6 Image of 3D Printed Specimen

2.4 Testing

2.4.1 Pin on Disc test:

As outlined by ASTM G99, pin-on-disk testing consists of a rotating disk in contact with a fixed pin with a spherical top. A schematic is shown below.

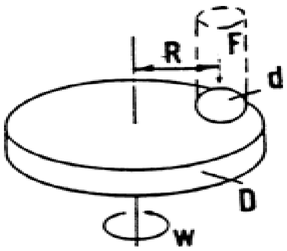


Figure shows Schematic Diagram of Pin on Disc Test Where,

F: Applied normal load

R: Radius of the wear track that is produced

d: Diameter of the spherical top of the pin

D: Diameter of the disk

W: Rotational speed

Although, ASTM G99 states that a spherical pin be used, many different specimen geometries may be employed to best simulate the operation of an actual system.

Test procedure: Immediately prior to testing, and prior to measuring or weighing, clean and dry the specimens. Take care to remove all dirt and foreign matter from the specimens. Use no chlorinated, non-film-forming cleaning agents and solvents. Dry materials with open grains to remove all traces of the cleaning fluids that may be entrapped in the material. Steel (ferromagnetic) specimens having residual magnetism should be demagnetized. Report the methods used for cleaning. Measure appropriate specimen dimensions to the nearest 2.5 µm or weigh the specimens to the nearest 0.0001 g. Insert the disk securely in the holding device so that the disk is fixed perpendicular (61°) to the axis of the resolution. Insert the pin specimen securely in its holder and, if necessary, adjust so that the specimen is perpendicular (61°) to the disk surface when in contact, in order to maintain the necessary contact conditions. Add the proper mass to the system lever or bale to develop the selected force pressing the pin against the disk. Start the motor and adjust the speed to the desired value while holding the pin specimen out of contact with the disk. Stop the motor. Set the revolution counter (or equivalent) to the desired number of revolutions. Begin the test with the specimens in contact under load. The test is stopped when the desired number of revolutions is achieved. Tests should not be interrupted or restarted. Remove the specimens and clean off any loose wear debris. Note the existence of features on or near the wear scar such as: protrusions, displaced metal, discoloration, micro cracking, or spotting. Re-measure the specimen dimensions to the nearest 2.5µm or reweigh the specimens to the nearest 0.0001 g, as appropriate. Repeat the test with additional specimens to obtain sufficient data for statistically significant results.

3. Results and Discussion

3.1 Pin on Disc Test:

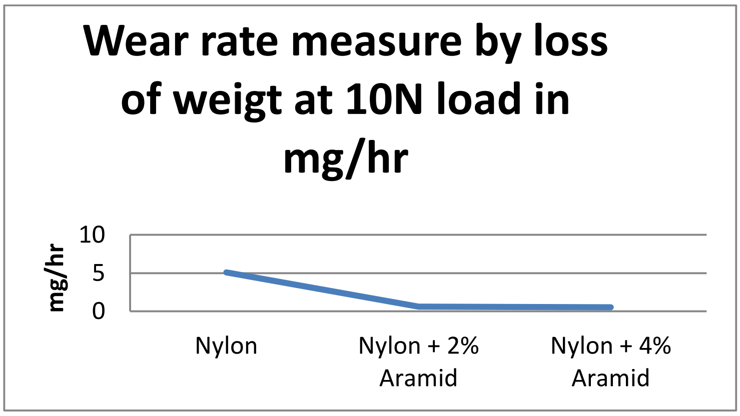
Load: 10 N, 20N and 30N

Speed: 500rpm

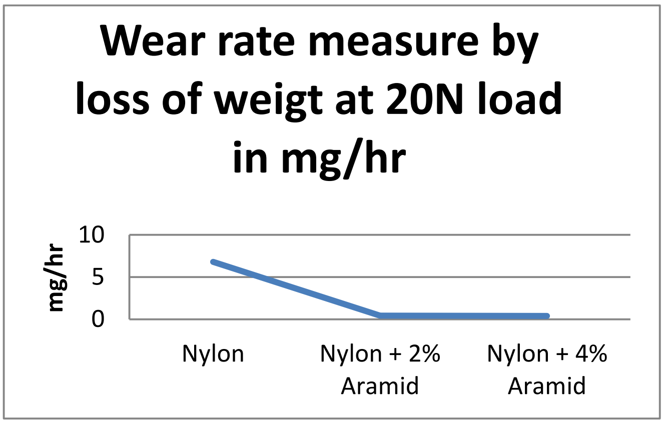
Track Diameter: 54mm

Sliding Velocity: 1.4 m/sec

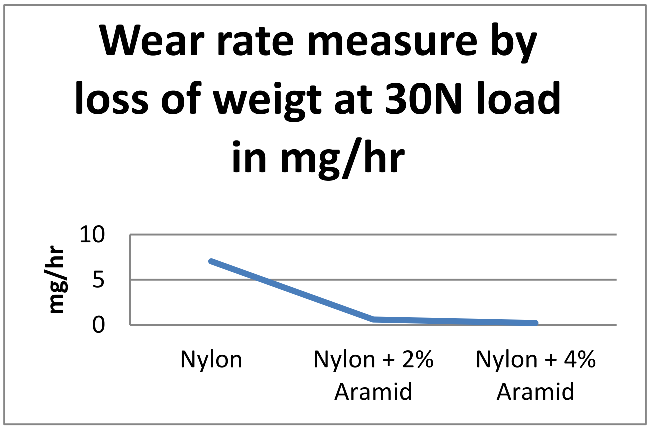
Test Duration: 30 min



Graph1: Pin on Disc test result at 10N load.



Graph2: Pin on Disc test result at 20N load.



Graph3: Pin on Disc test result at 30N load.

The test results of the samples show the improving trend of the wear resistance property of the composite material as compared to the non reinforced material. The specimen exhibits better wear resistant property with Nylon + 4% of Aramid.

4. Conclusion:

The reinforcement of Aramid fibre with the Nylon pellets has resulted in the better enhanced tribolical properties of the printed part. The process parameter of the FDM technique has resulted in the optimized performance in the process of printing the developed composite material. The printed material has substantially enhanced its characteristics along with the increment in the inclusion of Aramid. The further process parameter optimization could still make the product much more effective and better product.

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