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Effect of single particle size, double particle size and triple particle size Al_2O_3 in Nylon-6 matrix on mechanical properties of feed stock filament for FDM

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ABSTRACT

Fused Deposition modelling (FDM) is one of the additive manufacturing (AM) technologies used extensively for modelling and prototyping applications. In commercial FDM setup, filament wire is uncoiled from wire spools and plastic based material is supplied to produce the part. The application area of FDM is limited presently due to selective material availability in market. Some researchers have highlighted the use of reinforced composite wires as FDM filament. But hitherto no work has been reported on the effect of Single particle size (SPS), Dual particle size (DPS), Triple particle size (TPS) of Al_2O_3 (as reinforcement) in Nylon-6 matrix to be used as feed stock filament for FDM. In this paper, effect of SPS, DPS, and TPS of Al_2O_3 (as reinforcement) in Nylon-6 matrix on mechanical properties (like: percent age elongation, tensile strength, yield strength, Young's modulus) has been studied. Further, empirical relations have been developed for above mentioned properties and a surface characteristic of developed wires has been observed with SEM image.

1. Introduction

In the present competitive environment two major processes are being used to produce prototypes, namely machining and additive manufacturing (AM). Machining is generally more accurate and precise, but it is difficult to produce objects with complicated features/intricate dimensions. In contrast AM can produce objects with complicated features. In recent years, AM processes have been found to be capable of producing industrial products with controllable porosity [1], which allows materials to be used more efficiently [2]. Reducing the time to produce prototypes is a key to speeding up the development of new products. Today's commercially available AM systems work with different techniques by using paper, polymers and waxes etc. as process consumables [3]. FDM is one of the AM technique in which plastic/polymer based material usually acrylonitrile butadiene styrene (ABS) is used for preparation of prototypes [4–6].

The FDM system (used in the present study), developed by Stratasys Inc. USA (one of the commercial manufacturer), currently fabricate parts of elastomers, ABS and investment casting wax using the layer by layer deposition of extruded material through a nozzle using feedstock filaments from a spool [6]. Several studies have been reported to improve the part accuracy, surface finish, strength, etc. by proper adjustment of process parameters [7,8]. Since mechanical properties are important for the functional parts, it is absolutely essential to study influence of various process parameters on mechanical properties so that improvement can be made through selection of best settings [9]. Fig. 1 shows the basic schematic of FDM setup.

The feed stock filament is uncoiled from the spool and enters into heated liquefier assembly through feed wheels [11]. The wire changes its state from solid to semi liquid state and is made to eject through nozzle onto base of machine. The ejected material is made to deposit in the form of fine layers [12].

Melt flow index (MFI) is widely accepted as one of the crucial rheological property [13–17] that determines the basis of running in-house developed FDM filament in the machine. MFI is generally expressed in terms of weight (in g) of polymer which will flow per 10min of time period (i.e. g/10min.). It is to be worth noted that the present study has been performed by taking MFI as a crucial base

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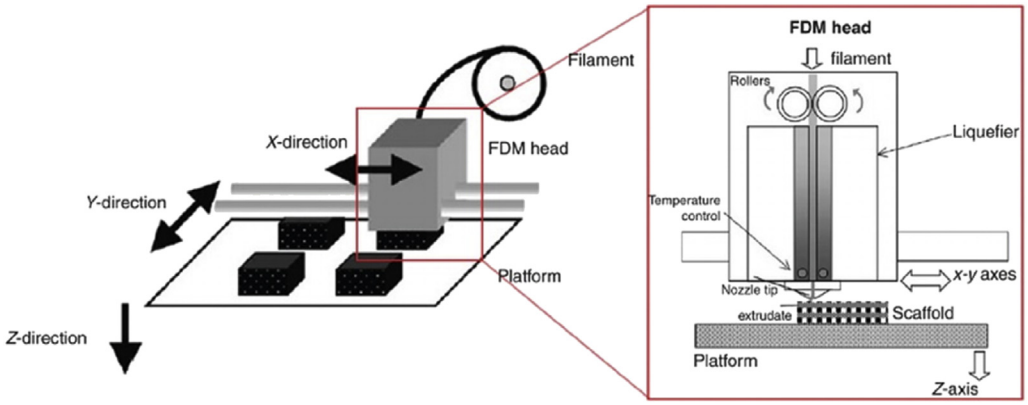

Fig. 1. Schematic of FDM [10].

property among other rheological properties as because it is very convenient and cost effective method used in field applications. The present study has been performed on commercial FDM setup (Stratsys, USA, u- Print model) on which filament wire of ABS P430 material (having MFI 2.41 g/10min.) is used. So, the present work is focused on developing alternate feed stock filament wire with MFI comparable to 2.41 g/10min. by reinforcing various combinations of sizes (SPS, DPS, TPS) of Al_2O_3 in Nylon-6 matrix and thereby observing their effect on mechanical properties of developed wire. It should be noted that the SPS represents single particle size (of 100 μm), DPS represents two particle sizes in equal proportion by weight (of 100 μm and 120 μm) and TPS represents three particle sizes in equal proportion by weight (of 100 μm, 120 μm and 150 μm). It has been observed that in reported literature, researchers have studied only the effect of SPS and very less exploration is done in the field of study of mechanical properties considering DPS and TPS. The above stated sizes of Al_2O_3 are taken, considering the diameter of nozzle head of FDM setup used, as if the size of particles more than 150 μm can choke the nozzle. Fig. 2 shows a basic schematic of MFI tester.

Various combinations of Nylon-6 granules along with reinforcements of Al_2O_3 as per pilot experimentation were mechanically mixed and placed in electric oven to eliminate any type of moisture present. It is to be noted that Nylon-6 has been taken as matrix material, as Nylon 6 has properties similar to that of commercial ABS material but the cost of Nylon-6 is very low than that of ABS. At high temperatures (especially during investment casting applications at de-waxing/de-plasticising stage), ABS produces ultrafine particles which have bas effects on human heath as well as on environment. Furthermore, Al_2O_3 was used as reinforcement as it is considered to be a good for draw ability properties. It is to be noted that various combinations/proportions of the nylon matrix and reinforcements are considered so that MFI of the total mixture may come nearer to that of commercial ABS material, i.e., 2.41 g/10min. The parent material/Nylon-6 granules and reinforcement is mechanically mixed and placed in an electric oven to eliminate any type of moisture present in mixture. The mixture is then put into the pre-heated barrel of MFI tester. The weight as per the ASTM standard (D 1238-95) is put on the piston to expel the molten material from barrel and thereby made to exit out of die opening as extrudate and weighed to find MFI in terms of gm/10 min. The mixture compositions were selected by selecting the MFI values near to 2.41 g/10min and fed into single screw extruder machine to draw the wires. Manufactured wires were tested using two column Universal testing machine (UTM) and mechanical parameters like Percent age elongation, Young's Modulus, Yield stress etc. were determined. Fig. 3 shows 3D view of UTM machine being used.

2. Experimentation

Present work is focused on enhancement of application area of FDM machine by developing filament wire, which has tailor made properties. For this experimentation work, set of pilot experiments (test runs) has been designed. Annexure 1 shows MFI values of

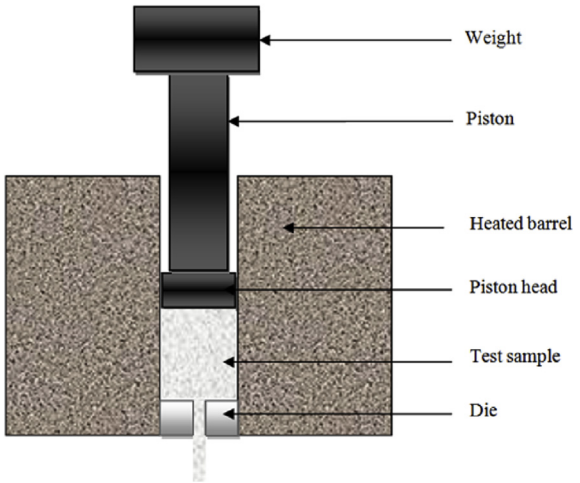

Fig. 2. Schematic of MFI tester [14].

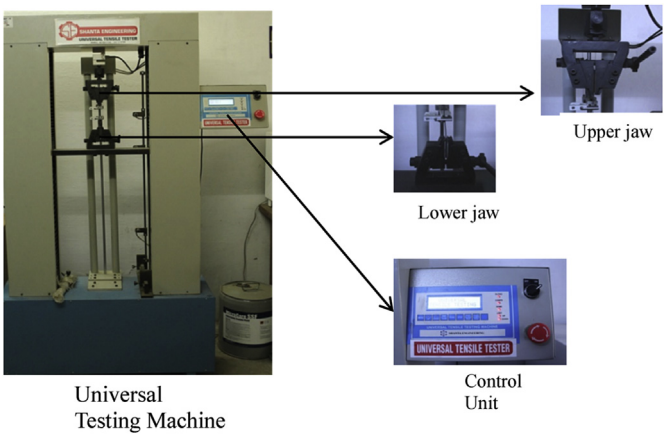

Fig. 3. 3D view of UTM and its parts.