Journal of Materials Processing Technology 226 (2015) 280–286

Contents lists available at ScienceDirect

Journal of Materials Processing Technology

journal homepage: www.elsevier.com/locate/jmatprotec

Optimization of the printing parameters affecting dimensional accuracy and internal cavity for HIPS material used in fused deposition modeling processes

Mahdi Kaveh*,[1], Mohsen Badrossamay, Ehsan Foroozmehr, Ardeshir Hemasian Etefagh[1]

Department of Mechanical Engineering, Isfahan University of Technology, 84156-83111 Isfahan, Iran

ARTICLE INFO

Article history:
Received 17 February 2015
Received in revised form 23 May 2015
Accepted 14 July 2015
Available online 22 July 2015

Keywords:
Fused Deposition Modeling
Investment casting
Parameter optimization

ABSTRACT

Fused deposition modeling (FDM) is an alternative process for fabricating wax pattern in investment casting technologies due to its ability to fabricate parts with complex geometries within a reasonable time using HIPS as extruded material. Considering the nature of investment casting, wax pattern must be fabricated accurately without internal cavity. In this paper, the effect of printing parameters (PPs) on precision and internal cavity of the fabricated part is investigated for materials with unknown PP. Hence, experimental method is presented to determine the optimum quantity of each effective PP for HIPS material. These parameters include extruded temperature, and raster width. Finally, in order to minimize systematic errors between the designed and actual dimensions, calibration factors for parts, holes, and thicknesses were calculated by designing proper benchmarks as well as statistical equations. This method can be used for either determining value of PPs for unknown materials or optimizing PPs for existing materials such as ABS, or PLA where an increase in dimensional accuracy or a reduction in internal cavity is desired.

1. Introduction

Since early development of industry, the purpose of prototyping was to observe practical problems associated with the designed parts and to perform part's failure tests such as mechanical, thermal, fatigue, etc. Fused deposition modeling (FDM) presents an efficient fabricating process thanks to its ability to fabricate initial models with complex geometries within a reasonable time and price framework. However, FDM can only fabricate parts with its base materials like ABS, HIPS, or PLA. And as a conclusion, metal prototypes cannot be made with this process. In the immediate objective of this paper, an efficient prototype fabrication process was presented that had advantages of FDM processes in terms of prototype fabrication with final part built from its design materials. In the mentioned fabrication process, there is a combination of FDM and investment casting processes. FDM comes into fabricating wax pattern in the investment casting process. Cheah et al. (2005) used ABS as a fused material in the FDM process, in order to fabricate wax pattern, and claimed that combustion of ABS results in residual ash, eliminating which from shell might be difficult in some geometries. Dickens et al. (1995) mentioned that wax models fabricated by ABS were very brittle and this might cause some damages to the wax once it reaches to the foundry. Agarwala et al. (1996) utilized the same process and reported that internal and surface defects of fabricated wax pattern could be eliminated by optimization of FDM parameters. Moreover, Cullis and Chalabi (1982) reported that combustion of polystyrene resulted in smoke generation and the specific density (D_s) of polystyrene had an inverse relation with the amount of smoke. High-Impact polystyrene (HIPS) is one of the raw materials of FDM processes which has characteristics of polystyrene.

In order to reduce mentioned problems, HIPS was utilized to eliminate the residual ash, and parameter optimization method was presented to reduce internal and surface defects of application. Bansal (2011) and Sood et al. (2009a) reported that in a FDM process, shrinkage caused a reduction in fabricated part dimensions; however, the value of thickness was always more than the desired value. In other words, for desired thickness and dimension, calibration factor must be assigned separately to eliminate systematic errors. Moreover, Sood et al. (2009b) demonstrated that

---

* Corresponding author. Address: No.45/1- bagh ziar Alley- se rahe simin St.-Isfahan, Postal Code: 81 777-67381. Iran.
E-mail addresses: mahdikaveh92@gmail.com, mahdikaveh@aut.ac.ir (M. Kaveh).

[1] Currently MSc student at Amirkabir University of Technology.

http://dx.doi.org/10.1016/j.jmatprotec.2015.07.012
0924-0136/

distortion might be increased with reducing layer thickness. On the other hand, Anitha et al. (2001) reported that layer thickness had an inverse relation with surface roughness. And Vasudevarao et al. (2000) stated that extruded temperature and raster width had no significant effect on surface finishing. It can be concluded that, for obtaining the best surface finishing, the minimum layer thickness before distortion appears in the part, must be chosen.

In this paper, an experimental method for obtaining optimized values of PPs for High Impact Polystyrene (HIPS) will be represented. In the first step of the proposed method, PPs and effects of them on dimensional precision and internal cavity of the fabricated part are investigated. Then, optimum quantity of each effective PPs were determined by experimental analysis. After these two steps, parts with acceptable precision and minimum internal cavity can be fabricated, but some systematic errors can be seen between the actual dimensions and the designed ones. Finally, with designing appropriate benchmarks and statistical equations, one can assign proper calibration factors to increasing accuracy of the dimension of parts, holes, and thicknesses. As mentioned before, this method of parameter determination and optimization can be used for other unknown materials as well.

2. Parameters

In FDM process, parameters affecting dimensional accuracy are divided into two separate categories of process parameters and PPs. Chouksey (2012) and B.H. Lee et al. (2005) reported that process parameters are layer thickness, orientation, air gap, and raster angle; and PPs are extruded temperature, feed rate, flow rate, and raster width. In the second group of parameters, each parameter may have different values for various materials. In this study, the effects of PPs (second group) on precision and internal cavity, and also on HIPS as the extruded material has been investigated; these parameters are briefly represented as follows:

a) Raster (extruded) width: described as the width of raster in raster pattern calculation.
b) Raster angle: described as the angle between raster and X axis.
c) Extruded temperature: described as the melt temperature for extruded material.
d) Flow rate: described as the amount of extruded material from the nozzle per unit time.
e) Feed rate: described as the linear moving speed in X and Y direction.

In this experiment, fabricated benchmarks with different tasks were evaluated based on dimensional precision, surface finishing, and amount of internal cavity, in order to determine optimum values for each PPs. Lee et al. (2004) claimed that designed benchmark must include simple geometries and features so that the measurement of data could be achieved by simple measuring instruments; besides, benchmark should be fabricated with low material usage along with an ability to generate reliable analytical data. Furthermore, during fabrication of the benchmark for a specific task, all process and printing parameters were kept constant, and the only changing parameter was the examined one. Constant parameters of the processes and materials of this study are shown in Table 1. Besides, the thicknesses of all benchmarks were set equal to 10 mm for the sake of unification. In following, utilized methods for gaining optimum value of extruded temperature and raster width are presented.

In this study, utilized FDM machine was "RapMan 3.0" with HIPS as extruded material, and "Axon 2" as G-code generation software.

Table 1
Constant parameters through whole experiment.

Parameter	Value
Standby temperature	140 °C
Prime speed	0.0942 m/s
Reverse speed	0.1413 m/s
Flow rate	0.1511 cm3/s
Feed rate	16 mm/s
Filling density	100%
Fill pattern	Parallel
Extruded temperature	Examined
Contour number	1
Extruded (raster) width	Examined

2.1. Temperature

In FDM process, extruded temperature is one of the most effective parameters on final pattern of raster and layers formation and as a result, on amount of internal cavity. In general, extrusion temperature of raster is defined as extruded temperature being different from those of the former raster as well as the lower layer. Yardimci et al. (1996) demonstrated that the temperature difference can affect the previous raster and/or the lower layer making them change their positions. These changes are caused by the shrinkage of polymer and bring about hollows in the final part. Besides, Alhubail (2012) reported that polymer might be relaxed or expanded at higher temperatures which means that we may have an increase in dimensions in higher extruding temperatures. Also, Yardimci et al. (1996) reported that shrinkage may cause dimensional reduction in fused deposition processes and shrinkage's effect has direct relation with temperature. In other words, temperature may have some effects on dimensional accuracy too. According to utilized material's catalogue, recommended range of extrusion temperature was 210–230 °C. In this paper, three temperatures of 210, 220, and 230 (Celsius) examined in order to covering all recommended range and the optimum temperature will be achieved from this range.

In the first step of temperature optimization, three models with three samples for each temperature were examined (a total of 27 samples). The aim was to detect effects of temperature on dimensions. In order to increase the reliability of the measurements, each dimension were measured at the beginning, meanwhile, and at the end of the extrusion (three times) and standard deviations were calculated for all dimensions. Error bars were determined for each sample by using Eq. (1) and average error of the sample is shown in Table 2 for each model. Moreover, for simplification, all calculations were based on E variable which is defined as the difference between measured and designed dimension, not the dimensions themselves; and the results were reported accordingly. Another equation for demonstrating dimensional precision of the tested models was Eq. (2) that represented fabricated part's dimensional error (E) in [−R, +R] interval with probability of 99%. Above equations are reported by Taylor (1996).

$$S_e = \frac{\sigma}{\sqrt{N}} \tag{1}$$

Error bar

$$-R \le E \le +R \text{ which } R = 2.576 \times \sigma(\text{mm}) \tag{2}$$

Error's interval with probability of 99%

As it can be seen from Table 2: (1) precision reduces with decreasing sample's dimension in all three extruded temperatures; and (2) main error of 220 °C samples have a major difference with the other two temperatures in case of small dimension (under 20 mm × 20 mm). One can conclude with these two results that an extruded temperature of 220 °C is not effective for HIPS. (Gaztelumendi and Nazabal, 1986) reported that raster relaxation