

**THE INFLUENCE OF INTERNAL STRUCTURES IN FUSED
DEPOSITION MODELING METHOD ON DIMENSIONAL ACCURACY
OF COMPONENTS**

Ján MILDE, Ladislav MOROVIČ

SLOVAK UNIVERSITY OF TECHNOLOGY IN BRATISLAVA,
FACULTY OF MATERIALS SCIENCE AND TECHNOLOGY IN TRNAVA,
INSTITUTE OF PRODUCTION TECHNOLOGIES,
ULICA JÁNA BOTTU 2781/25, 917 24 TRNAVA, SLOVAK REPUBLIC
e-mail: jan.milde@stuba.sk, ladislav.morovic@stuba.sk

Abstract

The paper investigates the influence of infill (internal structures of components) in the Fused Deposition Modeling (FDM) method on dimensional and geometrical accuracy of components. The components in this case were real models of human mandible, which were obtained by Computed Tomography (CT) mostly used in medical applications. In the production phase, the device used for manufacturing, was a 3D printer Zortrax M200 based on the FDM technology. In the second phase, the mandibles made by the printer, were digitized using optical scanning device of GOM ATOS Triple Scan II. They were subsequently evaluated in the final phase. The practical part of this article describes the procedure of jaw model modification, the production of components using a 3D printer, the procedure of digitization of printed parts by optical scanning device and the procedure of comparison. The outcome of this article is a comparative analysis of individual printed parts, containing tables with mean deviations for individual printed parts, as well as tables for groups of printed parts with the same infill parameter.

Key words

Mandible, CAD, Infill, Fused Deposition Modeling, 3D Scanning

INTRODUCTION

Fused Deposition Modeling (FDM) is an additive manufacturing process based on manufacturing components layer by layer. It is used for modeling, prototyping, and producing applications. The technology uses a plastic filament or a metal wire that is unwound from a coil and feeds the material to produce a component (1).

The technology was developed in the late 1980s by S. Scott Crump and was commercialized in 1990. The term *Fused Deposition Modeling* and its acronym of *FDM* are registered and trademarked by the Stratasys Company, which focuses on additive

manufacturing. The exactly equivalent terms, *Layer Plastic Deposition (LPD)* and *Fused Filament Fabrication (FFF)* were coined by the members of the RepRap project to give a phrase that would be legally unconstrained in its use (2).

The production of parts by FDM technology is not limited by shape, but limited by dimension. The possibility of production of free-form surfaces (FFS) (complex shaped objects) is the key advantage of this technology (3).

The aim of this article is to publish the results of the experiment: *“The influence of internal structures in FDM method on geometrical and dimensional accuracy of components”*. It is known, that in the process of injection molding and 3D printing of plastic materials, some plastic materials, especially ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid) are susceptible to shrinkage. The model used for the experiment was a human jawbone which was obtained by Computed Tomography (CT). In the second phase, the mandibles were manufactured and subsequently 3D digitized by the optical 3D scanner mentioned above. The final step was comparison of the printed models with the reference CAD model.

3D MODEL USED FOR EXPERIMENT

The model used in the experiment is focused on medicine. The digital model, which was used in this experiment, was a model of human mandible. The model was chosen due to its importance for the planned purposes in maxillofacial surgery, where it is very important to preserve the best dimensional and geometrical accuracy.

The original model was obtained by CT.

In Fig. 1, the imperfections of the mandible can be seen. The largest defects were situated on the condyles in the upper part of the mandible. There were also some significantly damaged areas and missing parts on the right side of the jaw. Due to the facts mentioned above, the editing and repairing of the damaged mandible model was necessary. For model editing and repairing, the software of Delcam PowerSHAPE 2016 and GOM Inspect V8 SR1 was used (3).

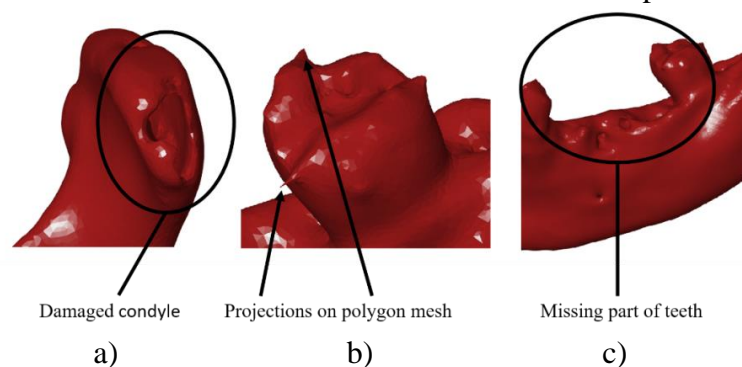


Fig. 1 Original STL model from CT scanner: a) projections on polygon mesh, b) damaged condyle, c) missing part of mandible (4)

EDITING THE DIGITAL MODEL

As the first step, the model was imported to the CAD software of Delcam PowerSHAPE 2016. Fig. 2 shows the model before editing. On the left hand side of the jaw, some parts of the model (teeth, bone) are missing. The left part of the mandible was cut and deleted from the model. The left side of the mandible was mirrored using the *“Mirror”* function. The newly created mandible (Fig. 2 b) had some small holes and gaps. The small holes were repaired using the *“Doctor Mesh* function”. The final step of the procedure was to export the new model to the STL format.

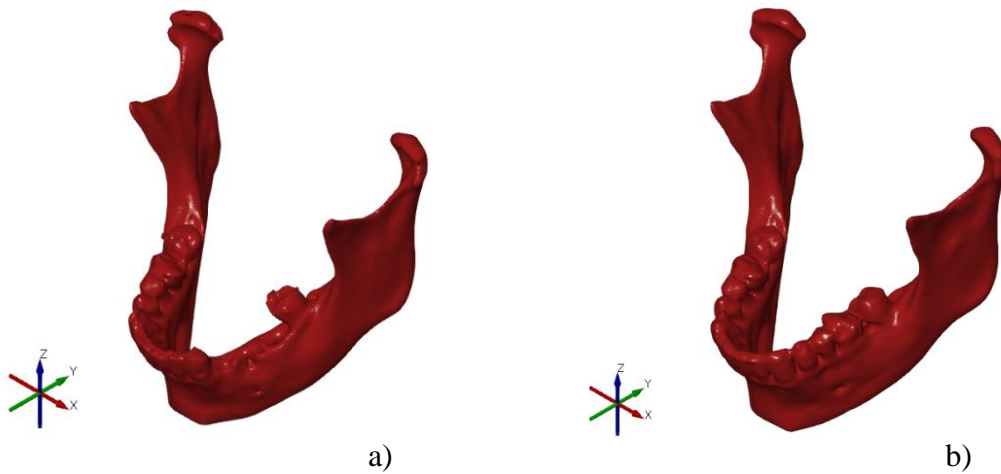


Fig. 2 *Editing the mandible model in GOM Inspect software:
a) selected mandible triangles of polygon mesh,
b) mirrored right part of the mandible (4)*

Errors, missing parts and damaged areas of mandible were corrected and repaired in the GOM Inspect V8 SR software. Three functions in total were used for repairing the model: “Mesh Bridge” for mesh connection creating, “Repair” and “Auto Repair Mesh” and function for closing the holes “Close Holes Interactively”.

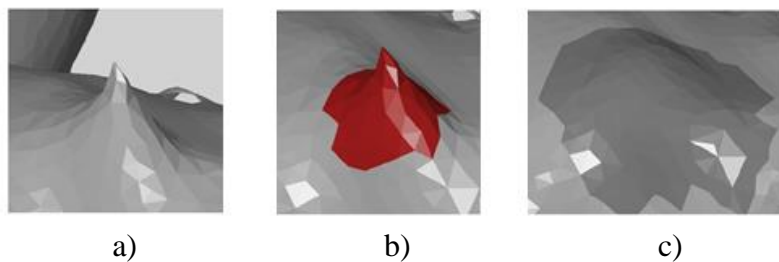


Fig. 3 *Repair of the model in the GOM Inspect software:
a) projection on the original mesh, b) selecting the surface triangles,
c) generated and edited part of mesh (5)*

After modification and repair of all of the damaged areas, the model was exported to an STL file, which was used for manufacturing, in this case the Zortrax M200 printer.

INFILL SETTINGS OF DIGITAL MODELS

The experiment focused on the influence of internal structures in the FDM on the geometrical and dimensional accuracy of components. Twelve prints were made in total (6). Four prints were manufactured for each type of infill.

- Mesh (0 %),
- Light (20 %),
- Medium (50 %),
- Full (90 %).

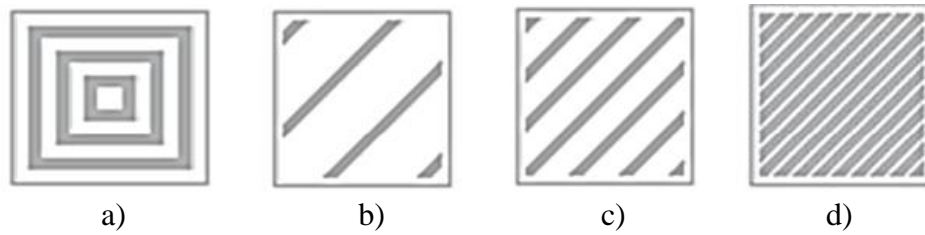


Fig. 4 Infill structures in software Z-Suite: a) Mesh, b) Light, c) Medium, d) Full

Before discussing the properties of an FDM part, it is important to know how the process of manufacturing works. The first step in generating an FDM part is to create a three dimensional solid model. This can be accomplished in many of the commonly available CAD software.

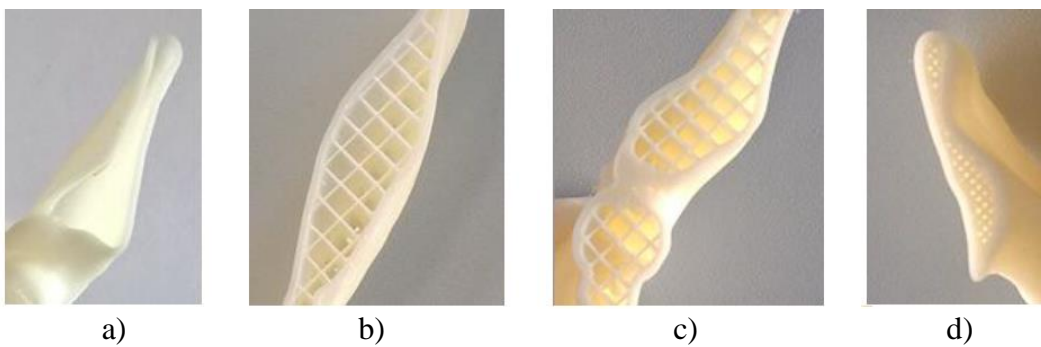


Fig. 5 Infill structures on printed mandibles: a) Mesh, b) Light, c) Medium, d) Full

The part is then imported to the software, in this case Z-Suite, via the STL format. The format reduces the part to a set of triangles by tessellating it. The FDM method works on the principle of adding material in layers. The material is a plastic filament unwound from a coil. Two sizes of the plastic wire were available: diameter of 1.75 mm (Manufacturers as Zortrax, MakerBot, Be3D) and diameter of 3.0 mm (Manufacturer Ultimaker). The material fiber is fed to the printing head where it is heated, fused and extruded through the nozzle in the form of fine fibres. There are several kinds of kinematic structures used in FDM. The most frequently applied movements of head and build platform of the FDM machine (in the case of serial kinematic structures) are as follows:

- Head moves along ~~in~~ axes X, Y and Z.
- Head moves along axes X and Y and the build platform moves in axis Z.
- Head moves along axes X and Z, and the build platform moves in axis Y.

Scheme of the FDM method is shown in Fig. 6 (head moves in axes X and Y and the build platform moves in axis Z).

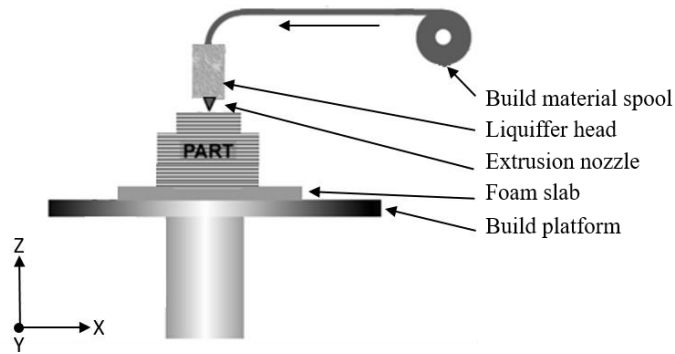


Fig. 6 Scheme of Fused Deposition Modeling

The fibre material used in the experiment was ABS combined with polycarbonate, an elastomer marked as Z-ULTRAT with a diameter of 1.75 mm.

Z- ULTRAT is a versatile material suitable for printing many different types of models. It is ideal for prototyping models with the features similar to the products manufactured in the injection molding technology. It is also suitable for mechanical and chemical post-processing. The objects 3D printed by Z-ULTRAT are strong, stable and resistant to creep. Properties of the material are suitable for evaluation of parts before production (4).

In the manufacturing phase of FDM technology, a supporting structure is often required. In simple terms, it supports all down facing surfaces, overhangs and undercuts. The supporting structure is generated by software, in this case in the Z-Suite, and can be customized. Parameters, which have influence on the dimensional and shape accuracy in the process of FDM are as follows:

- infill,
- layer thickness,
- model orientation,
- material,
- nozzle temperature.

The target parameter which was chosen for the research was the infill (internal structure). The manufacturing of mandibles was performed by Zortrax M200 (6).

EVALUATION OF THE ACCURACY OF DIMENSIONS OF THE COMPONENTS IN THE GOM INSPECT V8 SR1 SOFTWARE

The printed mandibles were digitized using optical 3D scanner of GOM ATOS II TripleScan. The measuring volume used for the digitization was MV 170 (170 x 130 x 130 mm). The models pictured in Fig. 7 are ready for scanning. The comparison of each scanned model with the reference CAD model and evaluation of the dimensions were made in the GOM Inspect V8 SR1 software. The parameter measured was the distance between two points in the 8 single sections in total (Fig. 8). In the GOM Inspect software, the distance between points was measured by the “Construct – Distance – 2-Point Distance” function. For a nominal and actual model, there were made the whole principle of the creation of distances, 8 in total. In every section, a point was added. The point was mirrored on the opposite side. Between the two points, a distance which shows difference between the nominal and actual models is made. The difference between the nominal and actual values is shown in Fig. 9.

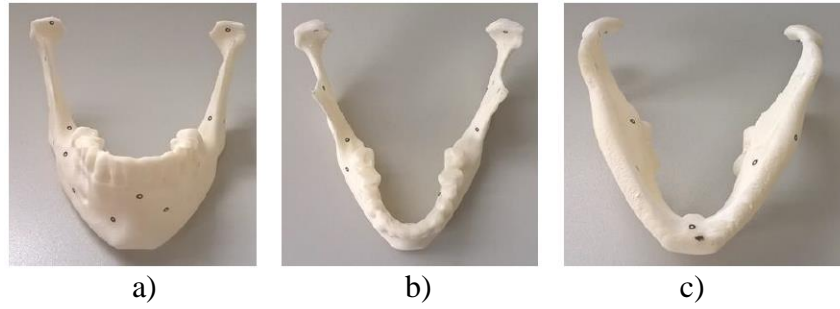


Fig. 7 Printed mandibles with reference points used for digitalization: a) front view, b) view from the top, c) view from the bottom (6)

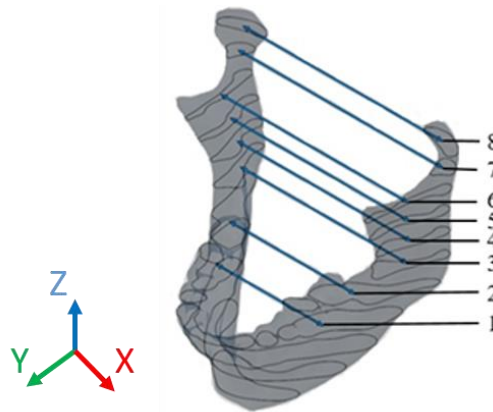


Fig. 8 The distances between elements (points) in sections in the axial direction X

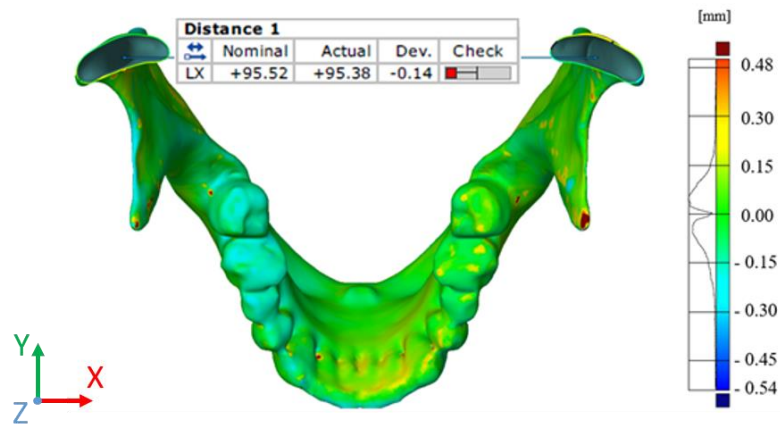


Fig. 9 The distance between two points on the mandible

Table 1 Nominal distances, actual distances, deviations and arithmetic mean of deviation (infill *Light* part number: 03) (6)

	Section	Nominal distance [mm]	Actual distance [mm]	Deviation [mm]
1.	Z 35 mm	51.35	50.47	-0.88
2.	Z 45 mm	60.28	58.93	-1.36
3.	Z 55 mm	79.96	79.55	-0.41
4.	Z 65 mm	83.23	82.93	-0.30
5.	Z 75 mm	85.70	85.69	-0.01
6.	Z 85 mm	89.62	89.50	-0.12
7.	Z 95 mm	97.85	97.19	-0.66
8.	Z 105 mm	95.52	95.38	-0.14
	Arithmetic mean of deviation			-0.4850

Table 2 Calculation of the average deviation of deformation of prints for each internal structure (infill) (6)

Infill	Arithmetical means of deviations [mm]			Arithmetical mean for Infill [mm]
Light	-0.6250	-0.6975	-0.4850	-0.6025
Mesh	-0.1400	-0.4675	-0.2238	-0.2771
Medium	-0.1213	-0.2850	-0.5550	-0.3204
Full	-0.4038	-0.4238	-0.4213	-0.4163

CONCLUSION

In the case of dimensional deviations, the best infill, with respect to the dimensional accuracy, was found to be *Mesh*, the infill with the smallest deviation of -0.2771 mm. The second lowest dimensional deviations were found at in *Medium* infill, -0.3204 mm. The infill marked as *Full* shows a dimensional deviation of -0.4163 mm. The worst infill in terms of dimensional accuracy was *Light*, which exhibited the greatest inaccuracies and deviations from the required dimension of -0.6025 mm on the model of the mandible. The elapsed time between manufacturing and 3D digitization has a huge impact on the accuracy of dimensions. This was due to the long period of stand when printing the parts (more than 72 hours), during which the ABS material had time to retract.

It was found that infill has a significant influence on the dimensional and geometrical accuracy. The lowest shrinkage effect was found on the parts where the amount of the internal material was the lowest. In other words, the biggest shrinkage effect was found on the parts where the amount of internal material was the largest.

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ORCID:

Ladislav Morovič 0000-0001-7631-2631