Available online at www.sciencedirect.com

ScienceDirect

IFAC-PapersOnLine 49-31 (2016) 42–48

Post processing for Fused Deposition Modeling Parts with Acetone Vapour Bath

Amirali Lalehpour*, Ahmad Barari**

Department of Automotive, Mechanical and Manufacturing Engineering, University of Ontario Institute of Technology, Oshawa, L1H 7K4, Ontario, Canada

** e-mail: amirali.lalehpour@uoit.ca*
*** e-mail: ahmad.barari@uoit.ca*

Abstract: Additive Manufacturing (AM) has the benefit being capable to create very complex geometries, which could be impossible with traditional methods or fabricated at high cost. However, the manufacturing cost of AM is not directly related to the parts complexity. From material costs perspective, the cost of AM parts is mostly related to the size of the product. However, some AM techniques, such as Fused Deposition Modelling (FDM), suffers from poor surface roughness restricting its application in some areas requiring high surface integrity. Because of this issue, a post processing stage is required to improve the surface roughness of the AM parts. In this work, an acetone vapor bath smoothing post process is employed to improve the surface roughness of parts manufactured by FDM. The smoothing parameters are the number of smoothing cycles and the cycle duration. Eventually, the total time during which the part is in acetone vapour is found to be the main factor affecting the final surface roughness. The surface of the parts are digitized using a 3D microscope and the extracted point cloud was used to analyze the surface. A total least square plane is fitted to the points and the deviation of points from this plane is used for calculation of the surface roughness. The results of this study suggests the best smoothing parameters to get the best surface roughness for each set of design parameters. The final surface roughness can be predicted by the experimental models developed based on the build orientation and layer thickness.

Keywords: Additive manufacturing, surface roughness, fused deposition modeling, total least square fitting, acetone vapour smoothing.

1. INTRODUCTION

The surface integrity of parts manufactured by AM is one of the main concerns which needs to be addressed and improved before more adaptation of this technology into industries (Jamiolahmadi and Barari (2014)). The poor surface roughness is due to the stair case effect resulting from the layer based nature of the AM process family. The main factor affecting the stair case effect is the layer thickness. A smaller layer thickness results in a better surface roughness, but increases the built time. Another factor reducing the surface integrity of parts fabricated by some of the AM processes, such as Fused Deposition Modelling (FDM), is the requirement of support material where there is not material underneath the current layer. The interaction between the support material and the built material increases the roughness. This interaction makes removing the support material hard and imposes extra cost and time on the process. FDM is one of the AM processes that suffers from poor surface roughness and also support requirement affects this process. It has many process parameters such as: layer thickness, part orientation, raster angle, road width and etc. The surface roughness of AM parts has been studied and the affecting parameters are discussed (Armillota et al. (1999) and Sood et al (2009)). Product's surface curvature can be used as an indicator to select the best layer thickness. Assessing the surface curvature is a way to select the proper layer thickness. Selecting the layer thickness based on surface curvature is referred to as adaptive slicing (Mani et al (1999), Pandey et al. (2003), and Sikder et al. (2015)). In spite of all possible improvements, the surface roughness of AM parts needs more enhancement to be in an acceptable level, FDM parts in particular. Post processing of the parts is performed to improve the surface roughness. Kim and Lee (2005) and Ahn et al (2007) considered the build orientation as the main factor influencing the surface roughness and intended to minimize the post processing. Post processing can be divided into two approaches: mechanical and chemical.

Kulkarni and Dutta (2000) proposed CNC machining for improving the surface roughness of FDM parts. Tool path generation was the focus of this study. Boschetto et al (2016) also used CNC machining for this purpose and introduced variable cutting depth which is related to the deposition angle. Other researchers have reported an improvement of surface roughness by introducing mechanical approaches into the process (William and Melton (1998) and Leong et al. (1998), and Pandey et al. (2003)). The main problems associated with the mechanical processes are inaccessibility of some regions on the surface, the delicate features, process costs and the need for clamping the part. Boschetto and Bottini (2015a, b) used a Barrel Finishing (BF) method which has the advantage of not requiring a clamping stage. The main design factor in this approach is build orientation and the BF working time is the primary process parameter affecting the final surface roughness. Longer processing times leads to better results. This mechanical method does not fulfil the requirements of a

2405-8963 © 2016, IFAC (International Federation of Automatic Control) Hosting by Elsevier Ltd. All rights reserved.
Peer review under responsibility of International Federation of Automatic Control.
10.1016/j.ifacol.2016.12.159

fully functional method as still there can be regions inaccessible by this process and also the delicate features might be damaged. An efficient method must be able to improve the surface roughness without changing the mechanical and geometrical properties of the surface, improve the surface roughness over the entire surface, and more importantly do not require clamping and extra costly operations.

Chemical approaches have a significant effect on the surface roughness without the restrictions associated with the mechanical ones. However, certain chemicals, for instance acetone, might be inapplicable to some built materials such as Polylactic acid (PLA) as they do not react chemically. Acetone is a good choice to post process the parts made of Acrylonitrile Butadiene Styrene (ABS). Barari (2014) and L.M. Galantucci et al. (2009 and 2010) showed that chemical post processing of the ABS parts with acetone has a significant effect on the surface roughness with a negligible change in prototype's dimensions. Kuo and Mao (2016) reported a decrease in smoothing time. The smoothing time was found to be a function of surface area. Garg et al. (2016), considered the effect of part orientation on surface roughness processed by acetone vapour bath and the stair case effect was decreased dramatically. The process parameters have not been discussed in these studies and no relationship is found between the post processing stage and the resulting surface roughness. For example, if a final surface roughness is required on the part, the procedures to achieve such roughness is not addressed in the research studies done so far.

The literature survey shows that the chemical methods yield better results than the mechanical ones in many aspects. Therefore, the aim of this study is to investigate the post processing parameters affecting the surface roughness and provide a thorough approach to determine the final surface roughness based on the considered post processing setups. In this study, the specimens do not need support material so effect of this factor is not taken into account. The main roughness source in this study is the inherent layer by layer nature of the FDM process. The results of this study can be used as design models for post processing of FDM parts. The suitable exposure time to acetone vapour for specific surface roughness can be determined.

2. ACETONE VAPOUR BATH SMOOTHING

The smoothing process with acetone is utilized to improve the surface finish of the ABS parts fabricated by FDM process. ABS do not react with acetone and the chemical properties of the part do not change. Acetone is a good choice for this purpose because of its low cost, very low toxicity and very high diffusion. However, acetone can change the geometry of ABS. In the smoothing process by acetone, it is boiled and the parts are suspended in the vapour bath. The interaction between acetone and ABS results in a slurry of ABS and acetone on the surfaces of the part. As acetone evaporates due to its nature, the ABS polymer strands will be left on the surface. The microscopic shape of ABS is changed by the surface tension of the acetone/ABS solution. The smoothing process improves the surface roughness but the amount of smoothing and part's dimensional accuracy requires more examination.

3. DESIGN OF EXPERIMENTS

The specimens are designed so as to have all angles from 5 to 90 degrees with 5 degree increments. Thus on each sample there will be 18 slopes. Two layer thicknesses are considered as 0.010 and 0.013 inch leading to 36 cases in total. Fig. 1 depicts the manufactured specimens. The slopes are designed on a cubes of 60×60 mm dimension. The raster angle used in manufacturing of the samples is 45 degrees. The bead width is equal to layer thickness used. The smoothing parameters taken into account are the number of cycles and cycle duration. Three levels are chosen for each one. Therefore, 3^2=9 smoothing setups are considered based on full factorial method in design of experiments (Table 1). The full factorial method is chosen as there is not enough data available for surface roughness at different surface angles. In general, 9×36=324 experiments are performed. An important note is that the samples are manufactured in such a way that on the final surface there are only horizontal beads alongside each other. Therefore, the raster angle used in the filling stage does not have a significant effect on the surface roughness vales.

Table 1. Smoothing factors.

Factor 1 # of cycles	Factor 2 Cycle Duration (Seconds)
2	8
3	10
4	15

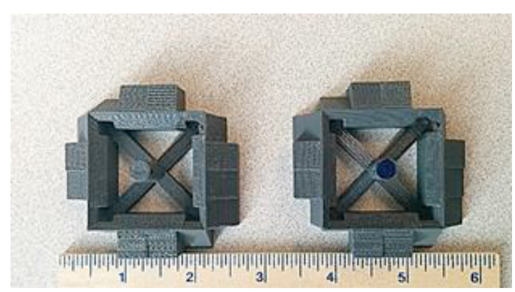

Fig. 1. The manufactured specimens with 0.010 in (right) and 0.013 inch (left) layer thickness.

4. METHODOLOGY

The 3D topography of the surfaces is examined under a microscope before and after the post processing with acetone vapor bath. The surfaces are digitized to get the 3D point cloud of the surfaces. The typical surface topography results for 0.013 inch layer thickness samples before smoothing and smoothing for 4 cycles with 15 seconds duration at surface slopes of 50 and 65 degrees are represented in Fig. 2. As it can be seen from the results, the staircase effect has been decreased significantly.

In order to examine the surface roughness, the digitized surfaces are considered and the Total Least Square (TLS) plane is fitted to the point cloud data. The total sum of arithmetic distance of all points from TLS plane is minimum.