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Investigation on the effects of process parameters in CNC assisted pellet based fused layer modeling process

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ABSTRACT

A new CNC assisted pellet-based fused layer modeling (FLM) process has been presented. It allows the fabrication of highly flexible parts which is not easily possible through the fused filament fabrication (FFF) process as buckling occurs when the flexible filament is fed into liquefier head. Instead of the filament, the presented FLM process utilizes the material in pellet form. The FLM process is different from the other extrusion based AM processes and has its own characteristics. Therefore, the current paper presents a parametric investigation in the developed FLM process by considering the ethylene vinyl acetate (EVA) material. Experiments have been conducted using the 'one factor at a time' (OFAT) approach. The effects of barrel temperature, bed temperature, screw speed, deposition speed, standoff distance between nozzle and bed surface have been studied on the melt flow rate, layer thickness and road width. The obtained results showed that the melt flow rate of EVA is increased with the increase in the screw speed and barrel temperature. A significant variation of approximately 27% was observed in the layer thickness with the change in the deposition speed and standoff distance. A decrease of 42.42% was observed in the road width when the standoff distance was reduced from 2 to 0.8 mm. Based on the investigation, a set of suitable process parameters was obtained to fabricate the flexible parts of the EVA material. The outcomes of the current study showed that the developed FLM process has the capabilities of fabricating parts utilizing a set of suitable process parameters.

1. Introduction

The substantial growth has been occurred in the field of additive manufacturing (AM) after the existence of first AM technique in the late 1980s [1]. The AM processes have gained popularity due to their capabilities of fabricating parts directly from the CAD model, without using any specific tooling [2]. Various AM processes have been developed in the last two decades, and a lot of research work is in progress worldwide on the development of new variants of AM processes. Moreover, the development of low-cost AM processes is in trend for printing the three dimensional (3D) parts of polymeric materials. Fused filament fabrication (FFF) process is one of the low-cost AM processes in which the three-dimensional parts are fabricated by using the filament of polymeric materials [3,4]. However, nowadays polymer-composite filaments are also available in the market for specific FFF machines [5,6]. A filament of appropriate size is used in the FFF process that uncoils from a spool and enters into the liquefier head with the help of drive wheels [7]. Thermoplastics such as acrylonitrile butadiene styrene (ABS), polylactic acid (PLA), and nylon are widely used materials in the FFF process to fabricate the parts for various end-use applications [8]. Most of the available polymers for the FFF process are relatively rigid in nature [9–11]. Currently, thermoplastic polyurethane (TPU) elastomer is also available at relatively high cost in the market for the use in the FFF process, however, compatibility of this material with the available FFF machines is still an issue.

Sometimes, the specific materials are desired to fulfill the consumer demands which may be a rigid polymer or flexible elastomer or polymer composite [10]. In order to serve the purpose, the AM system should be more generic, capable and compatible to accept a wide range of rigid and flexible polymer materials [12]. In the FFF process, the need of specific size and mechanical properties in the filament hinders the development of new materials. For instance, the materials used in the FFF process must have the certain rigidity to withstand against the force exerted by the counter-rotating rollers [13]. The elastomers have less rigidity and low column strength, hence the processing of elastomers through FFF process becomes tedious through the filament extrusion feeding system. Furthermore, the high melt viscosity of the elastomers requires a considerable amount of force for pushing the

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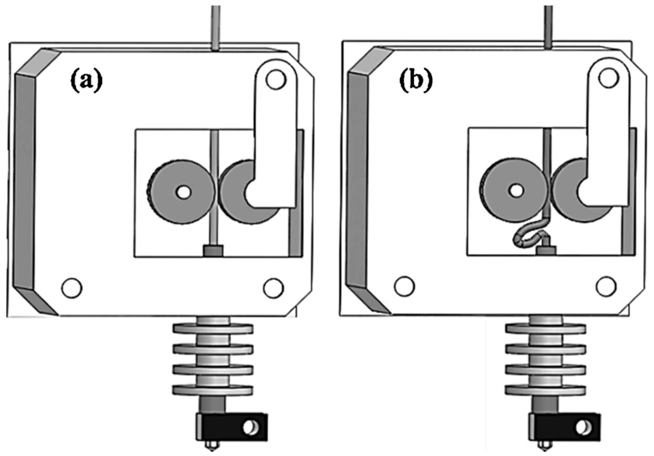

Fig. 1. Filament shapes during feeding of (a) rigid filament (b) flexible filament.

viscous material against a small nozzle opening. The requirement of this force cannot be fulfilled due to the less rigidity and low column strength of elastomers. Due to these contradictory properties, existing feeding system of the FFF process shows the incompetency in the processing of filaments made by highly flexible elastomers. When the rollers push the flexible filament into the liquefier head of the FFF machine, it buckles due to low column strength, as shown in Fig. 1.

In the literature, few studies have been reported on the modification of existing feeding system of the FFF process to see the possibilities of flexible part fabrication [14]. But then again, any modification in the existing feeding system of the FFF process may create the problem in the processing of other standard polymeric materials such as ABS and PLA, etc. Aforementioned problems related to the flexible part fabrication can be overcome via the development of a new generic extrusion based AM system. Therefore, a novel CNC assisted pellet based fused layer modeling (FLM) process is developed with the aim of achieving the low-cost flexible parts fabrication utilizing the pellet form of materials. The developed FLM process is integrated with the CNC milling machine to attain the required movements in x, y and z directions. The developed FLM process works on the screw extrusion based principle. An elastomeric material, ethylene vinyl acetate (EVA) material is considered in the present study. The developed FLM process fabricates the flexible parts by depositing the EVA material in a layer-by-layer manner. During the part fabrication, EVA in the viscous form is deposited in the road shape on the preheated bed surface in a prescribed manner.

As compared to other extrusion-based AM processes, the developed CNC assisted pellet based FLM process has its own unique characteristics. Hence, a fundamental investigation is needed to understand the effect of various process parameters and the part fabrication through the developed FLM process. The melt flow rate (MFR) of the extruded material is the critical process parameter in the FLM process as it can affect the heat transfer and solidification rate of the extruded material during the part fabrication. Also, the road shape of semi-molten EVA gets deform under the influence of surface tension, self-weight, pressure, and viscosity after deposition on the preheated bed surface. The process parameters such as barrel temperature, bed temperature, deposition speed, standoff distance between the nozzle and bed surface are the other influential parameters, which may affect the evolution of deposited road shape. In the developed FLM process, high-quality part fabrication is possible when these parameters are synchronized together.

Therefore, in the current study, a detailed parametric investigation is performed to see the effect of various process parameters on the MFR, road shape (thickness and width). One factor at a time (OFAT) approach is employed to design the experiments. Based on the results obtained from the current investigation, a set of suitable process parameters is selected to fabricate the flexible parts through the FLM process. The present study reports the initial investigations and current progress in the developed FLM process. Various advantages of the developed FLM process are highlighted such as capabilities of fabricating the high-quality flexible parts using the material in pellet form.

2. Experimental

The schematic diagram of the newly developed experimental setup of FLM process used in the present study is shown in Fig. 2. The developed experimental setup of FLM process has various components namely material deposition tool and three-axis CNC milling machine, as shown in Fig. 3. The material deposition tool of FLM process the material and converts it into the semi-molten state. This tool contains the

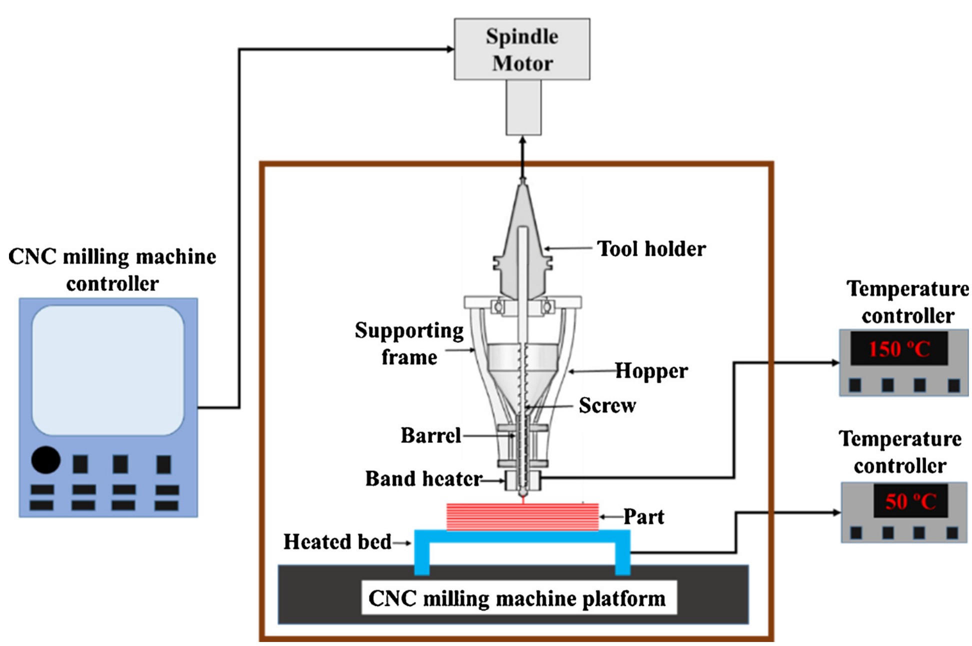

Fig. 2. Schematic diagram of the experimental setup of the FLM process.