Effect of 3D-printing and compression molding on anisotropy of ABS micro specimen: A comparative study based on DIC

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ABSTRACT

This paper aims to calculate and compare normal anisotropy coefficients in 3D-printed and hot-compression molded micro ABS specimens. To achieve this goal, micro specimens of additively-printed and compression-molded ABS were fabricated and tested using a micro-tensile testing apparatus integrated with an optical microscope while deformation of the specimens was recorded by a camera. Frames from this video were selected and strain distribution on a micron-sized area of interest was obtained using digital image correlation (DIC) analysis. It was shown that there exists a close agreement between DIC results and *in situ* optical observations. The plastic anisotropy coefficients (*R*-values) were then calculated from the surface strains as a function of applied strain. For this purpose, through-thickness strain component was obtained assuming plastic incompressibility condition. Results showed that both micro samples revealed an anisotropic response during plastic deformation. At low plastic strains, the printed micro specimen exhibits a more anisotropic behavior than the monolithic micro specimen. As the deformation proceeds, the normal anisotropy coefficient increases for the additively-manufactured micro specimen and decreases for the hot-pressed micro specimen.

KEYWORDS

Acrylonitrile butadiene styrene (ABS), 3D printing, compression molding, digital image correlation (DIC), anisotropy

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1. Introduction

3D printing, or additive manufacturing (AM), is a method by which complex parts are fabricated from 3D computer models. In this technique, the 3D CAD model is saved as a stereolithography file format (.STL) and then sliced into several thin layers using slicer software. The output is a G-code file that is imported to a printer. The printer extrudes molten materials in a layer-by-layer manner until the object is built up. The advantages of 3D printing over traditional manufacturing methods include achieving high precision, reducing or eliminating waste material, as well as being time- and cost-efficient [1].

Acrylonitrile butadiene styrene (ABS) is a thermoplastic polymer that is widely used in 3D printing because of its low price, good mechanical properties, and high impact resistance. In recent years, extensive research has been conducted to investigate the mechanical properties [2] and fracture behavior [3] of additively-printed ABS.

Due to the different raster and build angles, printed specimens demonstrate pronounced anisotropy in mechanical properties, that has been widely studied by many researchers (see, e.g., [2]). In these research studies, samples printed in different directions are subjected to tensile loading and the difference in stress-strain responses is considered as a measure of anisotropy. The authors of this paper recently published a paper [4] that investigated the effect of two processing methods (3D printing and compression molding) on the micromechanical behavior of ABS. They showed that the printed specimens demonstrated higher mechanical properties compared to the hot-pressed specimens. Also, results from DIC analysis showed more intense local strains in 3D printed specimens than the monolithic compression-molded ones. In the current paper, the influence of the two processes on the normal anisotropy coefficient is studied. To achieve this goal, micro-specimens of the 3D-printed and monolithic ABS are tensioned under the objective lenses of an optical microscope. DIC analysis is applied to the optical images acquired during deformation in order to quantify the normal anisotropy coefficient.

2. Experimental Procedure

Micro-specimens of ABS, with the dimensions shown in Figure 1, were printed using a Monoprice laboratory printer. Print settings are listed in Table 1. To investigate the effect of processing on anisotropy, an ABS sheet was fabricated from the filament used for the print. For this purpose, the filaments were heated at $200^{\circ}C$ for 4min. The molten material was then pressed to obtain a 1mm thick sheet. From the produced sheet, micro-specimens with the dimensions illustrated in Figure 1 were cut out using a micro CNC machine. 3D-printed and monolithic specimens were tensioned under constant strain rate of $\dot{\varepsilon} = 0.005\,/\,s$ using a micro-tensile testing apparatus integrated with an optical microscope. Details of the experimental setup were presented in reference [4]. The setup has already been used to study fracture micro-mechanisms in Mg alloys[5]. Before the tests, micron-sized black dots were sprayed on specimen surface to assure a random grayscale value distribution needed for subset matching in DIC analysis. A 30fps CMOS camera was utilized for recording the deformation of the specimens. From the recorded video, specific frames were snapshotted for DIC analysis. Using the ImageJ software, the size of pixels was obtained to be $\sim 2.9\mu m$. Images selected for DIC analysis were loaded in Ncorr open-source Matlab code [6] to calculate strains on specimen surface. A rectangular region of interest (ROI) within the gage area of the specimens was selected for image processing. Inside the ROI, circular subsets with a radius of 30 pixels and spacing of 4 pixels were defined as DIC parameters. Surface strains (ε_x and ε_y) were directly measured by 2D-DIC analysis. Through-thickness strain component (ε_z) was estimated from the strain incompressibility condition. This assumption was used for ABS in other research studies [7]. Note that the infill parameter was considered 100%. The evolution of normal anisotropy coefficient (*R*-value) was calculated as the ratio of width strain to through-thickness strain.

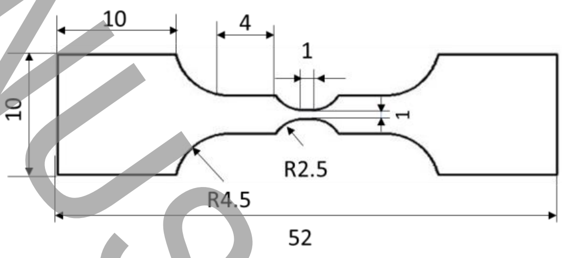

Figure 1. Dimensions of the micro-specimens

Table 1. Print parameters

Parameter	Value
Nozzle temperature	$235^{\circ}C$
Bed temperature	$60^{\circ}C$
Print speed	5mm/s

Infill	100%
Layer height	0.15mm
Raster angle	45°

3. Results and Discussion

The stress-strain curve for the printed specimen is given in Figure 2. The four points marked on the diagram are associated with moments at which the DIC analysis was performed and the normal anisotropy coefficients are obtained. Similarly, four points are marked on the stress-strain curve of the monolithic specimen (Figure 3). Figure 4 compares the evolution of mean *R*-values for both specimens. At the beginning of the plastic deformation (point 1 in both curves), the printed sample showed a more anisotropic behavior than the monolithic one (0.27 vs. 0.35). It should be pointed out that deviation from $R = 1$ is the criterion based on which the severity of anisotropy in the samples is measured. As the plastic deformation proceeded (points 2 to 4 in both curves), the deviation from $R = 1$ for the monolithic sample became greater than that for the printed sample. Consequently, the monolithic specimen exhibited a more anisotropic behavior. It seems that the alterations in the configuration of polymer chains are responsible for this behavior. At point 1, polymer chains in the printed specimen are oriented in the extrusion direction, leading to a more directional mechanical response and higher anisotropic behavior. It seems the orientation of the polymer chains was changed during tension so that it became more chaotic, which resulted in a more isotropic behavior. In the unprinted specimen, however, as the deformation continued, the initial irregular chains were opened and aligned in the direction of tension, resulting in a preferential orientation for the polymer chains, which led to an increased anisotropy at higher strains.

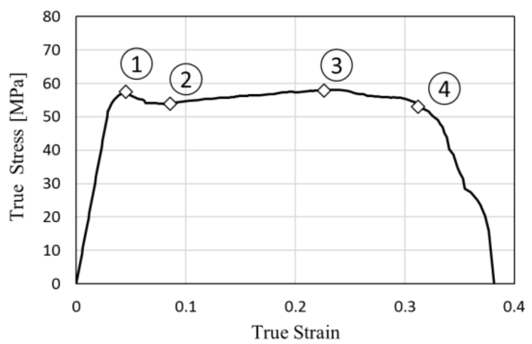

Figure 2. Stress-strain curve of the printed specimen

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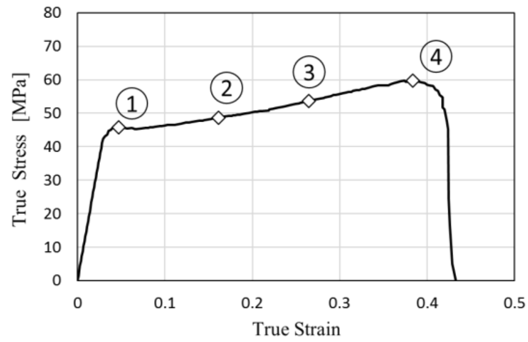

Figure 3. Stress-strain curve of the monolithic specimen

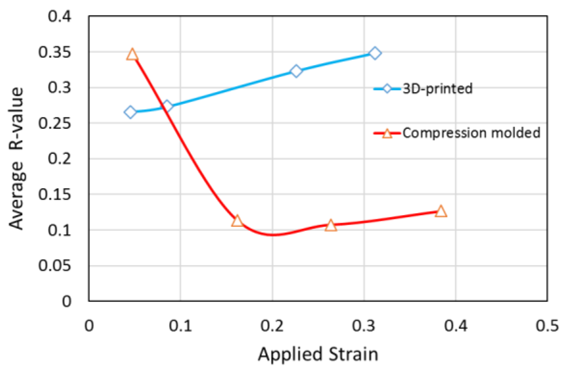

Figure 4. Variation of R-values of the two specimens

4. Conclusion

In this study, the effect of two processing routes (3D printing and compression molding) on the *R*-values of the micro ABS specimens was studied. It was observed that both specimens reveal an anisotropic behavior. In the early stages of plastic deformation, the 3D-printed specimen showed a more pronounced anisotropic behavior. As the deformation continued, the anisotropy of the monolithic sample increased, whereas the anisotropy of the printed specimen decreased. Such changes were attributed to the orientation of polymer chains in the two specimens.

5. References

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