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The effect of process parameters on tensile behavior of 3D printed flexible parts of ethylene vinyl acetate (EVA)

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ABSTRACT

Fused deposition modeling (FDM) is widely accepted AM process due to its capability of fabricating intricate geometries using filament of thermoplastic materials such as ABS, PLA, etc. Due to the limitations of the filament feed extrusion mechanism, existing FDM systems cannot fabricate flexible parts of soft-elastomers. Instead of filament shape, the material in pellet form has a broad scope for 3D printing of flexible parts. Ethylene vinyl acetate (EVA) material is widely used for the fabrication of flexible objects; however, the potential of this material has not been explored yet using the FDM process. In this study, flexible specimens of EVA material have been printed using a customized pellet based FDM system followed by the investigation on the effect of process parameters on tensile behavior. The effect of process parameters namely barrel temperature, platform temperature, build orientation, raster angle and number of contours have been studied on the tensile properties namely, ultimate tensile strength and % elongation at break. Response surface methodology (RSM) and analysis of variance (ANOVA) techniques have been used to study the effect of process parameters for attaining optimum tensile properties. It was found that barrel temperature, raster angle, and platform temperature affect the tensile behavior of EVA specimens significantly. The maximum obtained values of ultimate tensile strength and elongation at break were 8.83 MPa and 522.34% respectively. The outcome of the current study will help the engineers and designers to predict the tensile behavior of flexible parts for various applications.

1. Introduction

Additive manufacturing (AM) has been established as a manufacturing technology to produce intricate geometries in a quick time. The advantages of AM systems are pushing industries to print parts from mock-up to functional products. From the beginning, many variants of AM systems, such as stereolithography (SLA), selective laser sintering (SLS), fused deposition modeling (FDM) and laminated object manufacturing (LOM) have been developed. Among all AM systems, the FDM system is popular due to its potential of fabricating part at minimum expenses [1,2]. Due to this ability, it is widely used in various applications such as automobile, aerospace and medical, etc. However, poor surface finish [3], dimensional accuracy [4,5] and mechanical properties restrict the application of FDM in many areas.

Among aforementioned issues, poor mechanical properties of the printed parts have always been a major concern [6]. In the recent past, efforts have been made to determine the best mechanical properties by varying the printing process parameters. Tymrak et al. characterized the mechanical properties of the ABS and PLA made parts using various open source 3D printers [7]. The results were compared with the parts made on the commercial 3D printing systems which indicated that parts made from RepRap printer were equivalent in strength to the parts printed on the commercial FDM. Kotlinski discussed the mechanical properties of various materials used for 3D printing [8]. Data were collected and mechanical properties of parts printed on different 3D printers were compared. The obtained results of this study about mechanical properties help in quick analysis and comparison between different materials. Perez et al. studied the effect of various filler materials on the strength of the parts printed using ABS. The maximum ultimate tensile strength was obtained in the specimens made using TiO_2 reinforced ABS. Bellini and Guceri presented an analytical model for determining the tensile strength of 3D printed parts by varying process parameters [9]. It was found that the deposition path was the most significant parameter for part strength. Bagsik et al. analyzed the part quality by generating the samples of ULTEM material at different process parameters [10]. Tensile and compression tests were performed to determine the range of mechanical properties for this material. The results indicated that the mechanical properties of printed parts of

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ULTEM depend on the obtained inner structure. Rankouhi et al. investigated the tensile strength of ABS printed parts as the function of layer thickness and raster orientation. The obtained results of their study suggested that raster orientation and layer thickness both had the strong influence on the mechanical properties. Another study on mechanical characterization was carried out by Nikzad et al. on composite materials of iron/ABS and copper/ABS [11]. Experimental results showed the significant improvement in the part strength of iron/ABS and copper/ABS when compared with neat ABS samples. Carneiro et al. explored the possibilities of polypropylene (PP) as a new candidate material for the FDM [12]. Mechanical characterization of sample parts was done to assess the effect of process parameters on mechanical performance. The loss of 20–30% in the mechanical performance was observed in the printed parts when compared to the samples prepared by compression molding. Boparai et al. investigated the nylon6-Al-Al_2O_3 as an alternative material and prepared filament for the FDM process [13]. In their study, it was found that filament exhibits good thermal and wear properties but poor mechanical properties as compared to that of ABS material.

Moreover, few studies have been found in which nanoparticles have been reinforced in a polymer matrix to improve the properties of parts made by the FDM process. Shofner et al. added the nanofibers by varying the weight percentage in the ABS copolymer and developed the filament material for the FDM system [14]. They compared the composite filament with another filament of unfilled ABS. Significant improvements in the mechanical properties were observed. In another study, Francis and Jain developed the polymer-layered silicate nanocomposites for the FDM applications [15]. The results showed a significant improvement in part strength when compared with other macro-composites parts.

Above-cited literature shows that most of the studies were focused on the rigid thermoplastic materials and their composites such as ABS, nylon, etc [16,17]. It is observed that researchers have not given very much attention to soft-elastomeric materials, which are frequently used to fabricate the flexible parts. Few studies have been attempted to study the flexibility aspects of rigid materials [18]. However, it is insufficient for those applications where the highly flexible parts are needed. Therefore, FDM requires a new range of flexible materials for part printing for various applications.

In this study, an elastomer material, ethylene vinyl acetate (EVA) has been used for printing of flexible parts. Since, elastomers have high flexibility, high melt viscosity, and low column strength; pre-fabricated elastomer filaments cannot be processed in standard filament feed extrusion mechanism of FDM machine. Due to low column strength, a filament made with elastomers produces less force than required to push the high viscous melt of elastomers from the nozzle. Therefore, when rollers push the flexible filament into the liquefier of the FDM machine, it buckles as shown in Fig. 1. These constraints make commercial FDM systems incompatible for handling the flexible filaments.

In this study, a unique approach has been used to process the pellets of EVA material by developing a customized pellet based FDM system, namely material deposition tool (MDT). To assure the part strength and flexibility, the impact of different process parameters are studied on tensile properties, i.e., ultimate tensile strength (UTS) and percentage elongation at break (% ε_f) through response surface methodology (RSM) technique. The empirical relations are developed between the investigated process parameters and tensile properties. Furthermore, the genetic algorithm (GA) is also used to determine the unique set of process parameters to maximize the UTS and percentage elongation.

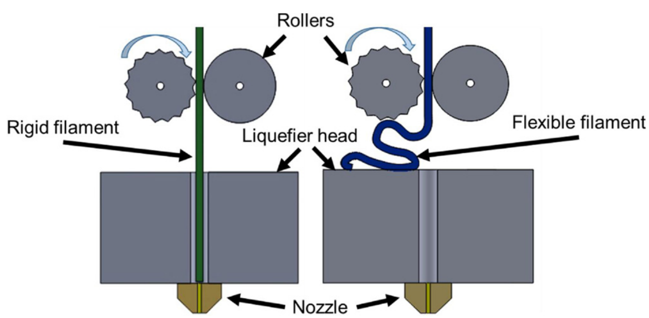

Fig. 1. Schematic diagram of rigid and flexible filament feeding in the FDM.

2. Experimental

2.1. Materials

Ethylene-vinyl acetate (EVA) is a thermoplastic copolymer of ethylene and vinyl acetate (VA). The weight percentage of VA varies between 0–40% depending on the end-use applications of the material. The properties of the copolymer vary with different VA content. The parts fabricated using this material, have the rubber-like softness and flexibility. The properties such as biocompatibility, non-toxic, crack resistive, low-temperature toughness, hot melt adhesive and insolubility make it more suitable for many applications. In this study, ethylene vinyl acetate (SEETEC EVA VS.430) material has been used. The average pellet size was 2 mm. Table 1 presents the typical properties of EVA material.

2.2. Processing

A fully customized variant of FDM, screw extrusion-based Material Deposition Tool (MDT) has been developed to process the EVA material. The MDT was assembled and mounted on three axes CNC machining center, which provides movement to MDT along x, y and z directions. Hence, part fabrication was done without any additional investment in the development of the positioning system. The main components of MDT are the barrel, screw, hopper, supporting frame, band heater, and tool holder as shown in Fig. 2. Screw rotates and pushes the pellets into space between continuously rotating the screw and heated barrel where pellets get viscoelastic form due to the application of friction and supplied heat. Then, this viscoelastic material is extruded from a small nozzle which moves in x and y directions for depositing material on the movable platform mounted on the bed of CNC machining center. Detailed information about the developed MDT are reported elsewhere [19,20].

2.3. Parameter selection and methods

In this study, new EVA material has been explored using novel pellet based FDM. Therefore, careful selection of process parameters is necessary to ensure the continuous extrusion with the desirable flow. Therefore, initial experiments were conducted to identify the process parameters and their range. Based on these experiments, five process parameters were selected in the study, i.e. barrel temperature (A), platform temperature (B), build orientation (C), raster angle (D) and number of contours (E). The other parameters were kept constant at layer thickness (0.60 mm), road gap (0 mm), road width (0.65 mm), deposition speed (1440 mm/min). Selected parameters and their levels are given in Table 2. The printing-related process parameters are represented by Fig. 3.

Table 1
Physical and mechanical properties of EVA material.

Properties	Nominal Values	
Density	0.94	g/cm^3
Vinyl Acetate Content	19	wt.%
Melting Point	84	°C
VICAT Softening Point	61	°C
Hardness (Shore D)	34	D scale