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DIMENSIONAL ACCURACY OF PARTS OBTAINED BY SLS TECHNOLOGY

DIMENZIONA TAČNOST DELOVA DOBIJENIH SLS TEHNOLOGIJOM

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Keywords
- selective laser sintering (SLS) technology
- tensile testing
- 3-point bend test
- Polyamide 12
- 3D scanning

Abstract

Dimensional accuracy estimation of additively manufactured parts obtained via Selective Laser Sintering (SLS) is examined. As benchmark models, tensile specimens according to ISO 527-2 standard and bending specimens according to ISO 178 are selected. For all additively manufactured specimens, dimensions are measured and compared with the original CAD models. Tensile specimens are 170×20×4 mm in bulk, and the specimens intended for 3-point bend tests are 96×8×4 mm in bulk. Both specimen configurations are additively manufactured in two different printing orientations, i.e. horizontal and vertical. All specimens are produced on the Fuse 1 device (FormLabs, Summerville, MA), using Polyamide 12 (PA 12) material. After fabrication and post-processing, all specimens are scanned on Atos Core 200 3D scanner and afterward compared with the original CAD models via the GOM Inspect programme (GOM Metrology GmbH, Braunschweig, Germany).

Ključne reči
- tehnologija selektivnog laserskog sinterovanja (SLS)
- ispitivanje na zatezanje
- ispitivanje savijanjem u 3 tačke
- Poliamid 12
- 3D skeniranje

Izvod

Cilj ovog istraživanja je procena dimenzione tačnosti aditivno proizvedenih delova, dobijenih tehnologijom Selektivnog Laserskog Sinterovanja (SLS). Ovde su uzorci za zatezanje i savijanje izabrani kao reper modeli, napravljeni prema standardima ISO 527-2, (za epruvete na zatezanje) i ISO 178 (za epruvete na savijanje). Svi aditivno proizvedeni uzorci se mere i porede sa originalnim CAD modelima. Gabaritne mere epruvete na zatezanje su 170×20×4 mm, a epruveta na savijanje 96×8×4 mm. Obe konfiguracije su aditivno proizvedene sa dve različite orijentacije štampe: horizontalna i vertikalna. Uzorci su proizvedeni na uređaju Fuse 1 (FormLabs, Summerville, MA), koristeći Poliamid 12 (PA 12) materijal. Nakon proizvodnje i naknadne obrade, svi uzorci su skenirani na, Atos Core 200 3D skeneru, nakon čega se tako dobijeni skenovi upoređuju sa originalnim CAD modelom u programu GOM Inspect (GOM Metrology GmbH, Braunschweig, Germany).

INTRODUCTION

In contrast to subtractive manufacturing technologies where the final product is obtained via the removal of the material, additive technologies represent the process of adding the material in a layer-by-layer fashion until the new object is created /1, 2/. In additive manufacturing, more known as ‘3D printing’, materials are melted, softened, polymerised, or radiated, depending on a particular technology, thus joining the newly applied layer to the previous one. As a final product, either a prototype or a real functional part is obtained /3/. Depending on the chosen printing technology, a post-processing treatment could be applied before the actual use of such a component.

Demands in many engineering fields and further developments of production technologies have led to the creation and advances of many additive manufacturing technologies, i.e. FDM (Fused Deposition Modelling), SLS (Selective Laser Sintering), SLA (Stereolithography), SLM (Selective Laser Melting), DLP (Digital Light Processing), DMLS (Direct Metal Laser Sintering), EBM (Electron Beam Melting), etc. A wide spectrum of materials is used here, from thermoplastics (such as PLA, ABS, PETG), thermosetting photopolymer resins, and ceramics, to metals (such as Ti alloys, stainless steels, magnesium alloys, etc.) /3, 4/. Although the most used additive manufacturing technologies for research and commercial purposes are FDM and SLA, SLS is also one of the notable technologies /3, 5/. The subject of this paper is the dimensional accuracy determination of parts obtained with the latter-mentioned technology.

In the SLS process, layers are joined by means of fusion of powder-based material using the energy source, /1, 5/. Each succeeding layer is applied with the addition of a thin powder layer above the already fused one, using a roller mechanism. Next, a laser beam passes over the defined cross-section, thereby fusing the selected material onto a previous layer /6, 7/. Therefore, material fuses in two of the following ways: powder interconnects horizontally in the same layer, and vertically in-between neighbouring layers. In printing preparation, the software estimates the shape of each layer, based on the calculated cross-sections from the CAD model. In brief, this is how a powder melting process is managed. Using the described process several different objects of various shapes and dimensions can be produced simultaneously, with the only limit in powder bed volume. SLS technology uses polymer materials, mainly polyamides, and metals such as stainless steel, aluminium, and titanium-based powders, /8/. Considering that metals require more energy for the sintering process than polymers when using metal powders, support structures are necessary for heat removal and a dedicated metallic platform must be installed. For this reason, the removal of such metallic parts from the platform requires a higher level of force to be applied. In addition, subsequent mechanical process (such as sandblasting and polishing), and thermal, i.e. tempering process, improves the surface quality of a final part. Since polymers here do not require additional supports for heat removal, fabrication of multiple parts placed in the powder bed, one above the other, is possible, hence, enabling better utilisation of powder bed in one printing process. The material used in this research is a polymer- polyamide PA 12.

The topic of this research is to evaluate the dimensional accuracy of SLS parts and determine which printing orientation, i.e. horizontal or vertical, creates greater dimensional deviations, and where they are.

MATERIALS AND METHODS

Dimensional accuracy of additively manufactured parts depends on many factors, such as applied technology, i.e. the way the final part is produced, material type used in the process. For SLS parts, the position of the part and its orientation in powder bed are the main aspects to consider /9/. Worth mentioning is the research conducted by Queral et al. /9/, who investigated the dimensional accuracy of several parts manufactured with different technologies, i.e. FDM, SLA, and SLS. Here, SLS parts show a dimensional accuracy of 0.2 %. Polyamide powder with the brand name ‘Duraform’ (3D Systems, Rock Hill, SC, USA) is used in the research, /9/.

In this research, two specimen types are used for dimensional accuracy evaluation, both according to dedicated standards /10, 11/. Tensile specimens are 170×20×4 mm in bulk, namely size 1A, according to ref. /10/. The bending specimen is of rectangular prism shape of 96×8×4 mm dimensions, according to ref. /11/. Tensile and bending specimen geometries with listed dimensions in mm are shown in Figs. 1 and 2, respectively.

CAD models are created according to standards /10, 11/ in SolidWorks® (Dassault Systèmes, Vélizy-Villacoublay, France), and after that manufactured on an SLS machine.

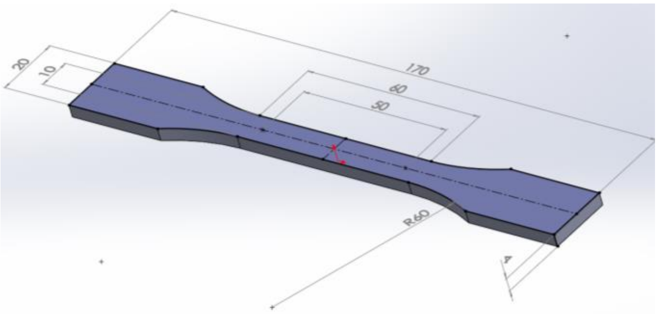

Figure 1. CAD model of tensile Type 1A specimen according to /10/.

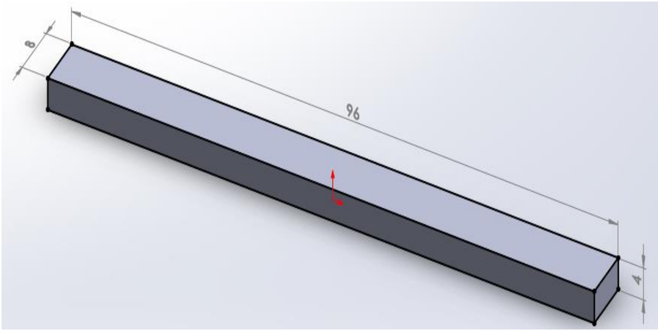

Figure 2. The CAD model of a bending specimen according to /11/

The process is performed on a Fuse 1 device (FormLabs, Summerville, MA), with two different specimen orientations, i.e. vertical and horizontal. The material utilized for the research is polyamide PA12. Tensile and bending specimens are manufactured separately. Hence two SLS processes are done. After specimen manufacturing, they are scanned via industry-grade 3D scanner Atos Core 200. This particular device has proven to bring satisfactory results in many engineering fields, such as automotive, aeronautics, and reverse engineering applications, as well as in academia and research institutions around the globe, /12/. 3D scanning is performed at room temperature, i.e. 23 °C, and relative humidity of around 50 %. Table 1 shows the performance characteristics of a particular device. Figure 3, up and bottom, shows both specimen types on an Atos Core 200 device during the 3D scanning procedure.

After 3D scanning of both specimen configurations, they are compared with the original CAD models to determine dimensional deviations. Comparison is done in GOM Inspect programme, and after aligning the scan to the CAD model using the ‘Surface Comparison on CAD’ tool, a final dimensional comparison can be assessed.

Table 1. Characteristics of Atos Core 200 with 2 cameras.

Measure area [mm]	Work distance [mm]	Resolution [mm]	Sensor dimensions [mm]	Operational temperature [°C]
200×150	250	0.13	206×205×64	+5 … +40

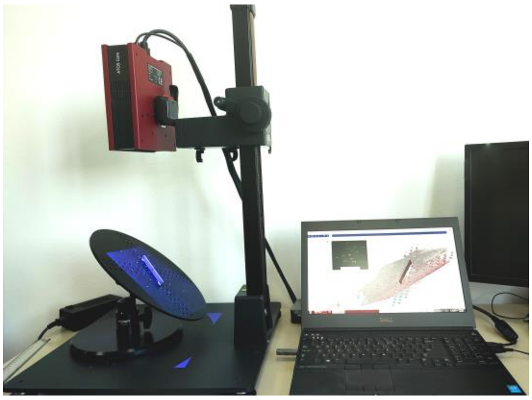

Figure 3. Tensile specimen (up); bending specimen (bottom) - mounted on the device during 3D scanning.

RESULTS AND DISCUSSION

As a result, deviation images clearly show how the 3D scanned model deviates from the CAD one and shows the exact locations of higher and maximal deviation values. Figures 4 and 5 show dimensional deviations of 3D scanned tensile specimens with horizontal orientation. Both specimen sides are shown, i.e. Fig. 4 shows the upper specimen part, and Fig. 5 depicts its bottom. Here, the maximal deviations from the CAD model occur on the specimen's far sides, i.e. top and bottom small surfaces, while minimal is present around the specimen radius and on the largest flat (top) surface. Worth mentioning is that in the specimen's middle side, and almost until the top and bottom side, where the tensile specimen is gripped in the tensile testing machine, there are no recorded deviations. Concerning actual dimensional deviation values, the maximal deviation is 0.40 mm, and the minimal one is 0.08 mm.

Figures 6 and 7 show dimensional deviations on tensile specimens created in the vertical orientation. Horizontally oriented tensile specimens have larger deviations on far sides, while vertically oriented ones have larger deviations on the largest, top, surface. Minimal deviation is recorded in the specimen middle section, on side surfaces. Regarding actual values, the recorded maximum is 0.35 mm, and the minimum is 0.08 mm.

As for bending specimens, their dimensional deviations are depicted in Figs. 8-11. Figures 8 and 9 show horizontally oriented SLS bending specimens. Here, the largest dimensional deviation is located on the bottommost surface, where the surface area is the smallest. In terms of actual values, the maximal deviation is 0.42 mm. In terms of minimal value, it is 0.03 mm and is located on the upper part of the 96×4 mm surface. Worth mentioning is that on the largest, i.e. 96×8 mm surface, deviations almost do not appear.

Next, Figs. 10 and 11 show vertically oriented bending specimens. Here, dimensional deviations are of much lower value than previous ones. Unlike horizontally oriented ones, the largest deviations are placed on uppermost and bottommost surface edges and hold a maximal value of 0.13 mm. Minimal values are as low as 0.01 mm and are located on edges between the largest surfaces, i.e. 96×8 and 96×4 mm ones.

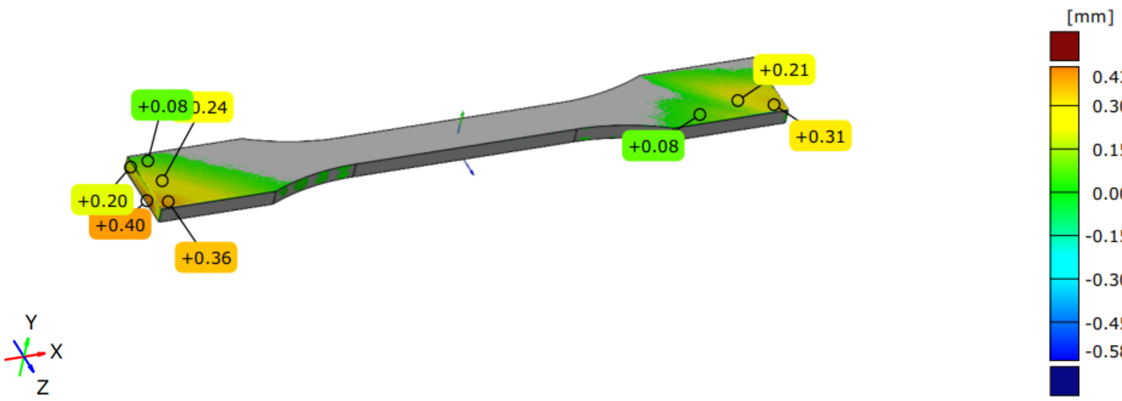

Figure 4. Horizontally-oriented tensile specimen - upper side.

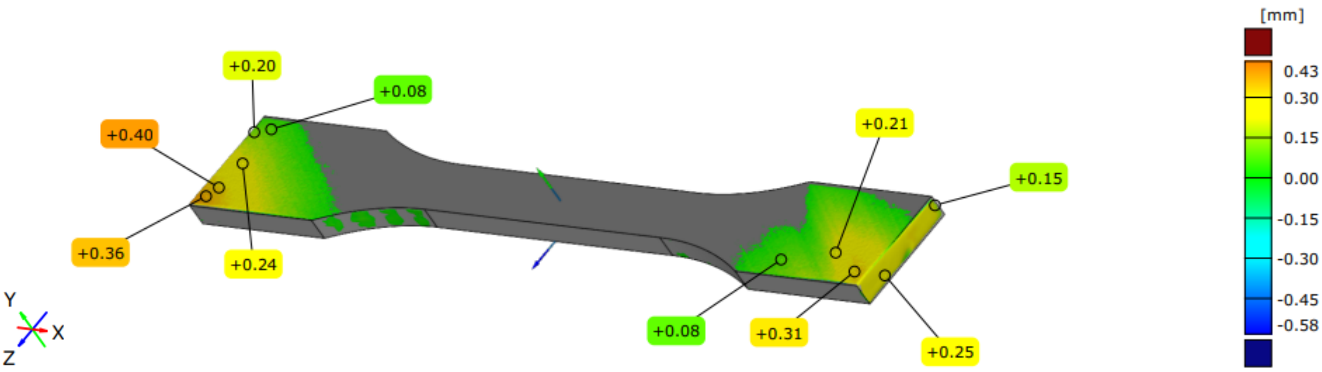

Figure 5. Horizontally-oriented tensile specimen - bottom side.

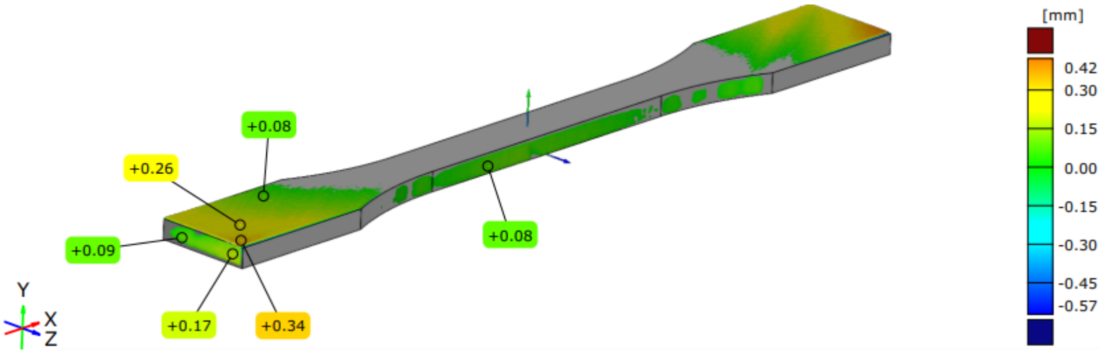

Figure 6. Vertically-oriented tensile specimen - upper side.

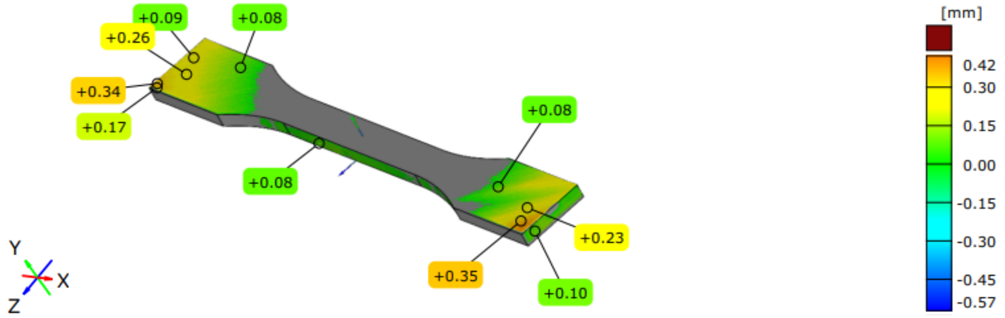

Figure 7. Vertically-oriented tensile specimen - bottom side.

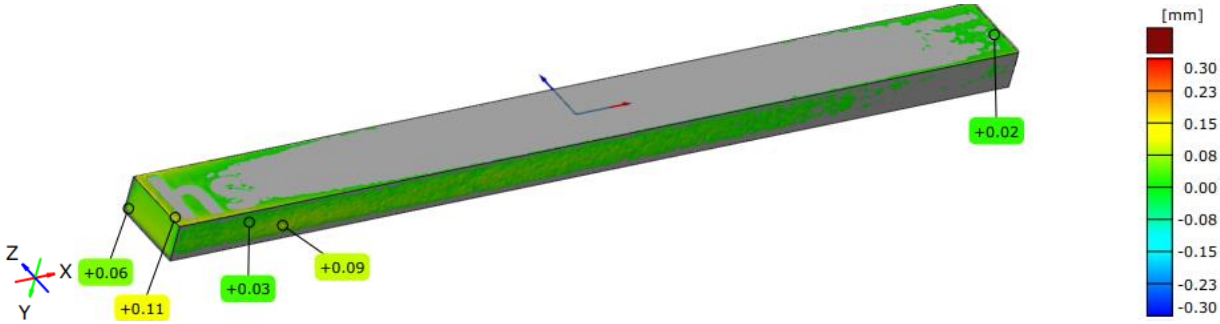

Figure 8. Horizontally-oriented bending specimen - upper side.

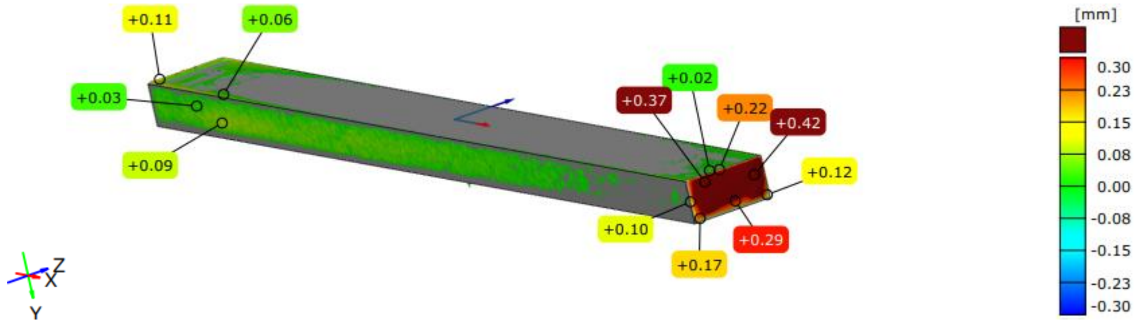

Figure 9. Horizontally-oriented bending specimen - bottom side.

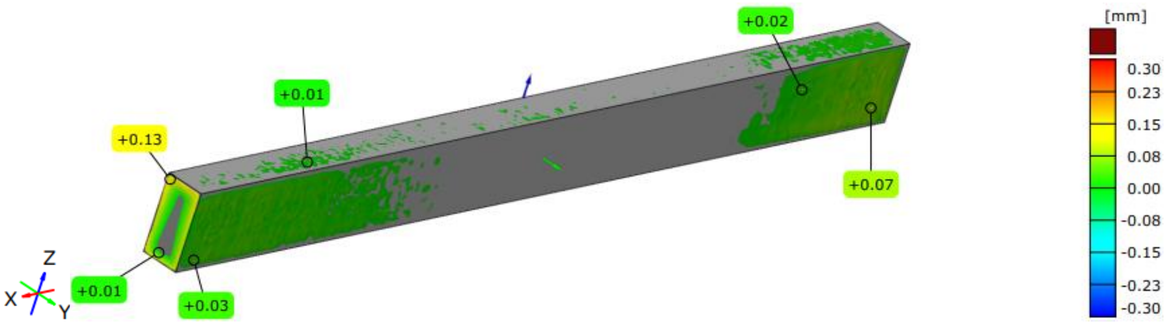

Figure 10. Vertically-oriented bending specimen - upper side.

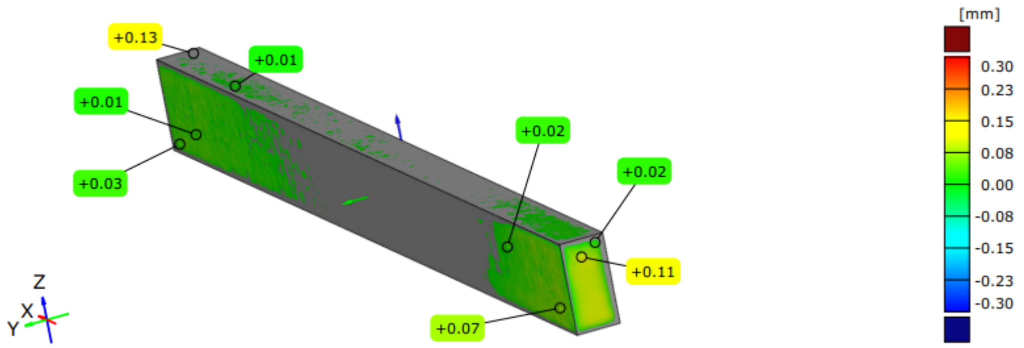

Figure 11. Vertically-oriented bending specimen - bottom side.

CONCLUSIONS

The research covers the dimensional accuracy evaluation of parts manufactured using additive SLS technology on PA12 material. Dimensional deviation is estimated from 3D scanned specimens aligned and compared with the original CAD model in dedicated software. As a result of GOM Inspect software, images with clear mapping of deviations and marked peaks are presented.

Research findings show that the maximal dimensional deviations occur mostly on surfaces with smaller areas. Namely, smaller surfaces here are placed on the far sides of the specimen, thus if there is some deviation in the printing process, the most noticeable deviations will be on the far-reaching sides of the laser beam, as is the case with horizontally-oriented specimens. Also, it is noticed that specimens of simpler geometry, i.e. bending specimens, have up to three times smaller deviation values in a vertical orientation, in comparison with a horizontal one, where the laser beam trajectory is longer when sintering far sides of the specimen.

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