INFLUENCE OF PART ORIENTATION ON GEOMETRICAL AND DIMENSIONAL ACCURACY IN FDM METHOD

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ABSTRACT: The paper is focusing on research of part orientation on geometrical and dimensional accuracy in Fused Deposition Modeling (FDM) method. The parts used for experiments have free-form surfaces. The part was produced by additive manufacturing method and then was digitized by optical 3D scanner. Each manufactured part was compared with the reference CAD model in the inspection software.
KEY WORDS: 3D scanning, free-form surfaces, additive manufacturing, CAD comparison.

1 INTRODUCTION

The aim of the article is publish the results of experiment „Influence of part orientation on geometrical and dimensional accuracy in Fused Deposition Modeling method“. This model was human jawbone. Manufactured objects (mandible) were subsequently 3D digitized and compared with the reference CAD (Computer Aided Design) model of the jaw.

According to (Békés, 1998) shapes can be produced fundamentally by adding materials (additive manufacturing methods), moving materials (casting technology, forming etc.) and removing materials (machining technology, blanking, cutting etc.). Additive methods of parts production include so called Rapid Prototyping (RP) that produces components layer by layer. The advantage of RP methods is for example the possibility to produce free-form surfaces (complex shaped objects) and often production time of parts compared with other "conventional" techniques (Popan et al., 2015). The best known methods of RP are: Fused Deposition Modeling (FDM), Selective Laser Sintering (Borzan et al., 2013), (Miron-Borzan et al., 2015) and Selective Laser Melting (Păcurar & Păcurar, 2014), Poly-Jet Modeling, Stereolitography.

2 DIGITAL MODEL OF HUMAN MANDIBLE

Digital model of human mandible was obtained from Faculty of Medicine, Comenius University in Bratislava. It is a digital model of the human jaw man (mandible) obtained by computed tomography (CT).

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The shape of the obtained model was subsequently digitally modified (software Delcam PowerSHAPE 2016 and GOM Inspect V8 SR1). The left part of mandible was missing as well as the upper part of the jaw, called condyles, which were damaged (Fig. 1).

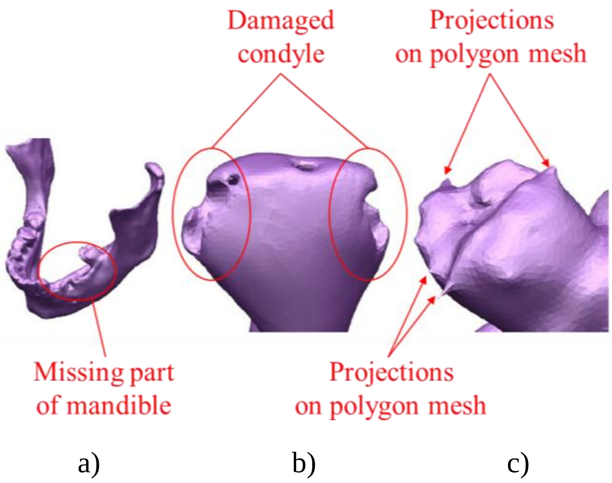

Figure 1. Digitized model of mandible by computed tomography: a) missing part of mandible, b) damaged condyle, c) projections on polygon mesh (Beláni, 2016)

3 EDITING OF THE DIGITAL MODEL

At the beginning, in the software Delcam PowerSHAPE 2016, on the polygon mesh of mandible, coordinate system was created (Fig. 2a). The left part of the .STL model was deleted and the remaining right part was mirrored (Fig. 2b). The small holes and gaps on polygon mesh were closed and corrected.

The remaining errors of the mesh (for example projections, another holes, etc.) were corrected in the software GOM Inspect V8 SR1 using the appropriate software functions ("Mesh Bridge" for creating mesh connection, "Close Holes Interactively" for closing the holes of mesh and

"Repair" for auto mesh repair. The triangles creating the projections on mesh were selected and deleted and the created hole was subsequently closed (Fig. 3). After closing all holes of mesh, smooth the mesh follows. Thus obtained and exported .STL file was suitable and prepared for additive manufacturing.

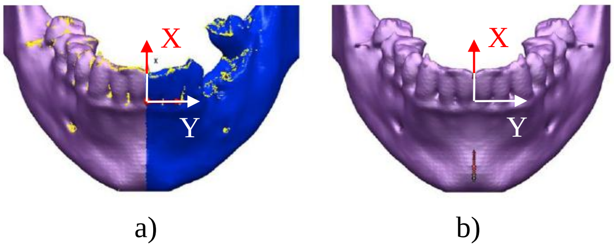

Figure 2. Editing of triangular (.STL) model of the mandible in software DELCAM PowerShape 2016: a) selected mandible´s triangles of mesh, b) mirrored right part of the mandible (Belánі, 2016)

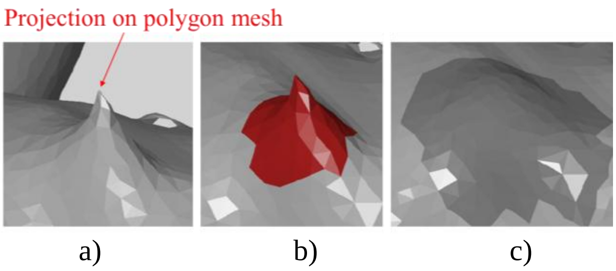

Figure 3. Editing of triangular mesh in software GOM Inspect V8 SR1: a) projection on polygon mesh, b) selecting of surface triangles, c) edited part of mesh (Beláni, 2016)

4 ORIENTATION SETTINGS OF DIGITAL MODELS

The experiment was focused on the influence of orientation of CAD model on the qualitative properties of parts. The term "qualitative properties" of parts in this case means the geometric identity of manufactured parts with CAD model.

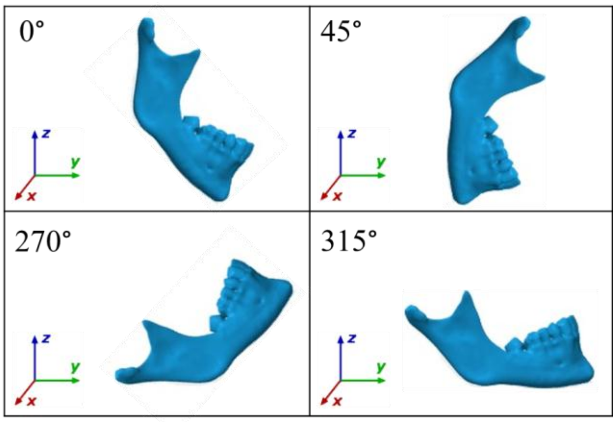

Figure 4. Four different orientations of mandible in the FDM process (Milde, 2016)

Four model orientations were defined (0°, 45°, 270° and 315°) (Fig. 4).

5 MANUFACTURING OF THE MODELS

Orientation of digital models and production parameters were prepared in software Zortrax Z-Suite. For each model orientation three parts were manufactured. For manufacturing of models FDM method was used.

In the case of FDM method, the thermoplastic material as the filament is unwound in the form of spool (diameter of the fiber is approx. 1.75 mm) and is fed to liquifier head of the device. The fused and extruded fiber through the extrusion nozzle (the diameter of the extruded filaments is approx. 0.4 mm) forms the layer of the model, i.e. layer by layer builds the model. The liquefier head (according to the kinematic scheme of the device) moves in the direction of axis X, Y, Z or axis X, Y, while the movement in the direction of axis Z preforms the build platform by the value of one layer thickness. The extruded material attaches with the previous layer. The fiber material is for example acrylonitrile-butadiene-styrene (ABS), poly-carbonate (PC) or poly-lactic acid (PLA). The scheme of additive manufacturing method FDM is on Fig. 5.

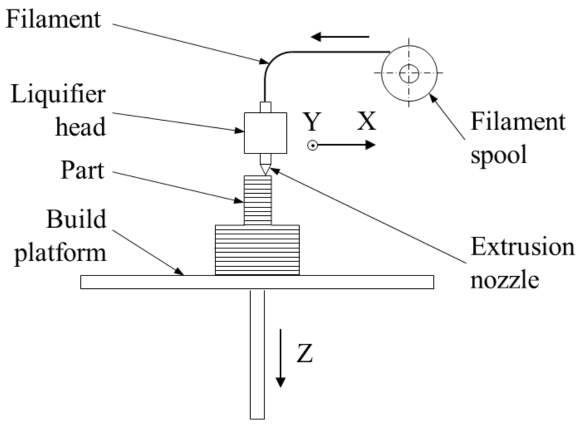

Figure 5. Scheme of additive manufacturing method Fused Deposition Modeling

In the case of FDM method, there are several parameters, that can affect the surface quality and dimensional accuracy, orientation and speed of the printing process.

The material used for experiments was a combination of ABS and PC (Z-Ultrat), which is suitable for producing mainly for its mechanical properties (such as hardness and strength) and also for its lower shrinkage value.

Manufacturing of mandibles was performed with the FDM device Zortrax M200, the layer thickness was 0.09 mm.

6 EVALUATION OF THE MANUFACTURED PART

Manufactured parts (12 pieces) were digitalized by optical 3D scanner GOM ATOS II TripleScan MV 170 (measuring volume: 170 x 130 x 130 mm). Evaluation of the part size and the shape conformity (reference CAD model and digitized 3D model of manufactured parts) was carried out in the software GOM Inspect V8 SR1.

6.1 Evaluation of distance between two points

The distance between two points was measured in the case of 7 point pairs for each part (Fig. 6). The nominal distance (measured on the reference CAD model) was compared with the actual distance (measured on the manufactured and 3D digitized model) (Fig. 7 and Table 1).

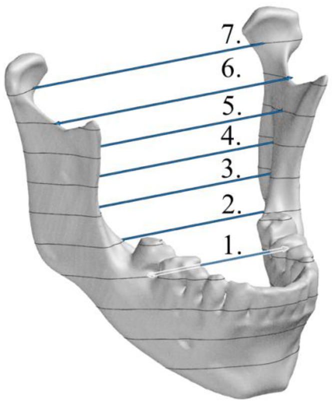

Figure 6. The distances between elements in sections in the axial direction X

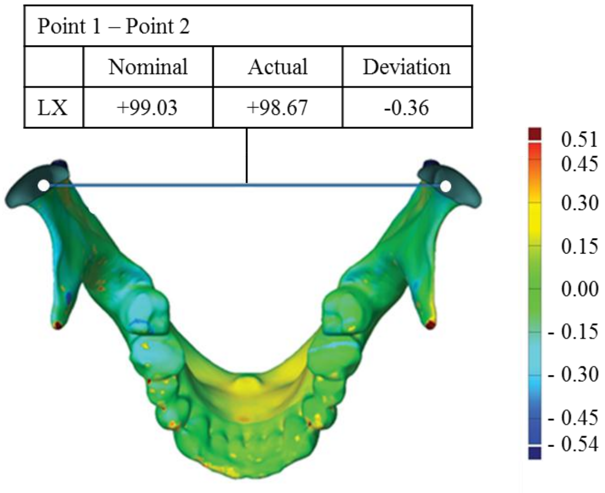

Figure 7. The distance between two points on the mandible (Vittek, 2016)

Table 1. Nominal distances, actual distances and deviations (orientation 0°, part number: 01)

Sections		Nominal distance [mm]	Actual distance [mm]	Deviation [mm]
1.	Z + 40 mm	+54.68	+52.28	-2.40
2.	Z + 50 mm	+68.06	+67.35	-0.71
3.	Z + 60 mm	+81.50	+81.48	-0.02
4.	Z + 70 mm	+84.34	+84.05	-0.29
5.	Z + 80 mm	+87.28	+87.15	-0.13
6.	Z + 90 mm	+92.82	+92.25	-0.57
7.	Z + 100 mm	+99.03	+98.67	-0.36

6.2 Evaluation of part shape

Evaluation of part shape was performed by comparison (Neamțu & Bere, 2014) of manufactured and 3D digitized part with reference CAD model (color deviation maps).

At orientation 0°, the manufacturing time takes 8 h 24 min and 33 g of material was used. According to the results of the color map of deviation (Fig. 8), the largest deviations were in the areas of support structure and where the building material touches the build platform. The largest deviation was -0.71 mm. The color map shows considerable deviation at the point of „nervus mandibularis“.

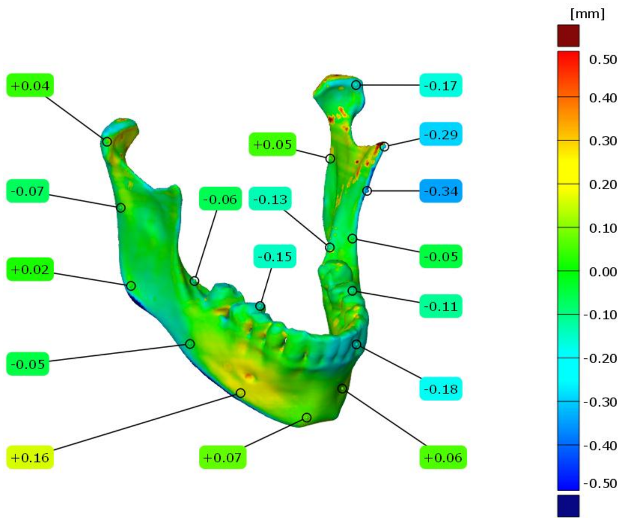

Figure 8. Analysis of shape deviations - orientation 0° (Vittek, 2016)

At orientation 45°, the manufacturing time takes 8 h 8 min and 31 g of material was used. The largest deviations are in the areas of support structure and where the building material touches the build platform. The largest deviation was +0.82 mm (scab after removal of the support structure) (Fig. 9).

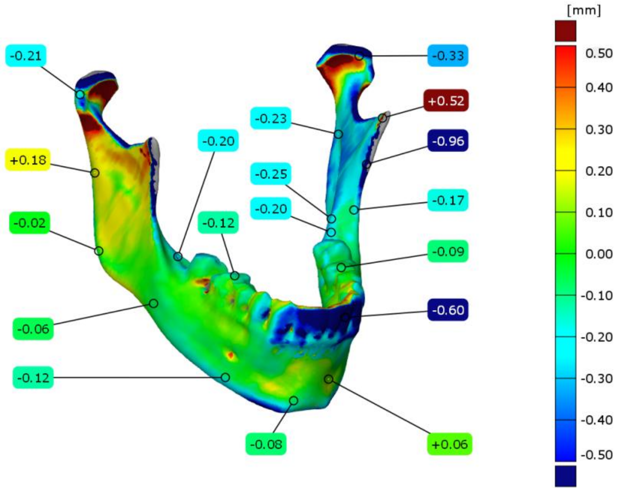

Figure 9. Analysis of shape deviations - orientation 45° (Vittek, 2016)

At orientation 270°, the manufacturing time takes 7 h 15 min and 31 g of material was used. The largest deviations in the area of support structures and in the place, where the building material touches the build platform. According to the color deviation map, the values of deviations have plus-minus values on all surfaces of the mandible (Fig. 10). Deviations were in the range of -0.9 mm to +0.9 mm.

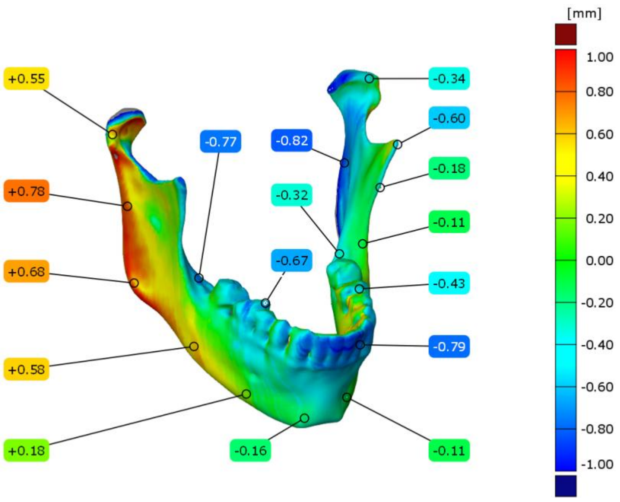

Figure 10. Analysis of shape deviations - orientation 270° (Vittek, 2016)

At orientation 315°, the manufacturing time takes 6 h 55 min and 30 g of material was used. The deviation showed negative values in the range of -0.45 to -0.89 mm. According to the color deviation map, the largest deviation was in the areas of support structure and where the building material touches the build platform (Fig. 11).

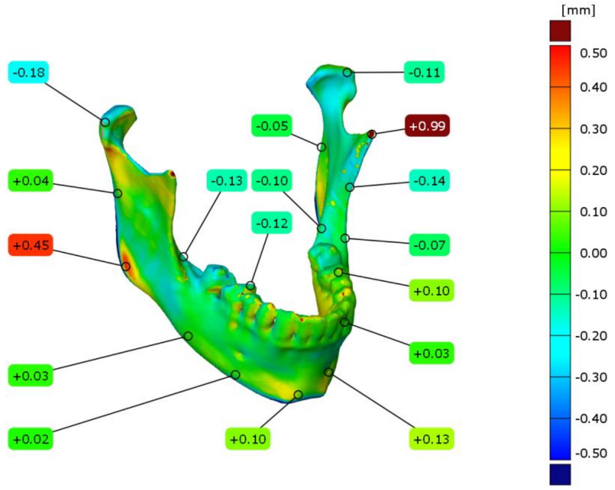

Figure 11. Analysis of shape deviations - orientation 315° (Vittek, 2016)

7 CONCLUSION

The lowest dimensional deviations were found at orientation 45° (+ 0.16 mm). Also, orientation in position 270° and 315° resulted in low dimensional deviations (+ 0.32 mm and -0.19 mm). The worst orientation in terms of dimensional accuracy was at orientation 0°, which created the greatest inaccuracies and distortions from required dimension (-0.52 mm) on the model of the mandible. Also the elapsed time between manufacturing and 3D digitization has huge impact on the accuracy of dimensions.

In the case of shape deviations, the best orientation, with respect to the dimensional accuracy, was reached at orientation 315°. The worst orientation was at 270° and 45°. Orientation 315 ° proved to be advantageous from an economic point of view, because the material quantity needed for manufacturing was the lowest (30 g).

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