

Dimensional Characteristics of Hydraulic Actuator Curve based on 3D Printing Filament Materials

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3D 프린팅 필라멘트 재료에 따른 유압액츄에이터 커브의 치수 특성

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(Received 02 November 2020; received in revised form 23 November 2020; accepted 30 November 2020)

ABSTRACT

In this paper, the 3D shape of a hydraulic actuator cover was 3D printed by applying two materials, namely PLA and ABS. Subsequently, the printed shape was scanned to analyze the material properties, dimensional change characteristics, dimensions, and scan shape as a real model. To compare and analyze material-specific 3D printing dimensions, a non-contact mobile laser scanner was used to scan a portion of the printed hydraulic actuator cover and the final alignment shape of the 3D printed part was studied on the basis of the design model.

Keywords : Hydraulic Actuator Cover(유압액츄에이터 커브), 3D Scanner(3D 스캐너), Reverse Engineering(역설계), 3D Printing(3D 프린팅), 3D Dimensional Verification(3D 치수 검증)

1. Introduction

With the advent of the Fourth Industrial Revolution and development of related technologies, various application methods are being proposed for prototyping and dimensional verification using 3D printing technology^[1-7]. In terms of prototyping, 3D

printers are being used to produce complex 3D-designed shapes, thereby greatly shortening product development processes. In particular, fused deposition manufacturing (FDM)-type 3D printers have been widely applied to various fields of business, and several studies are being conducted using this method. The prototypes are mainly prepared with PLA and ABS; in terms of dimensional verification, techniques to compare the dimensions of actual CAD model shapes with the

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3D-printed shapes have been applied after scanning the shapes using a noncontact 3D scanner. It is crucial for securing the reliability and accuracy of the dimensions of the 3D-printed shape^[8-11].

In this study, has 3D-printed shapes of the hydraulic actuator curve part are fabricated using two materials, namely PLA and ABS, and the dimensions of the actual model and scanned shape are measured via scanning. Subsequently, the dimensional change characteristics are analyzed, and the accuracies of the printed shapes are examined based on the 3D-printing material used.

2. 3D Printing of Hydraulic Actuator Curve

2.1 3D Printing Equipment

For 3D printing of the hydraulic actuator curve part, the Ultimaker S5, which is an FDM-type



Fig. 1 Ultimaker S5 3D printer

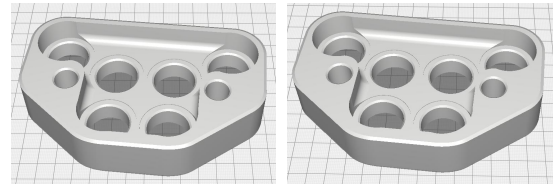
Table 1 3D Printing condition

Material	PLA	ABS
Print core	AA 0.4	AA 0.4
Layer height(mm)	0.1	0.1
Wall thickness(mm)	1.2	1.2
Top thickness(mm)	1.2	1.2
Bottom thickness(mm)	1.2	1.2
Infill density(%)	70	70
Infill pattern	Triangles	Triangles
Printing temperature(°C)	200	240
Build plate temperature(°C)	60	85
Print speed(mm/s)	30	30
Material consumption(g)	164g	145g
Printing time(hour)	31h 33m	31h 33m

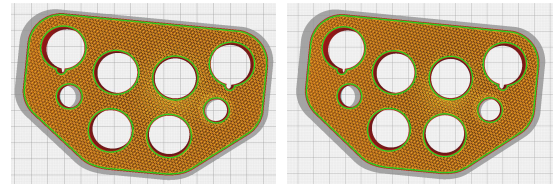
printer, was utilized (Fig. 1). The Ultimaker PLA and ABS (diameter of 2.85 mm, silver) were used as the filaments, and the supports of the printed materials were identically applied to each material to print the hydraulic actuator curve parts. To set the 3D printing conditions, the printer's dedicated software CURA was used. Table 1 shows the 3D printing conditions for the hydraulic actuator curve parts.

2.2 3D Printing Simulation and 3D Printing of Hydraulic Actuator Curve

Prior to printing the hydraulic actuator curve parts, the same conditions were set for both the PLA and ABS materials in the CURA software; the layer stacking height was set to 0.1 mm, and the infill density was set to 70%. Fig. 2 shows the shape imported from the software to 3D-print the hydraulic actuator curve part. Fig. 3 shows the internal shape when the stacking height and infill density are set to 0.1 mm and 70%, respectively. Figs. 4 and 5 show the printed results for the two materials.



(a) PLA (b) ABS
Fig. 2 CURA open model of cover parts

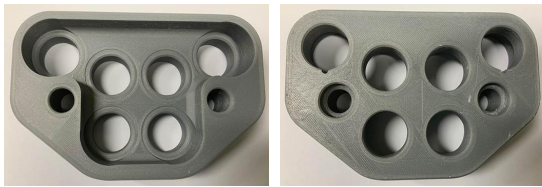


(a) PLA (b) ABS
Fig. 3 Cover slicing view in Ultimaker CURA software



(a) PLA Top (b) PLA Bottom

Fig. 4 3D printed cover with PLA material



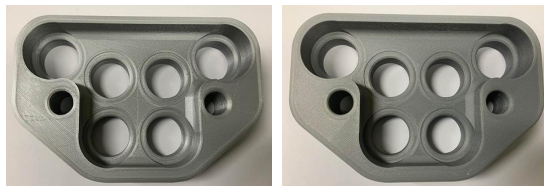
(a) ABS Top (b) ABS Bottom

Fig. 5 3D printed cover with ABS material

3. 3D Scanning and Dimensional Accuracy of 3D-Printed Output

3.1 Scanning of Printed Hydraulic Actuator Curve

The Artec Space Spider 3D Scanner, which is a noncontact mobile laser scanner from Redmond, was used in this study to scan the printed hydraulic actuator curve parts; this device scans the target object while moving around it, in a manner similar to data capture with a video camera. The scanner obtains automatically aligned data in real time at a speed of up to seven 3D images per second. Fig. 6 shows the 3D-printed curve parts with PLA and ABS filaments. Fig. 7 shows the scanning process

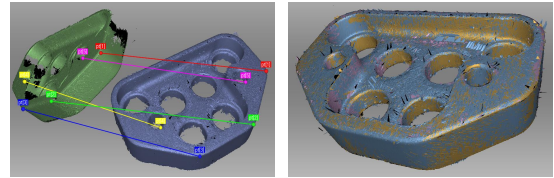


(a) PLA (b) ABS

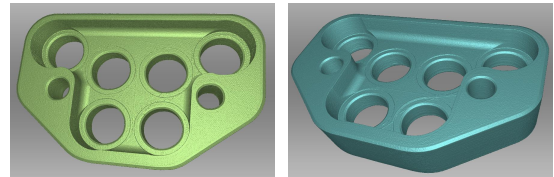
Fig. 6 3D printed cover parts



(a) 3D printed cover scan



(b) Align and global registration



PLA

ABS

(c) Sharp fusion results

Fig. 7 3D scanning process of cover parts

for the hydraulic actuator curve part as well as the process of conversion to 3D measurement data.

3.2 Alignment of Designed and Scanned Model Curve Parts

To compare the dimensions of the designed and 3D-printed shapes of the curve parts, these two models were first aligned using the Geomagic Control X software. Figs. 8 and 9 depict the aligned shapes of the designed and 3D-printed models of the curve parts for PLA and ABS, along with their consistency graphs, and Table 2 shows the detailed analysis results for the consistency. Accordingly, the standard deviation is 0.1394 for PLA and 0.1533 for ABS, indicating that the standard deviation for PLA is lower by 0.0139. Furthermore, the minimum and maximum values are -0.3492 for PLA and -0.3968 for ABS, respectively, indicating that the shapes printed with PLA are

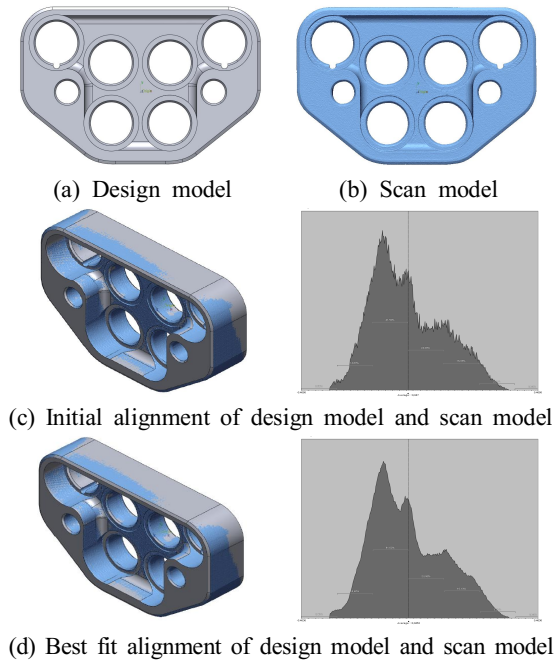


Fig. 8 3D printed cover alignment (material : PLA)

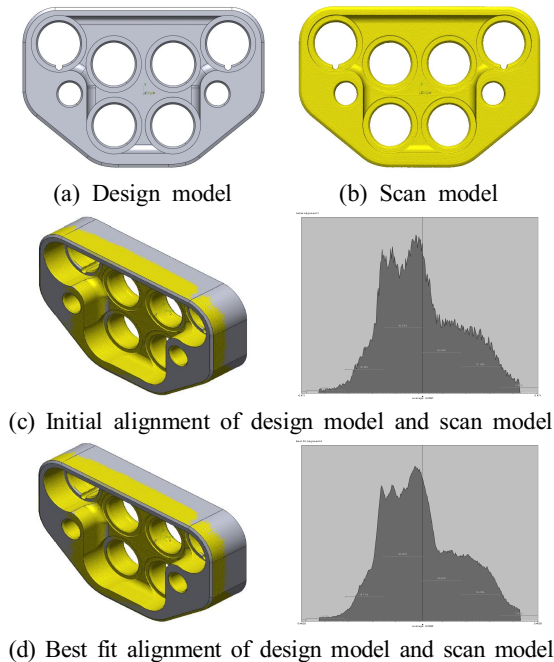


Fig. 9 3D printed cover alignment (material : ABS)

Table 2 Dimensional alignment analysis of design model and scan model

(Unit, mm)

Content	PLA	ABS
Min.	-0.3492	-0.3968
Max.	0.3492	0.3968
Avg.	-0.0453	0.0092
RMS	0.1466	0.1536
Std. Dev.	0.1394	0.1533
var.	0.0194	0.0235
+Avg.	0.1214	0.1424
-Avg.	-0.1289	-1.076

more accurately aligned than those printed with ABS.

3.3 Comparison of 3D Printing Dimensions

Based on the aligned scan shapes of the designed and printed curve models, the actual 3D-printed shapes of the curve part were compared according to the printing material used. For the dimensional verification, the inspection function of Geomagic

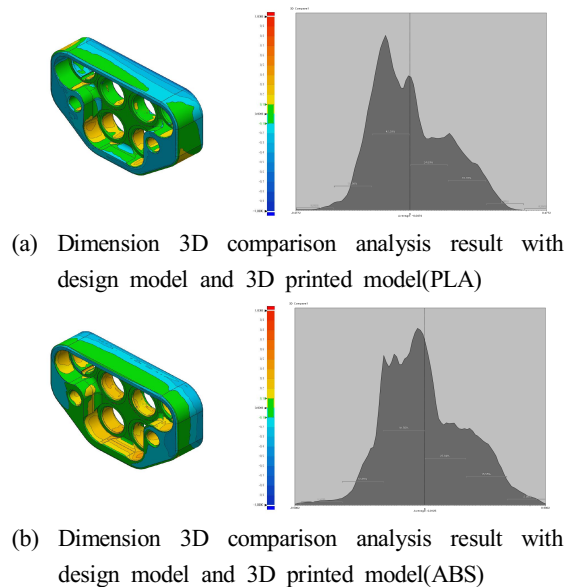


Fig. 10 Dimension 3D comparison analysis result with design model and 3D printed model

Table 3 Dimension 3D comparison result with design model and 3D printing model

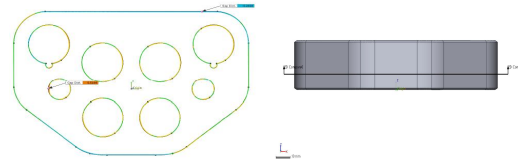
(Unit, mm)

Content	PLA	ABS
Min.	-1.6478	-1.784
Max.	0.819	0.8544
Avg.	-0.0474	0.0125
RMS	0.1509	0.163
Std. Dev.	0.1433	0.1626
var.	0.0205	0.0264
+Avg.	0.1208	0.1483
-Avg.	-0.1317	-0.115
In tol.(%)	39.3457	45.5281
Out tol.(%)	60.6543	54.4719
Over Tol.(%)	18.4198	28.2306
Under Tol.(%)	42.2345	26.2413

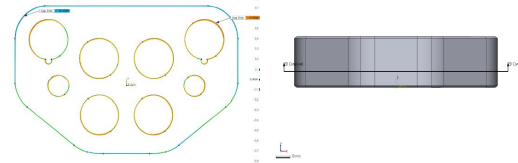
Control X was used, and the overall dimensional tolerance was set as ± 0.1 mm for the 3D comparison analysis; further, 2D comparison analysis was performed on the cross sections of the parts.

Fig. 10 shows the results of the 3D comparison analysis between PLA and ABS in color and graphically. According to Figs. 10(a) and 10(b), the inner hole portion shows a (+) tolerance value for ABS than the reference and compared to that for PLA. Table 3 shows the 3D comparison and analysis graphs of the designed and scanned models. The standard deviation is 0.1433 for PLA and 0.1626 for ABS, indicating that the deviation of PLA is lower by 0.0193. Moreover, the minimum and maximum values are -1.6478 and 0.819 for PLA and -1.784 and 0.8544 for ABS, respectively, indicating that printing with PLA is more accurate than with ABS.

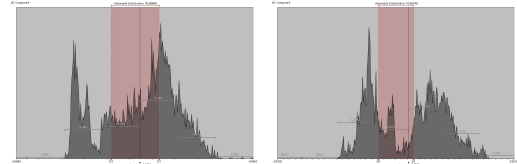
Fig. 11 and Table 4 are depict the results of the comparative analyses of the designed and scanned models for contours of sections obtained 20 mm from the top and dimensional tolerance of ± 0.1 mm. According to the graphs in Figs. 11(c) and 11(d) as well as Table 4, the In tol. is 49.1293% for PLA and 16.6819% for ABS, indicating that the tolerance dimension distribution is relatively higher for PLA than ABS.



(a) Dimension 2D comparison analysis with 20mm offset from top surface(PLA)



(b) Dimension 2D comparison analysis with 20mm offset from top surface(ABS)



(c) PLA

(d) ABS

Fig. 11 Dimension 2D comparison analysis result with design model and 3D printed model

Table 4 Dimension 3D comparison result with design model and 3D printing model (20mm offset from top surface)

(Unit, mm)

Content	PLA	ABS
Min.	-0.2601	-0.3305
Max.	0.3432	0.5242
Avg.	0.0087	0.0707
RMS	0.1334	0.2127
Std. Dev.	0.1332	0.2006
var.	0.0177	0.0402
+Avg.	0.1312	0.2296
-Avg.	-0.0983	-0.1343
In tol.(%)	49.1293	16.6819
Out tol.(%)	50.8707	83.3181
Over Tol.(%)	27.3276	51.9175
Under Tol.(%)	23.5431	31.4006

4. Conclusion

In this study, the hydraulic actuator curve shapes were 3D-printed using PLA and ABS as the materials and scanned for analyses. The dimensional changes to the printed shapes between the designed and scanned models were compared, based on the materials, using an inspection software, and the following conclusions were drawn.

1. From the comparison of the designed shape dimensions of the curve parts via 3D printing with PLA and ABS filaments, the curve printed with PLA had relatively higher dimensional accuracy than that printed with ABS.
2. The part printed with ABS had a relatively higher shrinkage than that printed with PLA.
3. In the assembling, manufacturing, and prototyping processes using 3D printing, relatively higher tolerances should be applied for ABS than PLA.

Acknowledgments

This work was supported by the research invigoration program of 2020 Gyeongnam National University of Science and Technology.

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