

GEOMETRY AND SURFACE ROUGHNESS OF POLYMERIC SAMPLES PRODUCED BY STEREOLITHOGRAPHY

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Abstract: The purpose of the present paper is to evaluate the geometric accuracy and surface roughness of polymeric samples manufactured by Digital Light Projection (DLP) Stereolithography. The standard cubic samples with dimensions 5 mm x 5 mm x 5 mm were printed of two polymers: NextDent C+B (white-yellowish color A3.5, VITA shade guide) and NextDent Cast (dark-red color), in two ways of placement to the base – horizontally and inclined at 45°. The samples were printed with two different layer's thickness – 35 µm and 50 µm. It was established that the samples of both polymers, manufactured in horizontal position with the lower layer's thickness (35 µm) possess highest dimensional accuracy and lowest interval of deviation. The most accurate are the dimensions parallel to the basis, while these, parallel or inclined to the print direction, have the highest deviations. The interval of the deviations of the dimensions of samples, manufactured inclined at 45°, is nearly 2-3 times higher, as the interval of the samples, made of NextDent Cast, is more than 50% higher than that of NextDent C+B. The horizontally printed samples have 1.5-2 times lower surface roughness compared to the samples, printed inclined at 45°. The surface roughness of the samples, made of NextDent Cast, is 30-50% higher than that of NextDent C+B independently of the layer's thickness. The increase of the thickness from 35 µm to 50 µm leads to 1.5-2 times higher surface roughness in the two samples' positions. The optical properties of both polymers in the research strongly influence the geometric characteristics, dimensional accuracy and surface roughness of the objects, manufactured by DLP stereolithography.

Keywords: 3D-PRINTING, STEREOLITHOGRAPHY, DIMENSIONAL ACCURACY, SURFACE ROUGHNESS

1. Introduction

The implementation of the Additive Technologies (AT) in the prosthetic dentistry is rapidly growing up during recent years [1,2]. They are mainly applied for fabrication of surgical guides in the field of implantology, frameworks of fixed and removable partial dentures, wax and cast patterns for different prosthetic constructions, zirconium, maxillofacial and complete prostheses [3]. The models, manufactured through AT, are very useful in treatment planning and constructing of dentures in Prosthodontics and they also save a lot of chair time to the patients. [4]. The most frequently used additive technologies in the dental medicine are: stereolithography, fused deposition modeling, selective electron beam melting, selective laser sintering /selective laser melting and inkjet-based printing [3,5].

During the process of stereolithography a concentrated beam of UV light focuses over the surface of a reservoir full of liquid photopolymer. The light beam draws the object over the surface of the liquid. Thus a layer of the monomer polymerises or cures at each determinate time period. The object is being built up layer by layer until the final shape is obtained [3,5].

Initially the stereolithography is implemented for fabrication of physical models of the human anatomy, for planning of surgery procedures and construction of custom implants in the medicine and dentistry. Now this process is being applied for manufacturing of denture bases, custom trays, models, including orthodontic models, surgical guides in implantology, provisional crowns and bridges, resin patterns for casting of metals and alloys [3,5,6]. The latest generation printing machines show high accuracy: 25 µm - 29 µm. The dimensional accuracy of the constructions depends on their orientation according to the printing direction, the thickness of the polymerisation layer and the optical properties of the applied resin [6,7,8].

Stereolithography is the first technology for 3D printing, developed by C.W. Hull [9]. Since its implementation during 80's of the past century this technology has rapid development. 3D printing machines, based on the new technological processes, are created constantly. New types of resins are being developed for each type of printing machine – specific for the definite printer and with definite application. Because of the big variety of machines and materials, there is no enough data for the influence of the

different parameters of the processing regimes and the type of the resin over the accuracy of the final constructions.

The purpose of the present article is to study the geometry and surface roughness of resin samples, fabricated via Digital Light Projection (DLP) Stereolithography with different thickness of the layer

2. Experimental methods

Standard cubic samples with dimensions 5 mm x 5 mm x 5 mm were fabricated with 3D printer *Rapidshape D30*, working on the principle of the DLP Stereolithography. They were printed from two types of resins: NextDent C+B and NextDent Cast, 5 pieces of each material (Table 1 and Fig. 1). NextDent C+B is indicated for production of provisional crowns and bridges and has white-yellow color A 3.5 according to the Vita shadeguide. NextDent Cast has dark pink color and is specially developed for manufacturing of cast patterns. The samples are printed simultaneously in two dimensional orientations. In the first orientation the edge of the cubic sample is parallel to the basis, and its diagonal plane is perpendicular to the basis (inclined position). The second dimensional position is with wall of the cube parallel to the basis (horizontal position). As we found out in our precious work [6], that the dimensions of the printed cubes are larger than that of the virtual model, the sample objects in the experiment are printed with two different thicknesses of the layer: 50 µm, recommended by the producer, and smaller thickness 35 µm. When the printing process is completed all the samples undergo final photopolymerization with duration, given by the company.

The geometry of the cubic samples is studied through measurement of the sides and diagonals (Fig. 2) of three samples of

Table 1. Type of material, thickness of the layer for printing, final light curing time and number of samples.

Material	NextDent C+B		NextDent Cast	
	0.035	0.050	0.035	0.050
Layer thickness, mm	0.035	0.050	0.035	0.050
Horizontal position, number	5	5	5	5
Tilted position at 45°, number	5	5	5	5
Final light curing, min	30		10	

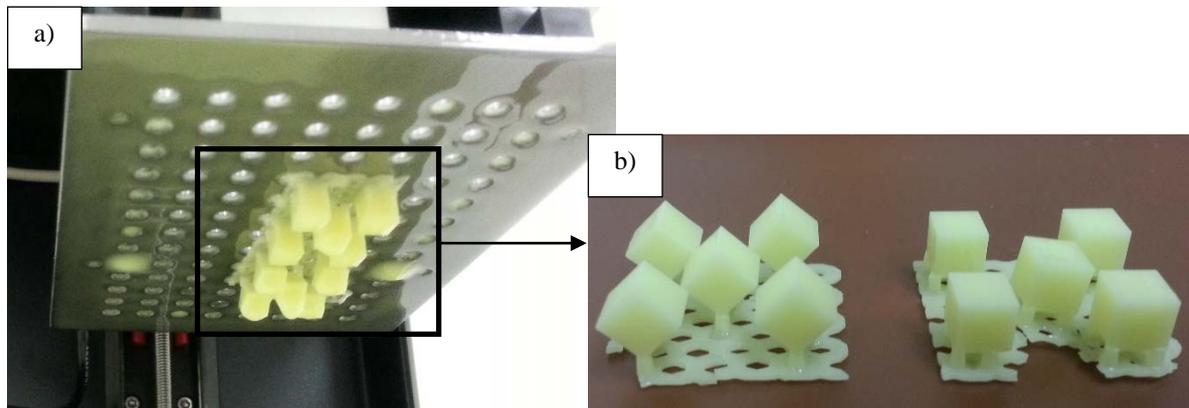


Fig. 1 Process of the samples manufacturing – a) and as-received samples of NextDent C+B polymer – b).

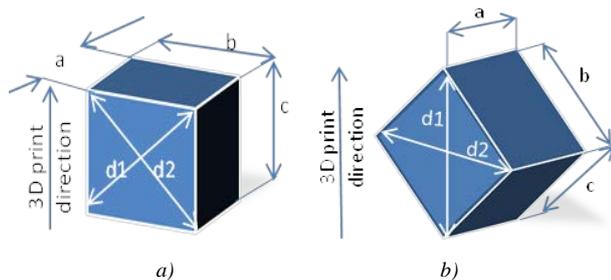


Fig. 2 Scheme of measuring of the samples, 3D printed in horizontal – a) and inclined – b) positions.

each material and each printing position. Over three of the walls of the samples, orientated in a different way to the printing direction, surface roughness is studied through measurement of its average arithmetic deviation R_a via profile-meter Taylor Hobson Surtronic 3.

3. Results and discussion

Accuracy of dimensions

Dimensions of the cubic samples, printed with different thickness of the layer, are shown at Fig. 3. Those dimensions, which are horizontally to the basis (along axis X and Y), possess the highest accuracy – a and b in horizontal position and a and $d2$ in tilted position. The dimensions, parallel to the printing direction – axis Z (c in horizontal placement and $d1$ in tilted placement), as well as those with inclination ($d1$, $d2$ in horizontal; b , c in tilted position) have the largest deviation. These results are clearly visible on Fig. 4, which shows the difference between the dimensions of printed samples compared to those of the virtual 3D model in %. The thinner the layer, the greater accuracy of the horizontal and

tilted dimensions when the samples are horizontal during printing.

The value of the maximum deviation of the dimensions of cubic samples, printed in horizontal position and inclined at 45° , is shown on Fig. 5. Both polymers demonstrate smaller value of the maximum deviation of the dimensions if the samples are horizontally positioned (0.100 mm at $50 \mu\text{m}$ thickness of the layer). The decreasing of the layer's thickness up to $35 \mu\text{m}$ lowers the dimensional maximum deviation to 0.060 mm for NextDent C+B and to 0.080 mm for NextDent Cast. The interval of variation of the deviations decreases also. The group of samples, printed with inclination, show twice greater interval of dimensional deviations. The maximum deviations are also higher: between 0.140-0.300 mm at $35 \mu\text{m}$ thickness of the building layer and 0.120-0.200 mm at $50 \mu\text{m}$ layer. The experimental objects made of NextDent Cast have greater values of the maximum deviation of the dimensions and larger interval of their variations, compared to the samples of NextDent C+B.

The present study shows that the highest accuracy and the lowest interval of dimensional deviation are demonstrated by samples of both resin materials which are horizontally printed with $35 \mu\text{m}$ thickness of the single layer. The dimensions with the highest accuracy are parallel to the basis – axis X and Y . The greatest deviation is presented by the dimensions parallel or tilted according to the printing direction - axis Z . The samples, manufactured with inclination, show almost 2-3 times bigger interval of dimensional deviation and it is more than 50% higher among the group of NextDent Cast objects in comparison to those made of NextDent C+B. These results prove the hypothesis from our earlier researches [6], that except the position of the object towards the printing direction [7,8], the optical properties of the monomer also influence the geometry of the objects, manufactured

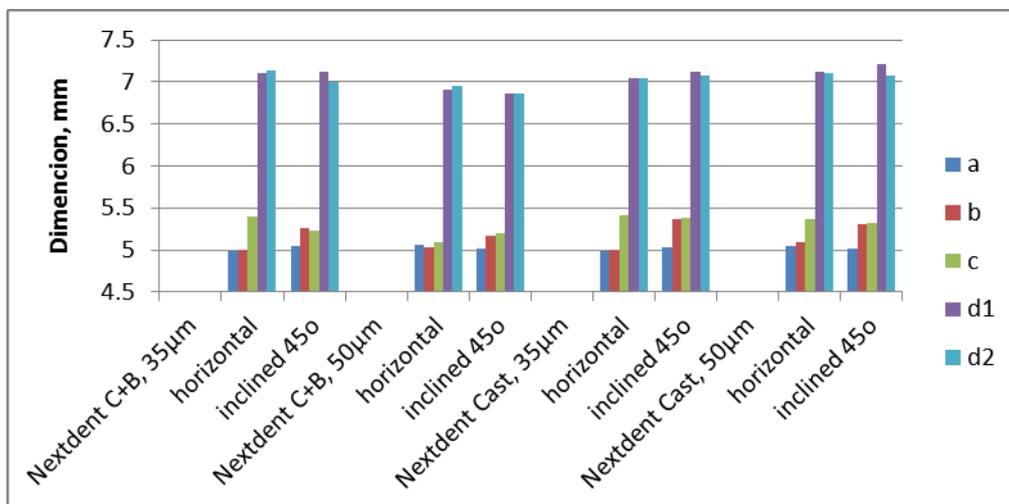


Fig. 3 Dimensions of cubic samples, manufactured of NextDent C+B and NextDent Cast with different layer thickness.

via stereolithography.

different angle by the two monomers. As a result an area outside the

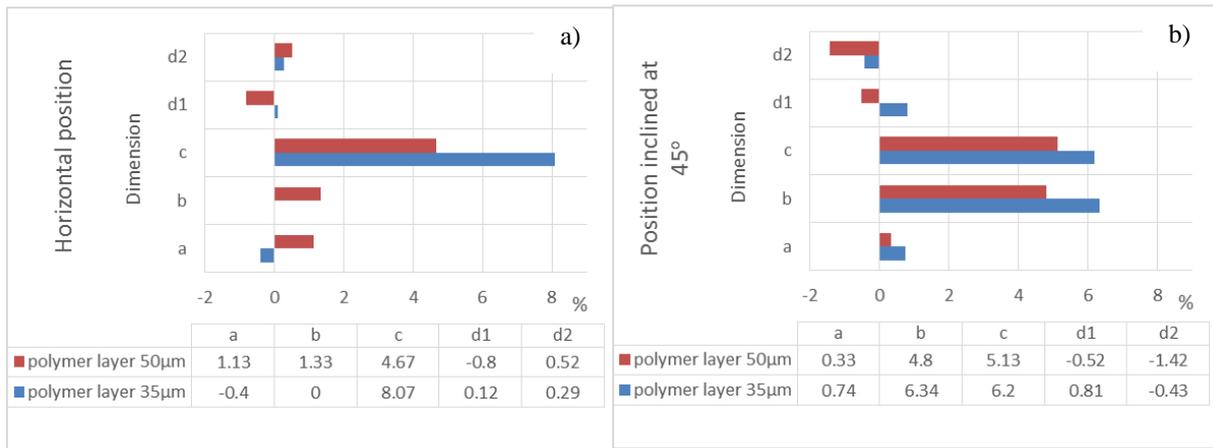


Fig. 4 Difference of the dimensions of 3D printed cubic samples with that of the 3D virtual model.

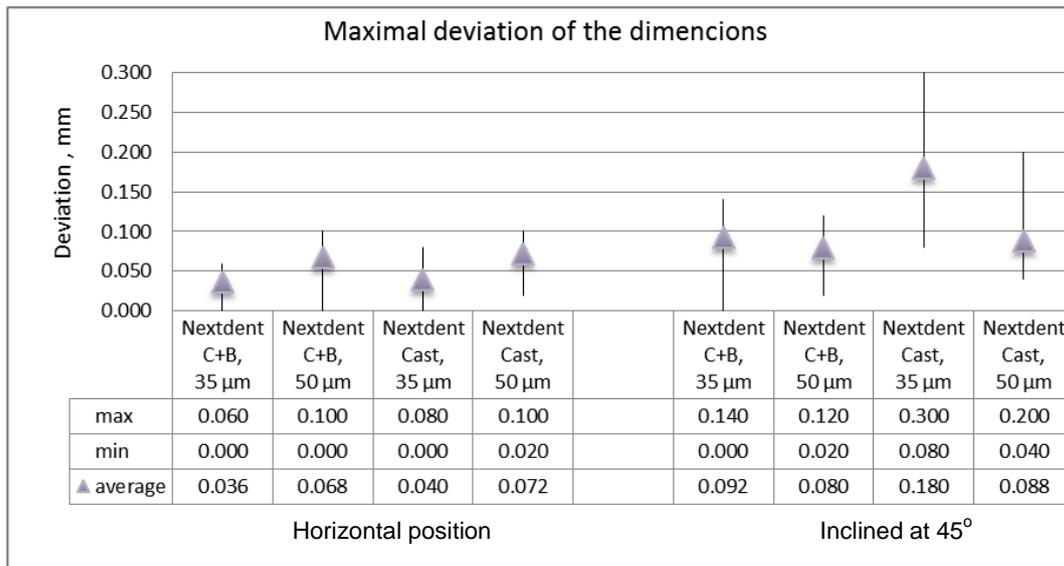


Fig. 5 Maximal deviation of the dimensions of cubic samples printed in two positions toward the basis - horizontal and inclined at 45°.

Both of the monomers in the study are not transparent and possess certain color with comparatively high intensity. This is the reason the polymerization process to undergo almost completely within the entire depth of the single layer among the samples with the smaller thickness of the layer. As a result only small quantity of the monomer needs additional polymerization which lowers the internal stresses and increases the accuracy. NextDent Cast is characterized by darker color than the NextDent C+B. Having in mind that the time for light exposure, recommended by the producer, is the same for both materials, it is expected the objects of NextDent Cast to have larger quantity of residual monomer. On the other hand, because of the different optical properties, the light rays not only penetrate of different depth but also are being reflected at

geometrical borders of the object can be exposed [7], which can lead to defects and enlargement of the dimensions.

Therefore, the optical properties of the applied monomers have decisive influence over the characteristics of the geometry and accuracy of the dimensions of the objects, fabricated via the technology of stereolithography.

Roughness

The samples in horizontal position have less surface roughness of their walls in comparison to those objects, printed in inclined position (Fig. 6). The least roughness is observed at the walls, situated horizontally to the basis. Their arithmetic mean deviation of roughness *Ra* is within and less than 0.5 µm, no matter of the

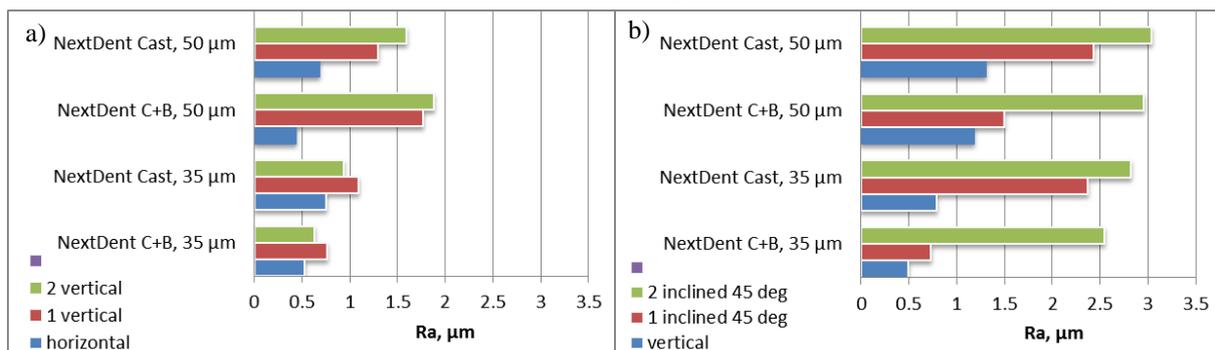


Fig. 6 The mean arithmetic deviation *Ra* of the roughness of surfaces of cubes 3D printed of two resins with different layer thickness in horizontal position - a) and inclined at 45° - b).

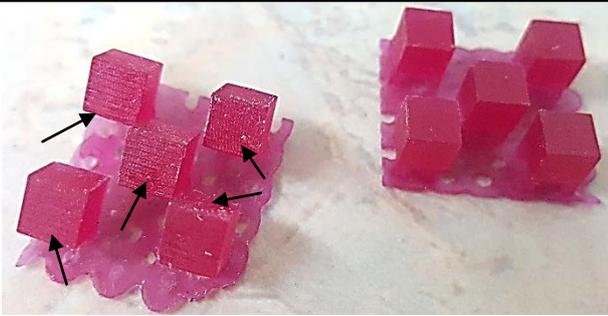


Fig. 7 Samples printed of NextDent Cast with 50 µm layer.

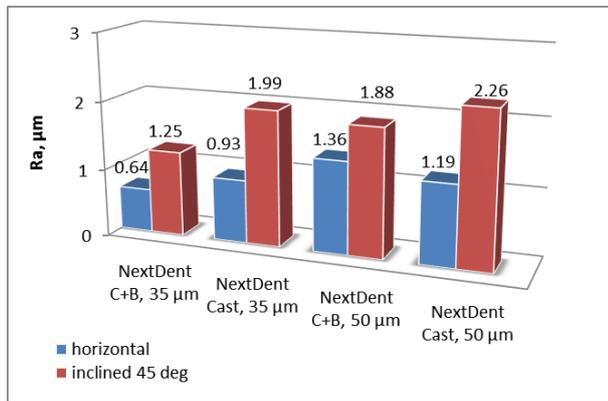


Fig. 8 Average Ra values of cubes 3D printed of two resins with different layer thickness.

thickness of the layer (Fig. 6-a). The roughness of the vertical walls is greater than that of the horizontal ones and it increases 1.5-2 times for both of the materials with the enlargement of the layer's thickness. Similar values of R_a are obtained for the vertical walls of the samples, manufactured in tilted position, too (Fig. 6-b). The walls, situated at 45° angle to the basis, have the highest roughness. The values of R_a are smaller for the walls which are closer to the supports, i.e. are being printed in the beginning of the process, and the values are greatest for walls, printed at the end (Fig. 7). Its values reach 2.54 µm (NextDent C+B, 35 µm layer) up to 3.04 µm (NextDent Cast, 50 µm layer). The tendency of increasing of the roughness with the increase of layer's thickness is observed clear as among vertical walls, and among those in inclined position.

The mean values of R_a (Fig. 8) demonstrate that the horizontal samples have 1.5-2 times less roughness than the others, positioned with inclination. No matter of the thickness of the layer, the roughness of the samples of NextDent Cast is with 30-50% higher compared to NextDent C+B. The increase of the layer's thickness from 35 µm to 50 µm leads to 1.5-2 times greater roughness in both printing positions, and it is more for the material NextDent C+B.

Single layers and surface defects, marked with arrows on Fig. 7, are well visible after the observation. The traces of the printing layers are in direct connection with their thickness, which is proved by the data for the mean values of R_a (Fig. 8). These traces are largest among the samples of the resin NextDent Cast – the material with the darker color, printed under inclination of 45° and with 50 µm thickness of layer. It is known that the roughness is in direct dependence with the thickness of the polymerization layer and the inclination of the surface according to the printing direction [7, 8]. The thicker the polymerization layer and the larger the angle to the printing direction, the greater the roughness is. On the other hand, the optical properties of the monomer have also influence and can cause surface defects and decreasing of the dimensional accuracy. This is a result of the ability of light rays to penetrate at various depths and to be reflected of various angles throughout materials with various optical characteristics. Thus an exposure of material outside the borders of geometry of the object occurs which leads to defects and increased roughness.

4. Conclusions:

The study of the geometric characteristics and the surface roughness of samples, manufactured of resins NextDent C+B and NextDent Cast with different thickness of the building layer via Digital Light Projection Stereolithography shows that:

- The highest dimensional accuracy and the least interval of deviation are observed among the samples of both resins, printed in horizontal position with a layer of 35 µm. Most precise are the dimensions which are parallel to the basis – axis X and Y, and most deviating dimensions, those parallel or inclined to the printing direction - axis Z. The samples, printed with inclination, have almost 2-3 times bigger interval of dimensional deviation. This interval is more than 50% greater for the samples of NextDent Cast, compared to those of NextDent C+B's samples.

- The samples with horizontal position are characterized by 1.5-2 times less roughness than the inclined samples. Independently of the layer's thickness, the roughness of the samples of NextDent Cast is 30-50% higher than its value for NextDent C+B. Increasing of the thickness from 35 µm to 50 µm causes 1.5-2 times greater roughness of the samples in both printing positions, and it is higher for the resin NextDent C+B.

The optical properties of the applied monomers influence decisively the geometric characteristics, the accuracy of the dimensions and the surface roughness of objects, produced by DLP stereolithography.

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6. References

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