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METROLOGICAL ANALYSIS OF THE IMPACT OF THE ARRANGEMENT OF MODELS ON THE 3D PRINTER PLATFORM ON THE DIMENSIONAL ACCURACY OF MODELS MANUFACTURED USING PHOTO-CURING TECHNOLOGY - PJM

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Abstract

The paper presents the results of metrological tests and measurements of dimensional accuracy of models manufactured using the photo-curing additive technology of POLYJET MATRIX - PJM. The material from which the samples were manufactured was a liquid polymer resin with the commercial name MED610, which is characterized by a high degree of biocompatibility, which increases the validity of the research in medical and dental applications. The key parameter considered was the location of digital CAD models in selected places of the virtual building platform and it influence of dimensional accuracy. The research results showed a clear impact of the arrangement of models on the building platform on the accuracy of the produced models, both in terms of external and internal diameters.

Keywords:

3D/4D printing, PJM, Metrology, MED610

1 INTRODUCTION

The development of technology related to the ongoing Industrial Revolution 4.0, and even sometimes defined the new transformation as 5.0, causes new expectations in the aspect of 3D printing technology regarding the quality of manufactured models due to the increasing potential industrial use, for example in the bearing, foundry or medical industry [Adamczak 2017; Requena-Perez 2024; Upadhyay 2017; Zmarzly 2022]. For such an application, dimensional and shape accuracy is an extremely important element, and the use of bio-medical materials, as presented in this publication, allows for increasing the potential use of test results in bio-mechatronics. The development of manufacturing technologies also forces the use of innovations in research processes, and in the case of measurements of selected geometric features and their deviations, modern innovative measurement methods are used [Adamczak 2016; Gogolewski 2023a, 2023b, 2023c; Townsend 2016; Isa 2024; Budzik 2023].

Research on the influence of the location of models on the building platform when producing models using 3D printing technology has been described in numerous research works, for example [Jansa 2023; Zarybnicka 2022]. However, they mainly concerned the influence of printing direction in one plane on manufacturing accuracy and selected mechanical properties. However, as practice has shown, the correct positioning of models on the building platform has a significant impact on the correct technological process, which depends on many different factors, depending on the 3D printing technology. The work [Kumar 2022] comprehensively presents the key 3D printing technologies and the technological parameters that affect the quality of the produced models in terms of dimensional accuracy. It also seems important to analyze metrological methods and measurement strategies [Pawlus 2017], which largely differ depending on 3D printing technology. For example, in measurements of the surface texture for different 3D printing methods, due to the different nature of the irregularities, there are different measurement errors affecting, for example, the number of unmeasured measurement points. For a variable thickness of the building layer, there is another problem with measurements dimensions for contact devices such as coordinate measuring machines – CMM or hand tools such as calipers. Many devices from two groups can be used to measure dimensional accuracy: contact and optical devices. In the case of the presented research, devices from both indicated groups were used. Each measurement method has its advantages and disadvantages. In the case of selected devices, it is possible to measure at the station immediately after completion or during the building process, while in the case of other methods, additional transport and mounting at the measurement station is necessary.

In the case of technologies from the Powder Bed Fusion group, such as selective laser sintering - SLS, selective laser melting - SLM, the arrangement of models on the platform must take into account e.g. the appropriate level of filling of the layer currently being built, usually not exceeding 30%. In the case of these methods, there is also a large impact of the location of the model in a given place on the platform, which relates mainly into the method of heat and cooling process. In the case of technologies such as photo-curing of liquid polymer resins - PJM/PJ and others based on jetting, an additional factor influencing the accuracy of the produced models is the printer maintaining appropriate stiffness and the parallelism of the plane of the building plate with the extruder equipped with head system.

The presented work analyzes sample models manufactured using the photo-curing technology of PolyJet Matrix - PJM and the MED610 material with high biocompatible properties and great potential use in the medical and dental industry. It seems that the research results presented in the article may be helpful in the analysis of the geometric accuracy of additive manufacturing systems carried out based on the PN-EN ISO/ASTM 52902 standard [ISO/ASTM 2023], which specifies the procedure for designing and manufacturing research models for their further verification.

2 MATERIALS AND METHODS

In the presented work 3D printer with the commercial name Connex 350 was used to build samples, manufactured by OBJET, currently Stratasys (Eden Prairie, Minnesota, USA), which implements the photo-curing technology of PolyJet Matrix - PJM. PJM technology is one of the most accurate 3D printing methods due to the very low layer thickness. In this technology, small drops of liquid resin are jetting in places of the currently built model layer, which corresponds to the cross-section. In the next step, the current layer is exposed to UV light from two lamps. Exposure initiates the polymerization process, both hardening the currently built layer and combining it with the previously created one.

Models of test samples were manufactured with a given layer thickness of 0.016 mm. Ring-shaped test samples were designed using CAD software - Solid-works, and their dimensions are shown in Figure 1. Two types of ring-shaped samples were designed, where the first type of samples had an external diameter of 50 mm and an internal diameter of 40 mm. The second type of samples had an internal diameter of 180 mm and an external diameter of 200 mm. Both samples had a thickness of 5 mm. Then, 3D models of the samples were saved as .stl. files with a linear accuracy of 0.01 mm and an angular accuracy of - 1°, and their view in the form of models approximated by triangles is shown in Figure 2. Selected mechanical properties of the MED 610 material are presented in Table 1, and the chemical composition of the resin in Table 2.

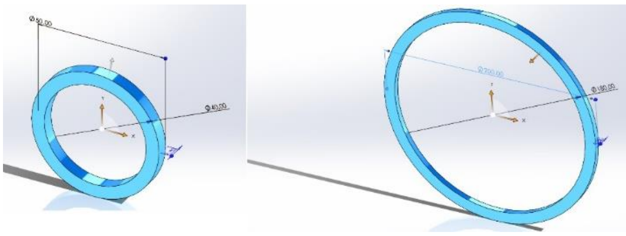

Fig. 1: Samples shapes and dimensions.

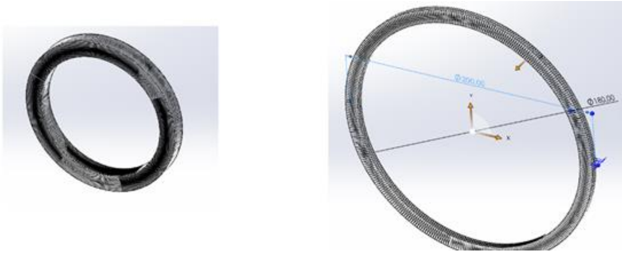

Fig. 2: Samples stl. files.

The aim of the presented research was to determine the influence of the location of models on the virtual construction platform on the dimensional accuracy of the manufactured models. This topic was taken up due to the fact that the 3D printer software always assumes the left quarter of the coordinate system (the place where sample 1 was manufactured - Fig. 3) as the "default" setting of models on the building platform, and as the preliminary results of our own work have shown, there are differences in the quality of produced models depending on their location on the building platform.

Table 1. Selected properties of MED610.

Properties		
Property	**Standard**	**Value**
Tensile strength	D-638-03	50–65 MPa
Ultimate elongation	D-638-05	10–25%
Young's modulus	D-638-04	2000–3000 MPa
Bending strength	D-790-03	75–110 MPa
Modulus of elasticity in bending	D-790-04	2200–3200 MPa
Water absorption	D-570-98 24HR	1.1–1.5%
Shore hardness	D Scale	83–85 D

Table 2. Chemical composition of MED610.

Component	% of weights
Isbornyl acrylate	15–30
Acrylic monomer	15–30
Urethane acrylate	10–30
Acrylic monomer	5–10; 10–15
Epoxy acrylate	5–10; 10–15
Arylate oligomer	5–10; 10–15
Photoinitiator	0.1–1; 1–2

In order to assess the impact of the location of sample models on the building platform on the dimensional accuracy of the manufactured models, smaller samples with an outer ring diameter of 50 mm were placed in the four corners of the platform. The larger sample model was placed in the central part of the building platform in such a way as to intensify the visible differences in dimensions.

The arrangement of samples on the building platform and the physically constructed sample models are shown in Figure 3. Figure 3 also shows the location of the extruder and its possible movement.

The measurement of the diameters of the samples was carried out using two devices: for samples with an external diameter of 50 mm, both the Mahr MarVision MM320 measuring microscope and a caliper were used, and for samples with a diameter of 200 mm, only a vernier caliper with a measurement resolution of 0.05 mm was used. The MarVision MM 320 has an XY stage travel range of 200 × 100 mm and resolution of 0.001 mm and a maximum error of 3 + L/100 µm. Its features include a zoom lens offering a magnification of ×0.7 up to ×4.5 and dimmable a LED transmitted light. In the presented studies, x4 magnification was used for measurement. Diameter measurement for all samples was performed at 15 locations (every 24° on the measured circle) to account for statistical calculations.

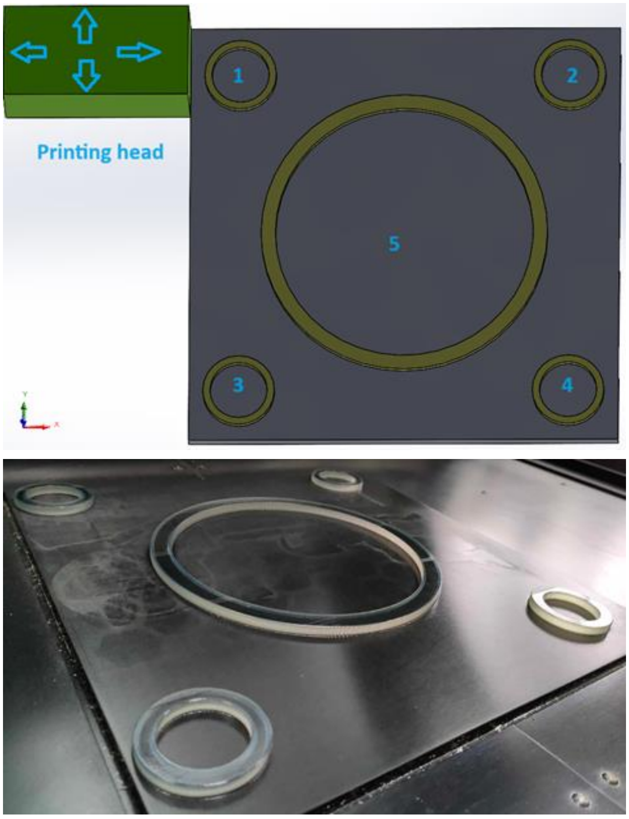

Fig. 3: Placement of samples on the build platform and manufactured models.

3 RESULTS AND DISCUSSION

The measurement results using a Mahr microscope for the internal and external diameters of smaller samples are presented in Figures 4 and 5, respectively. In the drawings, the value assumed in the 3D - CAD model is marked with a horizontal line. The dashed line shows the average value obtained from the measurements. Figures 6 and 7 show the results of internal and external diameter measurements for larger samples, respectively.

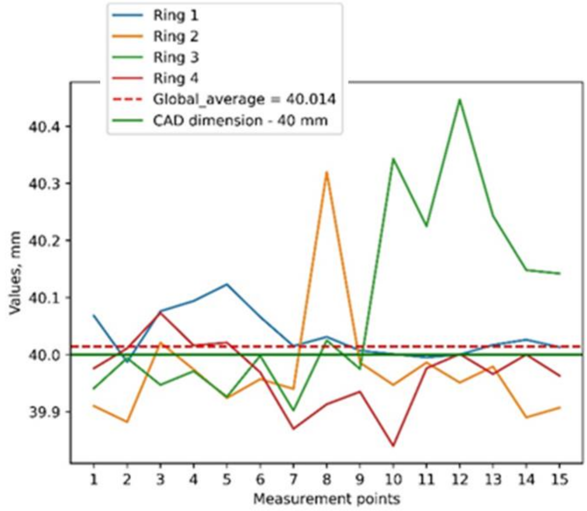

Fig. 4: Results of measuring the internal diameters of samples placed in the corners of the building platform.

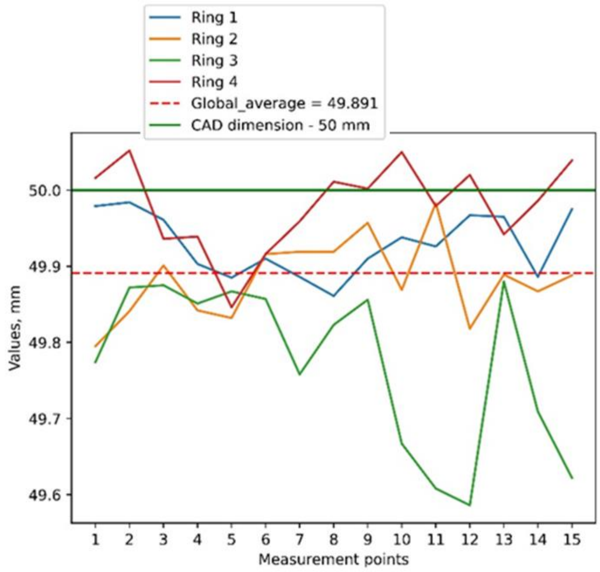

Fig. 5: Results of measuring the external diameters of samples placed in the corners of the building platform.

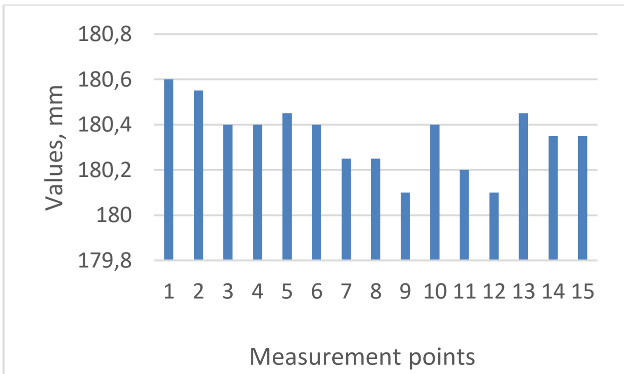

Fig. 6: Results of measuring the internal diameters of samples placed in the central part of the platform.

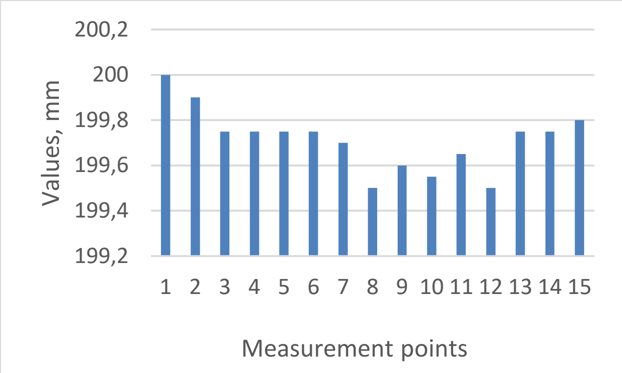

Fig. 7: Results of measuring the external diameters of samples placed in the central part of the platform.

Analyzing the test results obtained using a caliper for smaller samples placed in four places on the building platform, it is clearly visible that in the case of samples number 1 there is the smallest deviation from the given CAD model, which for the internal dimension is only 0.08 mm (average value 40.08). The deviation from the given dimension for sample 2 is also at a similar level and amounts to only 0.09 mm (average value 40.09). For both sample types, almost all 30 measurements showed values greater than the complex CAD model. In the case of samples 3 and 4, i.e. located in the lower corners of the building platform, most of the measured values for internal diameters were characterized by dimensions smaller than the specified CAD, and so for sample 3 the average deviation was - 0.13 mm (average value 39.87), and for sample 4 the average deviation was – 0.12 mm (mean value 39.88). The analysis of the results obtained using a microscope (Fig 4. and Fig 5.) shows similar characteristics, where for sample 1 the deviation is only 0.03 mm, and for sample 3 - 0.08 mm.

Analysis of the measurement results using a caliper for external diameters of CAD - 50 mm allows the conclusion that in all tested samples, regardless of location, the average value of 15 measurements was always lower than the CAD value. It is worth emphasizing that in this case, sample number 1 with the location recommended by the 3D printer software is characterized by the smallest value deviation of only 0.04 mm (average value 49.96). For the remaining samples, the results were as follows: sample 2, deviation - 0.05 mm (average value 49.95), sample 3, deviation - 0.2 mm (average value, 49.8), sample 2, deviation - 0.08 mm (average value, 49.92). It is worth noting that for sample number 3, both the values of external and internal dimensions were characterized by the largest deviations from those set in the digital model. Large deviations are very clearly visible, shown in green in Figures 4 and 5, for measurements from 10 to 12. Measurement using a microscope for external diameters also indicated the largest deviations for sample number 3, which amounted to an average of 0.23 mm. This position of the models on the building platform can be considered the least favorable

The analysis of the measurement results for sample number 5, manufactured in the central part of the Connex 350 printer's working platform, allows us to conclude that the average values of the measured internal diameter are - 180.35, and the external diameter - 199.71. Such large deviations may result from many factors, but it seems that the central location of the models on the building platform does not guarantee that the models will be manufactured with the highest dimensional accuracy. In the case of measurements of internal diameters of 180 mm, all measurements indicated a value of over 180 mm, and the standard deviation from the measurement sample was - 0.14. For an outer diameter of 200 mm, the deviation was at the same level, but in this case no measurement showed a value greater than 200 mm. As in the case of small samples, measurement in places 8-12 also in the case of a large sample and external dimension shows the largest dimensional deviations (see Fig. 7).

It is worth mentioning that the 3D printer was subjected to appropriate service before manufacturing the tested samples, where the service procedure does not assume any measurements related to the tested issues.

4 CONCLUSIONS

The measurement results using a Mahr microscope for the internal and external diameters of smaller samples and using a vernier caliper allow the following conclusions to be formulated.

The positioning of models on the building platform recommended by the manufacturer has a positive effect on the quality of the manufactured models in terms of dimensional accuracy. The recommended location is also characterized by the lowest standard deviation value. The least favorable variant is to locate the models in the central place of the 3D printer, where the standard deviation is also the largest for both external and internal dimensions. The test results presented in the publication should be taken into account when analyzing the geometric accuracy of additive manufacturing systems based on the PN-EN ISO/ASTM 52902 standard, which specifies the procedure for designing and manufacturing models for their further verification.

In the future, we plan to expand the scope of research with additional measurements for the PJM technology using devices diagnosing the parameters of the 3D printer's building platform and with additional analysis for other technologies, mainly from the SLS selective laser sintering group and others from the PBF.

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