한국기계가공학회지, 제20권, 제1호, pp. 66～73(2021.01) ISSN 1598-6721(Print)
Journal of the Korean Society of Manufacturing Process Engineers, Vol. 20, No. 1, pp. 66~73(2021.01) ISSN 2288-0771(Online)

https://doi.org/10.14775/ksmpe.2021.20.01.066

Dimensional Characteristics of 3D Printing by FDM and DLP Output Methods

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DLP, FDM 3D 프린팅 출력 방식에 따른 치수 특성에 관한 연구

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

ABSTRACT

In this paper, we analyzed and considered the precision of parts produced by 3D printing methods. For the latch systems applied to the Wingline folding doors, the 3D shape of the door hinge part was printed using FDM and DLP methods. Then, the 3D printed shape was scanned to measure the dimensions and dimensional changes of the actual model. In the comparison and analysis of the 3D printed door hinge parts, because the output filling density is 100% owing to the characteristics of DLP 3D printing, the filling density in FDM 3D printing was also set to 100%.

Keywords : Door Hinge(도어 힌지), FDM Method 3D Printer(FDM방식 3D프린터), DLP Method 3D Printer(DLP방식 3D프린터), Dimension Characteristics(치수 특성)

1. Introduction

With the advent of the Fourth Industrial Revolution and the development of related technologies, various application technologies are being applied to prototyping and dimensional verification using 3D printing technology. For prototyping, 3D printers are used to produce 3D-designed shapes, greatly shortening the product development process[1–5]. Typically, the fused deposition modeling (FDM) method, a common material extrusion (ME) process, stereolithography (SLA), a type of photopolymerization (PP), and digital light processing (DLP) are most actively used in the polymer series. However, there is a problem in the assembly process due to the change in dimensions based on the materials manufactured by the 3D printer[6–8]. Dimensional verification and geometric dimension management are required to

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address this problem. For dimensional verification, techniques for comparing the dimensions of the actual CAD modeling shape and 3D printed shape have recently been applied after 3D printing the 3D design shape and scanning the shape through a non-contact 3D scanner[1–8].

This study 3D printed the 3D shapes of the door hinge part in the door latch system applied to a wing-in-ground (WIG) craft by applying two methods: FDM and DLP. The dimensions of the actual model and scanned shape were measured by scanning the printed shape. Subsequently, the dimensional change characteristics were analyzed, and the accuracy of the printed materials was examined for 3D printing methods.

2. 3D Printing of Door Hinge

2.1 3D Printer Research Equipment

In this study, Ultimaker S5, an FDM type printer, and Zbuilder, a DLP type 3D printer, were used to compare 3D printed materials. For the part output of the FDM printer, a polylactic acid (PLA) filament (diameter 2.85 mm, silver) and polyvinyl alcohol (PVA) water-soluble support material (diameter 2.85 mm) were used. Photocurable resins were used as materials for the DLP 3D printer. For the FDM printer, CURA, a dedicated software program, was used, and Materialize Magics Ver.24 and E-stage 7.0 were applied for the DLP 3D printer’s layout and support installation.

(a) Ultimaker S5 FDM 3D printer (b) Zbuilder DLP 3D printer

Fig. 1 DLP, FDM 3D printer

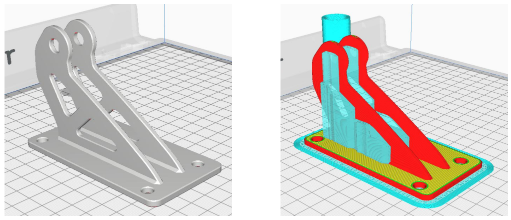
Table 1 3D printing condition

Parameter	FDM	DLP
Layer Height	0.1mm	0.1mm
Infill(%)	100%	100%

2.2 3D Printing Simulation and 3D Printing for Door Hinge

This study, for comparative analysis of door hinge parts using the 3D printing method, set the infill density for FDM 3D printing as 100% (the same condition as DLP 3D printing) to proceed with printing because the infill density is 100% due to the characteristic of DLP 3D printing. Fig. 2 illustrates the process from slicing to output after slicing with a 0.1mm stacking height in CURA software for FDM 3D printing of the door hinge.

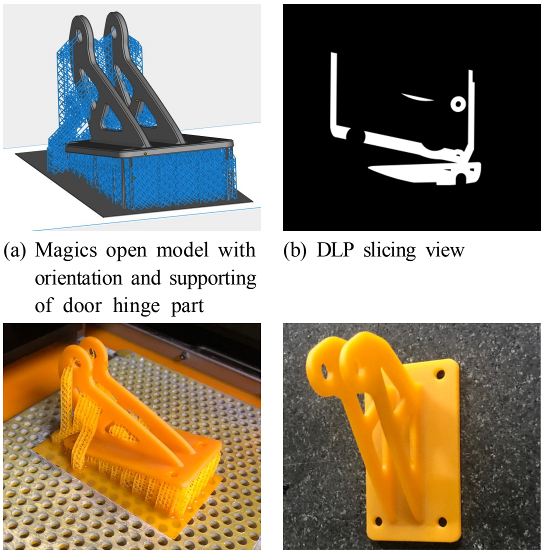
Fig. 3 illustrates the process of installing supports using the E-stage of Materialise after setting the



(a) CURA open model of door hinge part (b) Door hinge slicing view in CURA

(c) FDM 3D printed door hinge with remove support

Fig. 2 FDM 3D printing process of door hinge parts



(a) Magics open model with orientation and supporting of door hinge part
(b) DLP slicing view
(c) DLP 3D printed door hinge part
(d) DLP 3D printed door hinge part with remove support

Fig. 3 DLP 3D printing process of poor hinge parts

stacking direction at a tilted angle to prevent separation from the build plate in the case where the area of the first layer is large due to the nature of DLP 3D printing.

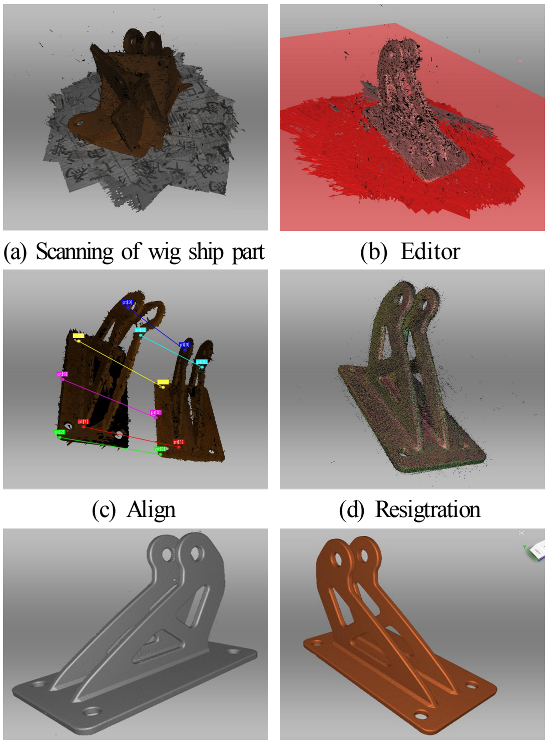
Fig. 3(b) illustrates one layer of the cross-section of the slicing layer of the DLP 3D printer, and Fig. 3(d) illustrates the output after DLP 3D printing is completed and the support is removed.

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

3.1 Door Hinge Scanning

This study used an Artec Space Spider 3D Scanner, a non-contact mobile laser scanner from Redmond, to scan the door hinge. This scanner performs the scanning task while moving around the object as if taking a video and obtains automatically-aligned data in real-time at up to seven 3D images per second.

Fig. 4 illustrates the scanning process of complete



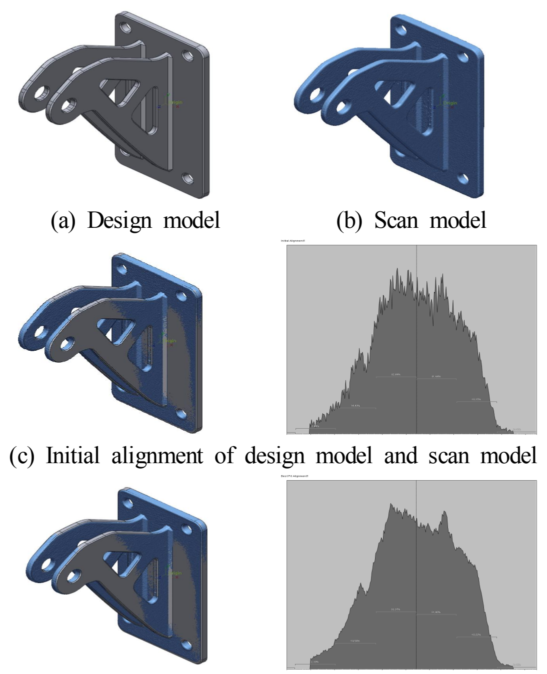
(a) Scanning of wig ship part
(b) Editor
(c) Align
(d) Resigtration
(e) Fusion
(f) Final edit

Fig. 4 3D scanning process of door hinge part

3D printing for the door hinge, which is the 3D scan object in Section 2.2, and the process of converting it into 3D measurement data.

3.2 Alignment of Door Hinge Design Model and Scan Model

For comparing the design model's dimensions and the 3D printed shape of the door hinge part, the design model and scan model of the door hinge part were aligned using Geomagic Control X software. Figs. 5 and 6 illustrate the alignment process of the door hinge printed using DLP. As depicted in Fig. 5, datum alignment was performed after performing initial and best alignment because an alignment error between the design and scan models was identified. Fig. 7 illustrates a graph of the alignment and consistency between the scan

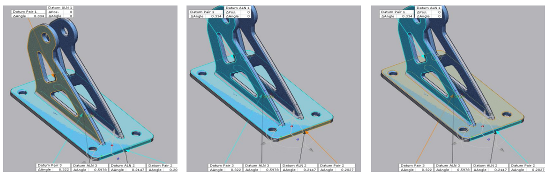


(a) Design model (b) Scan model

(c) Initial alignment of design model and scan model

(d) Best fit alignment of design model and scan model

Fig. 5 DLP 3D printed door hinge alignment

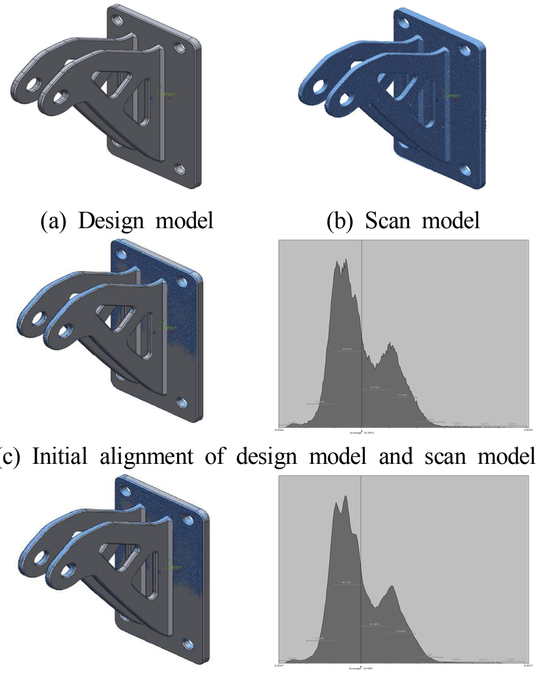


(a) Datum ALN1 (Plane) (b) Datum ALN2 (Plane) (c) Datum ALN3 (Plane)

Fig. 6 DLP 3D printed door hinge part datum alignment

Table 2 Dimensional datum alignment analysis of design model and scan model

Name	Result Name	Dev.	△Angle	△Pos.
Datum ALN 1	Result - Data 1	0		
Datum ALN 2	Result - Data 2	0.2147	0.2147	
Datum ALN 3	Result - Data 3	0.5978	0.5978	



(a) Design model (b) Scan model

(c) Initial alignment of design model and scan model

(d) Best fit alignment of design model and scan model

Fig. 7 FDM 3D printed door hinge alignment

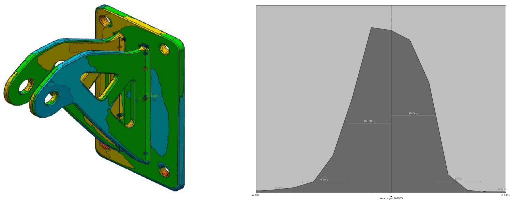
Table 3 Dimensional alignment analysis of design model and scan model

(Unit, mm)

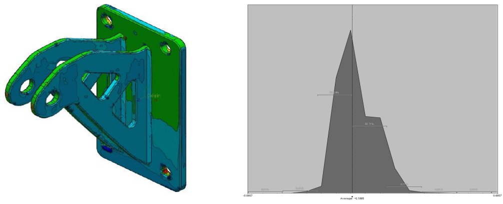
Content	Tolerance	Result data
Min.	±0.1	-0.4989
Max.	±0.1	0.4989
Avg.	±0.1	-0.1841
RMS	±0.1	0.2175
Std. Dev.	±0.1	0.1159
var.	±0.1	0.0134
+Avg.	±0.1	0.515
-Avg.	±0.1	0.2037

model outputs from the FDM method and the design model. Tables 2 and 3 present the detailed analysis tables of the consistency for DLP and FDM.

3.3 Comparison of 3D Printing Dimensions of Door Hinge



(a) Dimension 3D comparison analysis result with design model and 3D printed model(DLP)



(b) Dimension 3D comparison analysis result with design model and 3D printed model(FDM)

Fig. 8 Dimension 3D comparison analysis result with design model and 3d printed model

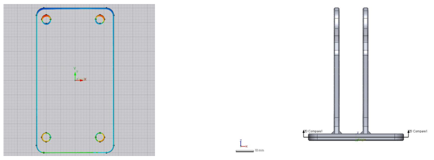
Table 4 Dimension 3D comparison result with design model and 3D printing model

(Unit, mm)

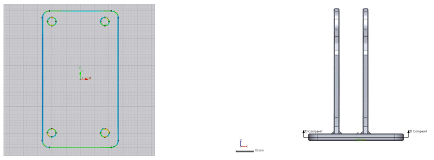
Content	Tolerance	DLP	FDM
Min.	±0.1	-0.8298	-12.0163
Max.	±0.1	0.8811	12.0457
Avg.	±0.1	0.00	-0.1865
RMS	±0.1	0.2166	0.2985
Std. Dev.	±0.1	0.2166	0.2331
var.	±0.1	0.0469	0.0543
+Avg.	±0.1	0.1274	0.0759
-Avg.	±0.1	-0.1345	-0.2088
In tol.(%)	±0.1	46.5806	24.9048
Out tol.(%)	±0.1	53.4194	75.0952
Over Tol.(%)	±0.1	30.1799	0.9608
Under Tol.(%)	±0.1	23.2395	74.1343

Based on the final alignment shape of the scan and design models for the door hinge part of Section 3.1, the 3D printing dimensions of the WIG craft`s door hinge were compared for the FDM and DLP 3D printing methods. For the dimensional inspection, the inspection function of Geomagic Control X software was used. The dimensional tolerance was set to ±0.1 mm to perform the 3D comparison analysis of the design model and the scan model, and 2D comparison analysis used the cross-section of the part. Fig. 8 illustrates the results of the 3D comparison analysis of DLP and FDM methods. Based on Fig. 8 and Table 4, the standard deviation of the design model and the scan model for DLP is 0.2166, which is lower than 0.2331 for FDM, although the overall consistency is high. In contrast, based on the color distribution diagrams depicted in Fig. 8(a) and 8(b), FDM has a wide color distribution, whereas various colors are observed throughout the part in DLP. This result suggests that the FDM method, compared with the DLP method, induces a dimensional difference due to the influence of relatively high surface roughness, exhibiting a consistent dimensional range.

Figs. 9 to 10 illustrate the results of the dimensional inspection on the bottom and side sections of the door hinge part. According to Tables 5 and 6, the range that satisfies the tolerance of ±0.1 in the bottom section is 14% for DLP and



(a) Dimension 2D comparison analysis with 2mm offset from Bottom Plane (DLP)



(b) Dimension 2D comparison analysis with 2mm offset from Bottom Plane(FDM)

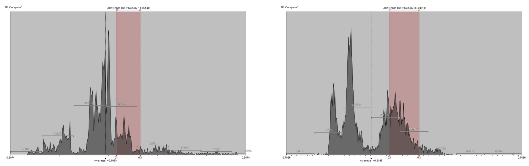
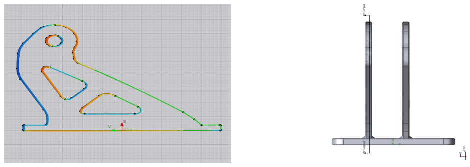
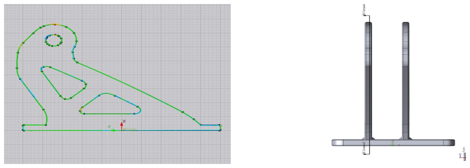


Fig. 9 Dimension 2D comparison analysis result with design model and 3D printed model



(a) Dimension 2Dcomparison analysis with 2mm offset from Right Side Surface(DLP)



(b) Dimension 2D comparison analysis with 2mm offset from Right Side Surface (FDM)

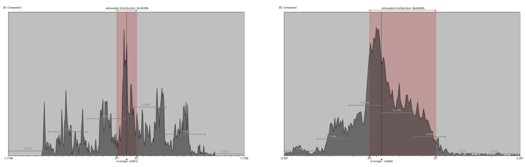


Fig. 10 Dimension 2D comparison analysis result with design model and 3D printed model (2mm offset from Right Side Surface)

Table 5 Dimension 2D comparison result with design model and 3D printing model (2mm offset from top surface)

(Unit, mm)

Content	Tolerance	DLP	FDM
Min.	±0.1	-0.8328	-0.5757
Max.	±0.1	0.9122	0.3229
Avg.	±0.1	-0.1923	-0.2195
RMS	±0.1	0.3274	0.2895
Std. Dev.	±0.1	0.265	0.1887
var.	±0.1	0.0702	0.0356
+Avg.	±0.1	0.2768	0.0797
-Avg.	±0.1	-0.2692	0.264
In tol.(%)	±0.1	14.6514	30.2401
Out tol.(%)	±0.1	85.3486	69.7599
Over Tol.(%)	±0.1	9.8439	4.0372
Under Tol.(%)	±0.1	75.5047	65.7227

30% for FDM, and the range for the side section is 24% for DLP and 66% for FDM. These results indicate that the FDM 3D printing method has higher dimensional accuracy than the DLP method.

Table 6 Dimension 2D comparison result with design model and 3D printing model (2mm offset from right side surface)

(Unit, mm)

Content	Tolerance	DLP	FDM
Min.	±0.1	-0.8298	-0.4571
Max.	±0.1	0.8811	0.4278
Avg.	±0.1	-0.0013	-0.0643
RMS	±0.1	0.3898	0.1168
Std. Dev.	±0.1	0.3898	0.0976
var.	±0.1	0.1519	0.0095
+Avg.	±0.1	0.2973	0.0585
-Avg.	±0.1	-0.3315	-0.1038
In tol.(%)	±0.1	24.4233	66.6243
Out tol.(%)	±0.1	75.5767	33.3757
Over Tol.(%)	±0.1	39.5014	2.954
Under Tol.(%)	±0.1	36.0753	30.4217

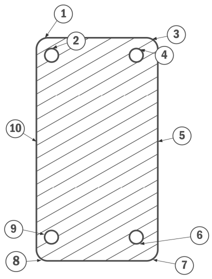


Fig. 11 2D dimension measurement point of door hinge with 2mm offset from bottom surface

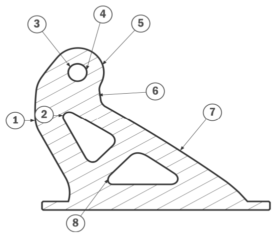


Fig. 12 2D dimension measurement point of door hinge with 2mm offset from right side surface

Figs. 11 to 12 illustrate the measurement locations set for the door hinge. Tables 7 and 8 present the dimensional inspection result values for each location, indicating that the FDM method has higher dimensional accuracy than the DLP method.

Table 7 Dimension 2D comparison result with design model and 3D printing model(2mm offset from top surface)

(Unit, mm)

No.	Tolerance	Gap dist. DLP	Gap dist. FDM
①	±0.1	-0.8328	0.0089
②	±0.1	0.9122	0.0524
③	±0.1	-0.6908	-0.0933
④	±0.1	0.6982	-0.1332
⑤	±0.1	-0.292	-0.3486
⑥	±0.1	0.4827	0.3229
⑦	±0.1	-0.232	-0.0227
⑧	±0.1	0.1156	-0.1246
⑨	±0.1	0.3189	-0.0793
⑩	±0.1	-0.1658	-0.5143

Table 8 Dimension 2D comparison result with design model and 3D printing model (2mm offset from top surface)

(Unit, mm)

No.	Tolerance	Gap dist. DLP	Gap dist. FDM
①	±0.1	0.8298	0.0089
②	±0.1	0.8811	-0.3339
③	±0.1	0.7169	0.4571
④	±0.1	-0.4735	0.0099
⑤	±0.1	0.5684	-0.0057
⑥	±0.1	0.5771	-0.1043
⑦	±0.1	0.0117	-0.1072
⑧	±0.1	0.6203	0.1504

4. Conclusions

This study applied the design model of a door hinge part in the door latch system of the WIG craft in a 3D printer and scanned the door hinge shape printed through the FDM and DLP methods. The dimensional change of the printed shape by design model and method was examined using the inspection software, thereby drawing the following conclusions.

1. The FDM method has consistent dimensional accuracy compared with the DLP method.
2. In the dimensional inspection of the bottom and side sections, the FDM method exhibited relatively higher dimensional accuracy than the DLP method.
3. The FDM method, compared with the DLP method, produced weak dimensional errors due to the effect of high surface roughness, exhibiting higher dimensional accuracy.

Acknowledgments

This work was supported by Gyeongnam National University of Science and Technology Grant in 2020~2021.

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