Numerical evaluation of ABS parts fabricated by fused deposition modeling and vapor smoothing

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ABSTRACT

Fused deposition modeling (FDM) is one of the popular 3D printing technologies due to an inexpensive extrusion machine and multi-material printing. However, FDM could only use thermoplastics such as ABS and PLA and has a problem related to the post-processing. In this study, the mechanical properties of ABS parts fabricated by FDM were measured. The ABS parts were divided into one with vapor smoothing process and the other without the vapor smoothing process which is one of the the post-processing methods. Using dynamic mechanical analysis (DMA) and dilatometer, temperature-dependent storage modulus and CTE for ABS specimens were observed. Based on the measured thermo-mechanical properties of ABS parts, finite element analysis was performed for an automotive bumper made of ABS. Moreover, response surface methodology was applied to study the relationship among design parameters of thickness of the bumper, ambient temperature, and application of the vapor smoothing process. In result, a design guideline for a ABS product could be provided without time-consuming experiments.

1. INTRODUCTION

Recently, additive manufacturing also known as 3D printing has received a great deal of attention in many fields such as automotive, aerospace, engineering, medicine, biological systems, food supply chains and so on (Gao et al. 2015). Compared to the conventional subtractive manufacturing such as turning, cutting, milling and grinding, the additive manufacturing has unique advantages in design flexibility, personal fabrication, cost of geometry complexity, dimensional accuracy and so on (Gao et al. 2015). However, the additive manufacturing has disadvantages of trade-off between building scalability and layer resolution, cost for mass manufacturing, material heterogeneity, need of anchor and support material, and requirement for post-processing. In order to overcome above drawbacks, many researchers have studied for the next generation of the 3D printing techniques (Gao et al. 2015). In this study, we focus on the post processing technique for the additive manufacturing. Sometimes 3D printed objects such as overhangs and undercuts need support material. So the post processing is necessary to detach the support material from the printed objects. Moreover, the printed parts need to be polished in order to guarantee a smooth surface finish. The polishing process could be sanding or vapor smoothing. The sanding may not be possible for tiny or complex geometries. On the other hand, the vapor smoothing could be effective for the complex shapes fabricated by 3D printing.

Kuo and Mao (2016) developed the acetone-vapor polishing system to smooth acrylonitrile butadiene styrene (ABS) parts manufactured by fused deposition modeling (FDM). They suggested that this system has flexibility to maintain dimensional accuracy high polishing efficiency and so on. Garg et al. (2016) evaluated three methods of immersion in lukewarm pure acetone, hot vapor treatment, and cold vapor treatment for long duration in order to improve the surface finish of FDM parts. They proved that chemical treatment with cold vapor could be one of the best ways to improve surface quality. Chohan et al. (2016) suggested a mathematical model for average surface roughness of vapor treated parts. They reported that vapor smoothing time is an important factor for the average surface roughness. However, these polishing processes dissolve the outer surface of ABS parts so that this system could affect the structural reliability.

In this study, we evaluate mechanical properties of ABS fabricated by FDM and the vapor smoothing. FDM belongs to a category of material extrusion, which is an inexpensive and very popular 3D printing technique (Gao et al. 2015). But FDM struggles with poor surface finish so that the vapor smoothing technique could be very helpful to enhance the quality of the printed objects. FDM could use thermoplastics, ceramic slurries and metal pastes as a printed INK. ABS being one of thermoplastics is investigated in term of mechanical property. Many researchers have studied mechanical property of 3D printed objects fabricated by FDM. Belter and Dollar [5] measured strength of 3D printed ABS parts using three-point bending test. Melenka et al. (2015) measured material properties of

FDM- printed PLA objects using an MTS tensile testing machine. Cantrell et al. (2017) measured mechanical properties of 3D printed ABS and polycarbonate (PC) parts using a universal tensile machine. In this study, temperature-dependent mechanical properties of 3D printed ABS parts fabricated by FDM and the acetone-vapor smoothing are measured by using dynamic mechanical analysis (DMA) and dilatometer. Based on the measured data, finite element analysis and response surface methodology are performed in order to generate a design guideline for an automotive bumper made of ABS.

2. METHODOLOGY AND RESULTS

This section is divided into two subsections. The first describes thermo-mechanical properties of ABS specimens measured by DMA and dilatometry. The second subsection depicts numerical simulation for an automotive bumper made of ABS.

2.1. Thermo-mechanical properties of ABS specimens

Four different splits were measured, which were exposed to different amount of acetone vapor; 0ml, 5ml, 10ml and 15ml. Three specimens per each split were fabricated in the same condition. Thermo-mechanical properties of the ABS specimens were obtained, which are the storage modulus and CTE as shown in Fig.1 and Fig.2.

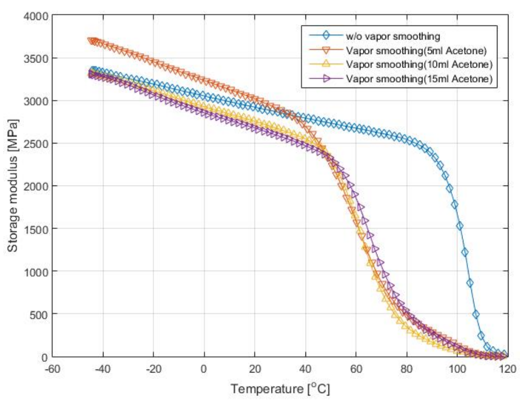

Figure 1. Average of temperature dependent storage moduli for four splits

Fig.1 graphically shows the difference between specimens without vapor smoothing process and ones with vapor smoothing process. The glass transition temperature of the specimens with the vapor smoothing process is lower than one without the vapor smoothing process. However, we hardly observe a relationship between the storage modulus and the amount of acetone vapor in the range of 5ml to 15ml. We may search the other range in term of the amount of acetone vapor. This will be further work.

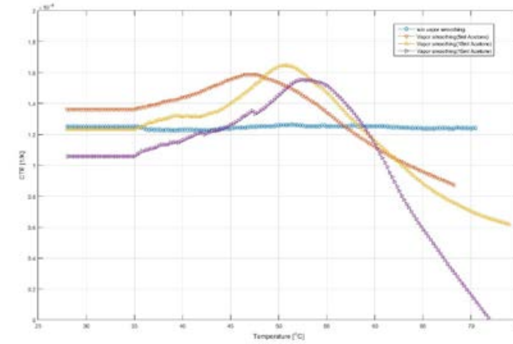

Figure 2. Average of the temperature dependent CTEs for four splits

Fig.2 shows that CTEs vary as the temperature increases. CTE of the specimen without vapor smoothing is relatively constant. However, CTEs of the others with vapor smoothing have large variations and have one peak between 45°C and 60°C. As the temperature increases more than 60°C, CTEs of the samples with vapor smoothing decreases. As same as the results obtained by using DMA, we could not observe any correlation between CTE and the amount of acetone vapor in the range of 5ml to 15ml.

2.2. Numerical evaluation for an automotive bumper made of ABS

In this section, a portion of a bumper is modeled and structurally evaluated by using finite element analysis as shown in Fig. 3 and Fig. 4. Fig 3 shows the geometry of the automotive bumper. Fig 4 graphically shows fixed boundary conditions, load boundary conditions, and body temperature condition on the geometry. In Fig. 4, the symbol of A, B and C mean boundary conditions of fixed support, pressure, thermal condition.

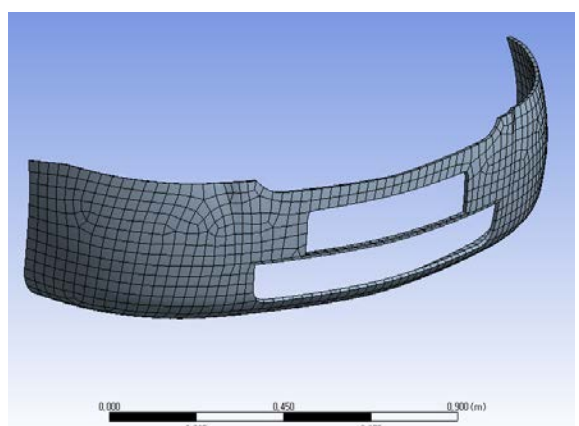

Figure 3. Finite element model for an automotive bumper

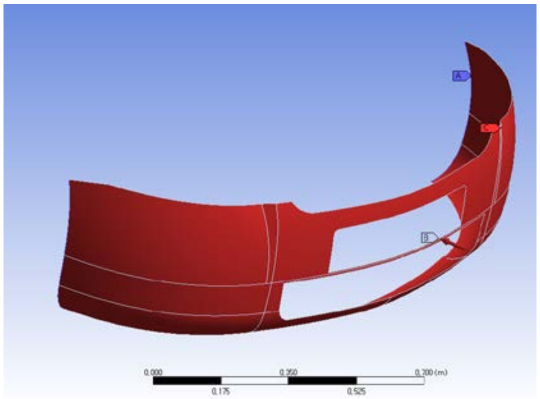

Figure 4. Boundary conditions for the finite element model

Input parameters for the response surface methodology were temperature, thickness of bumper, element size, and application of the vapor smoothing. The output parameter was a maximum of total deformation of the bumper as shown in Fig. 5.

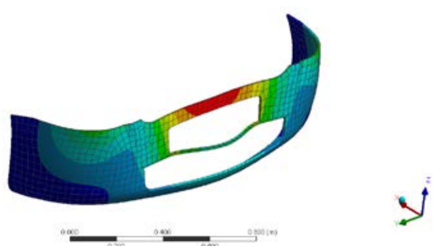

Figure 5. Total deformation of the bumper

Using the response surface methodology and the finite element analysis, contour plots were computed by using Minitab software as shown in Fig.6. According to the vapor smoothing process, two design guidelines could be provided for bumper designers.

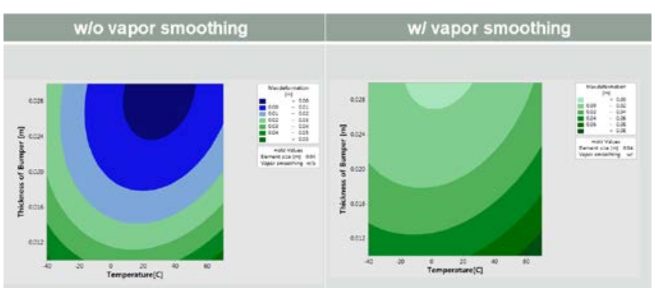

Figure 6. Contour plots according to the vapor smoothing process

3. CONCLUSIONS

In this study, the temperature-dependent mechanical properties of ABS parts were measured, which were fabricated by FDM and the vapor smoothing technique.
The vapor smoothing process weakens thermal stability of ABS 3D printed parts. Based on the measured thermos-mechanical properties of ABS specimen, finite element analysis and response surface methodology for an automotive bumper made of ABS were performed so that design guidelines could be provided.

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