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COMPARATIVE STUDY AND MECHANICAL ANALYSIS OF SOME ADDITIVE MANUFACTURED DENTAL MODELS

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Abstract: *The paper deals with a comparative analysis from a mechanical point of view of some dental structures realized by various additive technologies, which have a special development in the dental field in recent years. For comparison were considered dental models realized by means of different technologies, materials and 3D printing equipment. Results of the mechanical tests were analyzed, following which conclusions can be drawn that can contribute to the optimal choice of the appropriate application for the respective dental model.*
Key words: *Additive manufacturing, dental models, dental prostheses, 3D printing, selective laser sintering, fused deposition modeling, vat photopolymerisation*

1. INTRODUCTION

The spectacular development of additive technologies in last years has brought a lot of benefits in medical field and especially in dental medicine. Additive manufacturing has greatly influenced many areas of healthcare, and this aspect has outstandingly enhanced the overall health and patient's life quality [1]. The main advantages of 3D printing applications in the medical field can be summarized as: realization of precise and detailed prototypes / models of the organs with pathology in order to investigate the specific subtleties before the interventions or even the imitation of the surgical interventions on these models [2], execution of disposable sterile instruments [3] or even the printing of human tissues, opening in this way the doors to the large development of the transplant field [4]. Furthermore, to those mentioned above, there are several uses of 3D printing in medicine already established, such as: multiple applications in dental implantology, prosthodontics and orthodontics [5], otolaryngology [6] and realization of various orthopaedical prosthetic elements [7].

Taken into consideration the imposing evolution of these fabrication methods applied in medical field, in the near future it is possible that 3D printing can replace conventional manufacturing procedures for the obtaining of products for various purposes, including the prosthetic dentistry field. ¶

One of the most important applications of additive manufacturing in dentistry consist of realization of dental models, and the examination of their mechanical characteristics is key factor to choose a particular material for a certain utilization.

Fig. 1. Tested dental models

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The authors have already realized studies regarding the mechanical behavior of some parts manufactured by additive technologies [8], but also of some dental models made by fused deposition modeling technology using the same 3D printer and vat photopolymerization technology [9, 10]. Regarding the study in this paper, dental elements made by different technologies, different materials and different 3D printing equipment were considered. In order to compare the mechanical performances and implicitly to establish the suitable application, several dental models were made and tested by different additive technologies and different materials, as follows in Figure 1: 1—polylactic acid (Wanhao FDM 3D printer); 2— acrylonitrile butadiene styrene (Wanhao FDM 3D printer); 3—polylactic acid (Makerbot FDM 3D printer); 4—polylactic acid (Delta 3D printer); 5—Nylon (SLS 3D printer); 6—photocurable resin (DLP 3D printer).

2. MATERIAL AND METHODS

For the objectives of the paper, six dental models [11] were executed using different technologies starting from raw materials in the form of a fine-grained polyamide powder, thermoplastic filament and liquid resin with photosensible characteristics. In the case of nylon powder, selective laser sintering (SLS) technology was used, where the laser selectively processes the powder according to the particularities defined in digital model, thenceforth, the work platform descends with the value imposed of the layer thickness from the software and the construction continues until the three-dimensional structure is fulfilled. Regarding the obtaining of nylon dental sample (from polyamide powder) using SLS technology were used following parameters: a 30 W CO_2 laser power and 0.1 mm layer thickness [12].

Concerning the liquid raw material, a dental prototype was realized using DLP (Digital Light Processing) technology, which is part of the family of additive technologies by photopolymerization. The difference and the big advantage over stereolithography technology (SLA) is that DLP method operates faster because the entire layer is processed until the photosensible resin solidifies [10]. A standard photocurable resin was used, and the layer thickness was set at 0,05 millimeters.

With regard to the FDM technology, four dental samples were produced using three different additive manufacturing equipment: PLA model on Makerbot 3D printer, PLA model on Delta 3D printer, PLA and ABS model on Wanhao Duplicator 4S 3D printer [13-21].

Fig. 2. Experimental set-up for testing

The process parameters and work conditions for the realization of models were the same, apart from the thickness of layer – it was used 0.2 mm for Delta and Makerbot printers and 0.27 mm for Wanhao equipment.

A force transducer [8] with a maximum range load of 500 N and a chisel type accessory were used to experimentally examinate the specimens. The angle at the top of the chisel is 60° and its width is 10 mm. With this accessory, both the incisors and the molars were subjected to compression, as shown in Figure 3.

Fig. 3. Testing the incisor and molar areas

Figure 4 shows the traces left by the accessory on the FDM (Makerbot) and SLS dental models. In these experiments it was followed the evolution of the deviation in function of the force applied on all six models tested in the molar and incisor region in order to differentiate their mechanical performances [21].

Fig. 4. Effect of testing on FDM dental model (top) and SLS dental model (bottom)

3. RESULTS AND DISCUSSIONS

The experimental results were imported from the excel file into the Matlab and then grouped according to several criteria. The obtained results were graphically illustrated from several points of view: the type of region subjected, the material and equipment used [21].

Figure 5, 6 and 7 presents a comparison of the results achieved for the incisor and molar region for specimens realized through different additively manufacturing fabrication methods.

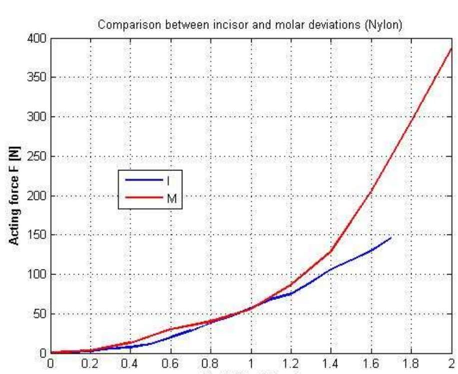

Fig. 5. Comparative results between incisor and molar deviations for models printed with SLS

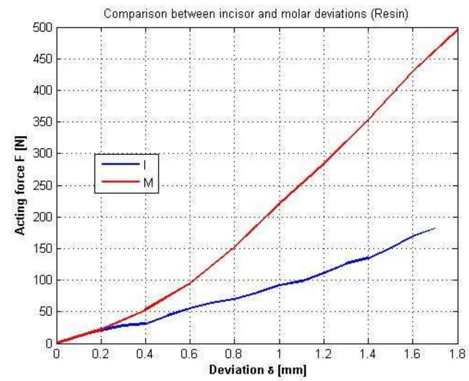

Fig. 6. Comparative results between incisor and molar deviations for models printed with DLP

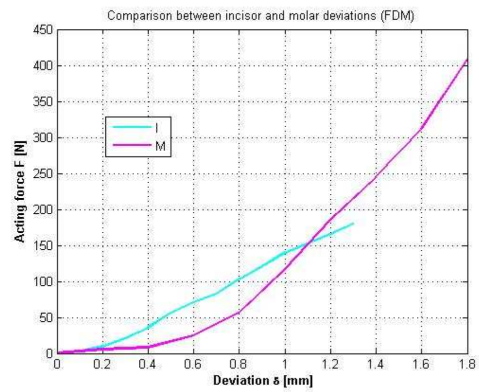

Fig. 7. Comparative results between incisor and molar deviations for models printed with FDM

For the chisel type accessory used, it is observed that the force that the molar can take over is higher compared to the incisor tooth for all tested samples.

Figure 8 and 9 show a comparison between the SLS fabricated sample, DLP fabricated sample as well as the FDM fabricated sample in the molar and incisor regions. They were denoted by N, R and FDM, respectively. It is observed a linear evolution of the characteristics for both molars (Figure 8) and for incisors (Figure 9), except for an area around the origin. The best linearity was obtained for the photocurable resin sample in the molar area. Also, this model is the most difficult to deform in the molar area, the PLA model dominating instead in the incisor area, and the nylon model being the easiest to deform in both cases. For example, in the case of molar area a deviation of 1,6 mm is obtained at subjecting load of 205 N for nylon sample, 430 N for resin model and 312 N for PLA sample respectively.

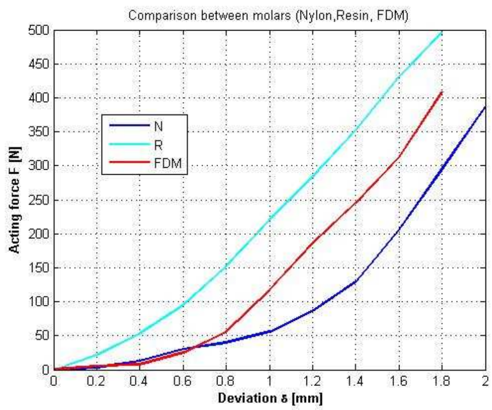

Fig. 8. Comparative results between models in function of technology used in the molar area

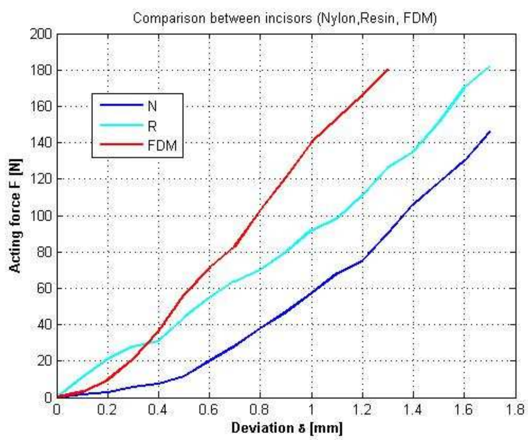

Fig. 9. Comparative results between models in function of technology used in the incisor area

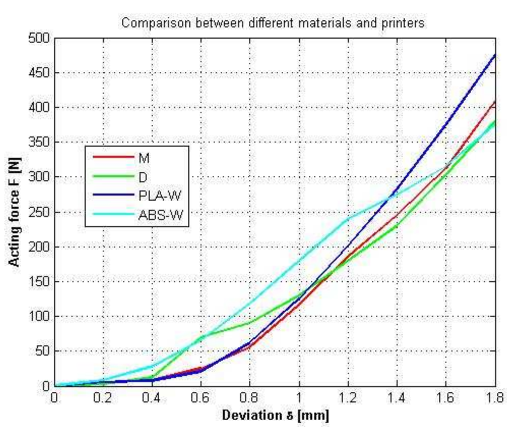

Fig. 10. Comparative results between FDM models in function of 3D printer used

Figure 10 makes a comparison between the materials and the equipment used concerning FDM technology. The following were used: Makerbot printer and PLA material (M), Delta printer and PLA material (D), and in the case of Wanhao equipment ABS and PLA were used. The test results from the figure 10 refers to molar region.

The best linear characteristic is obtained for Makerbot 3D printer and PLA material, but also for the Wanhao printer with the PLA material. The same does not happen for the Wanhao printer with ABS material due to the special processing conditions this material needs. The graph even shows an area where ABS is the most difficult to deform, knowing that this material has adequate mechanical characteristics, but overall has an unstable and nonlinear behavior. This aspect can be explained by the difficulties that can appear during ABS printing, specifically the cooling shrinkage or deformation. This material requires strict control of the printing parameters and is very sensitive to thermal disturbances, that is why it is advisable to use a printer with a closed and heated working chamber to obtain the desired and necessary properties [21].

4. CONCLUSIONS

The authors realized a theoretical and experimental study regarding mechanical performances of additively manufactured dental prosthetic samples taking into consideration different printing methods, raw materials forms and equipment used. It is remarked a linear evolution of the characteristics for both incisors and for molars for almost all materials tested, except for an area around the origin. The force that the molars can take is greater than the force that the incisors can take, considering their structure. Regarding the materials used, the best results were obtained in cases of PLA and nylon samples. Regarding the additive technologies that led to almost linear results, the SLS and FDM technology can be highlighted. In the case of FDM technology, this aspect is closely related to the equipment used: Wanhao and Makerbot. PLA is a eco friendly material and has shown stable mechanical behavior, and it can be concluded that it is possible solution to produce demonstrative models for the dental prosthetic field. The same can be sustained about the samples realized by SLS and DLP methods, with the help of which more high-performance samples can be obtained from several points of view (precision, surface quality), but at the same time requires much higher costs in terms of materials and equipment used compared to FDM technology.

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Studiu comparativ și analiza mecanică a unor modele dentare realizate prin tehnologii aditive

Rezumat: Lucrarea se referă la o analiză comparativă din punct de vedere mecanic a unor structuri dentare realizate prin diferite tehnologii aditive, care au o dezvoltare specială în domeniul dentar în ultimii ani. Pentru comparație au fost considerate modele dentare realizate prin intermediul diferitelor tehnologii, materiale şi echipamente de imprimare 3D. Au fost analizate rezultatele testelor mecanice, în urma cărora se pot trage concluzii care pot contribui la alegerea optimă a aplicării corespunzătoare pentru modelul dentar respectiv.

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