Experimental Researches Regarding Mechanical Behaviour of Dental Prototypes realized by Additive Technologies

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Abstract. The paper presents the behaviour of dental models subjected to mechanical loads. Maxillary dental arcade was obtained by additive technologies – fused deposition modelling and digital light processing. Also, it were used different materials - ABS, CarbonFil, biocompatible ABS, photopolymeric resin and the dental prototypes were tested in two areas - molar and central incisor zones with a transducer force HV 500. The experimental results highlighted the behaviour of the dental models realized by additive technologies in order to determine the maximum compressive force and maximum deformation of the maxillary in function of the material and the technology used.

1 Introduction

The manufacturing technologies used can be classified into two large groups. From the first group are the processing technologies by removing the material, starting from a larger quantity of raw material and removing the excess material by using conventional methods (milling) or unconventional methods (laser, electroerosion, ultrasound). The second group is represented by the material redistribution processing technologies, starting from a correct amount of raw material, which it redistributes to the mold required by solid deformation (forging, punching, extruding) or redistribution in the phase liquid or semi-liquid (casting, injection moulding). Recently, the third group of technologies, which fundamentally differs from the first two, in the sense that they use another principle for the materialization of a piece, technologies known as additive technologies, which make the piece by adding material, as much as necessary and where necessary [1].

The key word that all these technologies use is a section. The pieces are quantified by a succession of realizing sections using a constructional section piece repeat process. Therefore, a three-dimensional problem was reduced to a flat one. The price paid for this dimensional reduction is a decrease in the precision and surface quality due to the scale effect. Additive technologies are well-established manufacturing methods and follow the same basic steps: obtaining the CAD model, transferring the CAD model to the sectioning

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processor, triangular modelling in specialized software, part printing, and post-processing. The use of fabrication systems by the addition of material has begun in the production of models for the development or upgrading of products. It is thus possible to replace model manufacturing processes using conventional machinery and technologies, which are generally costly and low in productivity, with these new technologies capable of producing models or prototypes with acceptable accuracy in a very short time.

In this study several prototypes of dentures from different materials were realized and tested and using 2 different additive technologies. These models can be applied to the correct diagnosis and choice of appropriate therapy, improving communication between different physician teams. Also, the three-dimensional physical model can be used in the planning of surgical interventions that can be practiced on these models or to use them for didactic purposes for future specialists [1].

2 Material and methods

Additive technologies are a new class of technologies for the physical realization of a virtual model using a family of special equipment [2]. They ensure the addition or bonding of material in successive sections as much as needed and where necessary. The advantages of these new technologies result from the fact that parts with complexities and shapes can be manufactured, which by other technologies are impossible to process. Moreover, the complexity of the piece does not influence the cost of manufacturing, as it happens in other technology groups. All existing additions to the technology currently in use use the same principle, differentiating between them in relation to the nature of the raw material used and the properties and performance of the manufactured models. In this study, dental models were made using the liquid-based raw material technology - the DLP process and solid-state technology - the FDM process. The first method uses the principle of building on a horizontal platform, submerged in the liquid photopolymer. Solidification is achieved by the photopolymerization produced at the impact of a light ray with the upper surface of the liquid. The polymer has special properties in the sense that a UV or visible radiation initializes the polymerization at a depth of several tenths of a millimetre below the surface of the liquid, which corresponds to the thickness of a layer. After solidifying the first layer, the piece is submerged with a new polymer cross-section thickness and a new cross section of the workpiece is solidified. The entire cycle is repeated until the piece is solidified in its entirety [3, 4]. The second technology used in this study - FDM, is based on heating the material to be deposited up to its melting point and then depositing this molten material where it is needed to build the desired model [5]. Dental models made by additive technologies, which will subsequently be subjected to mechanical stresses, are presented in Fig.1.

Three different thermoplastic materials - ABS, ABS medical and PETG reinforced with carbon, and two conventional photopolymer resins - Industrial blend and Wanhao standard have been used in this research to realize dental models. ABS - a highly versatile polymer used in many industries and exhibiting a variety of properties. In 3D printing, the ABS is a tough plastic, high temperature resistant (it begins to deform at about 100ºC) and with light flexibility (compared to the PLA) which helps to achieve the objects that need to be joined. It is soluble in acetone - with a brush absorbed in acetone, the surfaces can be easily finished, becoming shiny, and the various parts of an object can be glued together. It contains, in its composition, oil. In large dimensions, it presents a risk of deformation. The Smartfil ABS MEDICAL filament is designed for 3D printing of medical items requiring a biocompatibility of range 6. The biocompatibility of range 6 allows the material to come into contact with the human body for a certain period of time. The Smartfil ABS MEDICAL filament is a quality material that allows 3D printing of fine parts without deformation. CarbonFil is based on the PETG polymer with 20% ultra-lightweight and relatively long carbon fiber, which has led to a particularly rigid 3D fiber reinforced filament. CarbonFil is twice as rigid as pure PETG and yet even 10% more impact resistant, which is a remarkable feature of the carbon fiber reinforced filament [6].

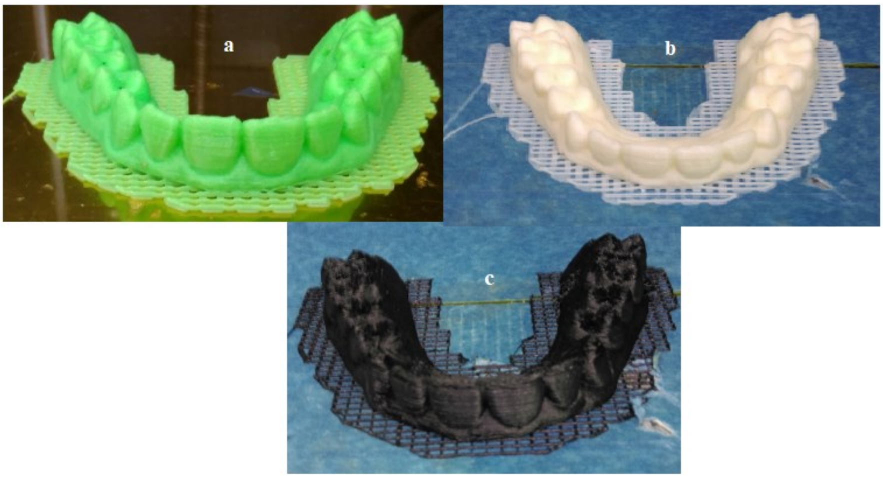

Fig. 1. Dental models realized by fused deposition modeling from different materials: a – ABS; b – ABS medical; c – PETG reinforced with carbon fiber [5, 7].

In terms of the materials used to obtain dental models through the photopolymerization process, two photosensitive resins from different manufacturers with similar properties were used.

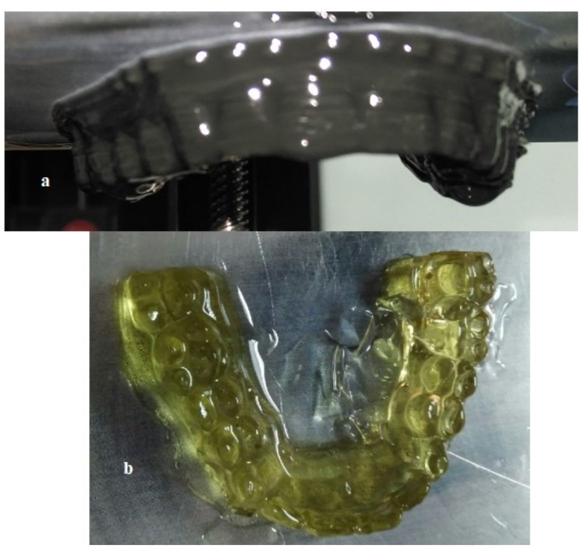

Fig. 2. Dental model realized by digital light processing technology from different materials: a – Wanhao Standard Resin; b – Industrial blend resin [7].

Standard Wanhao resin is a common material for printers using the DLP process and is a raw material accessible to any type of user and possesses satisfactory mechanical properties. Industrial Blend resin is widely applicable in the field of high-precision three – dimensional printing for 3D printers, printing on stereolithography technology (DLP) due to its compatibility and versatility. Industrial photopolymer has a fairly high polymerization rate (on average 0.5 seconds for a layer of 0.05 mm on standard DLP printers with a lamp power of about 240W) [8].

3 Experimental

The loads to which the teeth and dental prostheses [9] are subjected are very complex, dynamic and unpredictable. Practically, depending on the individual situation of each patient, different types of loads may occur, but they occur at the same time and not successively. In order to study the mechanical behavior of the combined compressive and shear stresses, the Test Stand HV-500N was used with hand wheel for measuring compression and tension forces [10]. Two areas of interest were chosen - the molar area and the central incisive area, as shown in Fig. 3. Fig.4 shows the dental models on the experimental stand before testing.

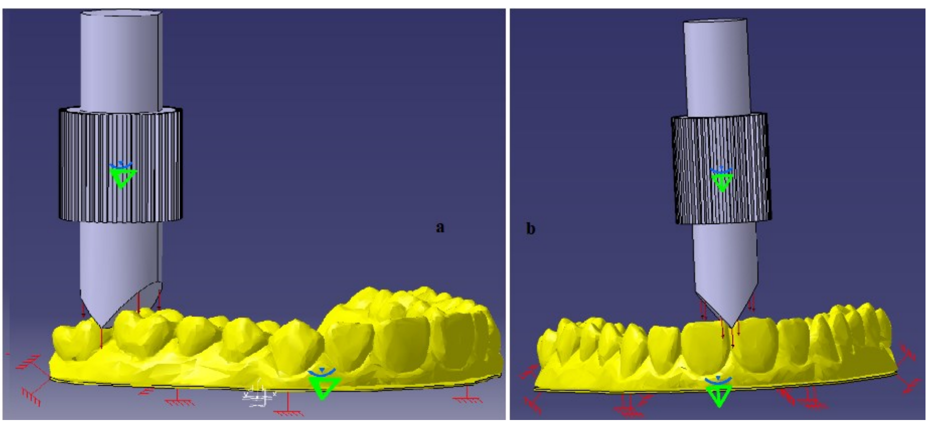

Fig. 3. Model of dental prosthesis test: a - molar area; b - central incisive area

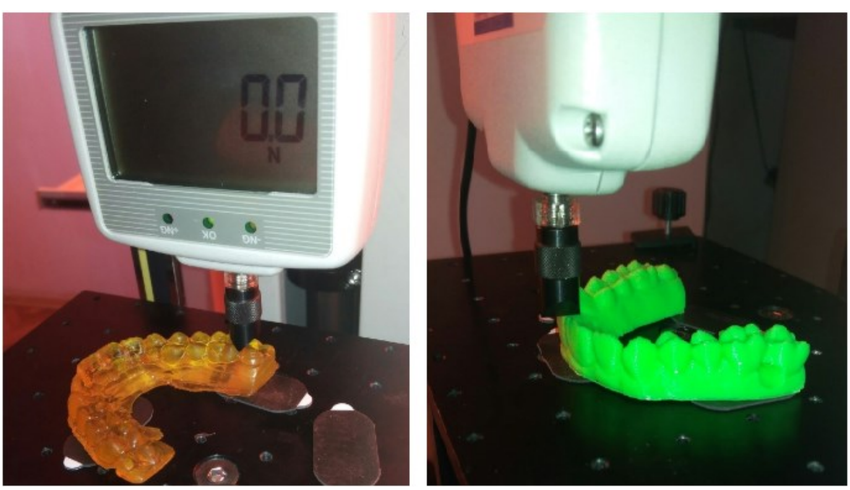

Fig. 4. Dental models on Test Stand HV-500N

The five dental models made by two different additive technologies have undergone mechanical combined stresses in two different areas. The maximum deflections, as well as the force at which these were obtained, were determined. Table 1 represents the results of measurements for the five investigated models, F_{max} – representing the force at which the maximum deflection f_{max} was obtained.

Table 1. Results of experimental research regarding mechanical behaviour of dental prototypes

Material	Molar area		Incisive area	
	F_{max} [N]	f_{max} [mm]	F_{max} [N]	f_{max} [mm]
ABS	498	1.44	488.3	2.6
ABS medical	494	1.9	492.5	3
PETG	497	4.64	498	4.94
Standard resin	488.9	2.1	355.5	3
Industrial resin	492.9	2.5	331.3	3.3

These tests can be useful in determining the optimal material according to its applicability. The results of the tested dental models in the molar area at combined stresses of compression and shear are represented in Fig. 5 for thermoplastic material and Fig.6 for photocurable resin. It can be observed from the tabel, that the ABS prototypes prove to be the most mechanically resistant, giving the smallest deflections - 1.44 mm for ABS and 1.9 mm for the biocompatible one, respectively. On the other side, PETG reinforced with carbon pieces get the biggest deformations over 4.6 mm. Photopolymeric resins have fairly good behavior in the molar area, with arrows below 3 mm.

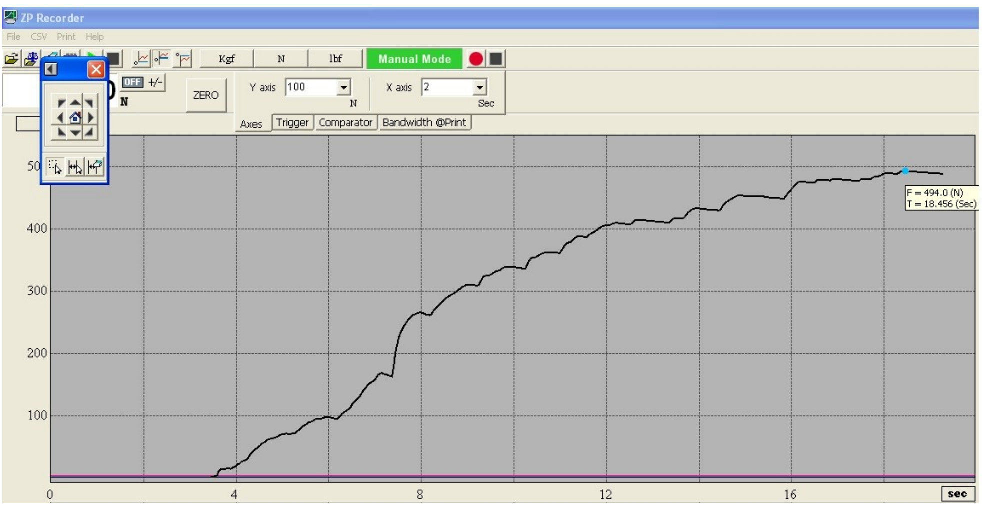

Fig. 5. Evoloution of force in function of time of biocompatible thermoplastic dental prototype in the molar region

Also from the experimental stand software it is possible to view and record the evolution of the force over time. Fig.6 shows the time-based behavior of the dental model made from industrial resin.

Concerning the experimental tests for the central incisive area for thermoplastic materials, the things remain unchanged. As in the first case, ABS and biocompatible material realize the smallest deflections, being the most resistant, and PETG is the easiest to deform - getting deflections of nearly 5 mm at a force of 498 N. Fig.7 shows the evolution of force in function of time of biocompatible thermoplastic dental prototype in the molar region. These tests have demonstrated the use of ABS material in various engineering or medical applications where high mechanical strength is required. However, the accuracy and quality of printed surfaces is better for dental models made through DLP technology.

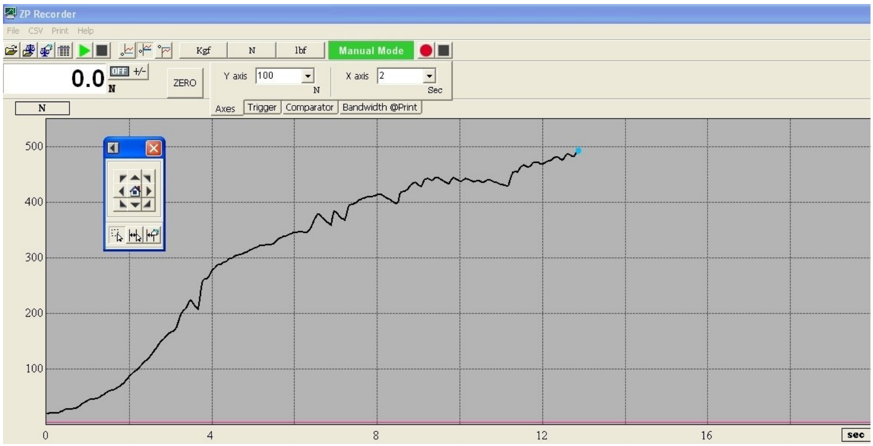

Fig. 6. Evoloution of force in function of time of industrial resin dental prototype in the molar region.

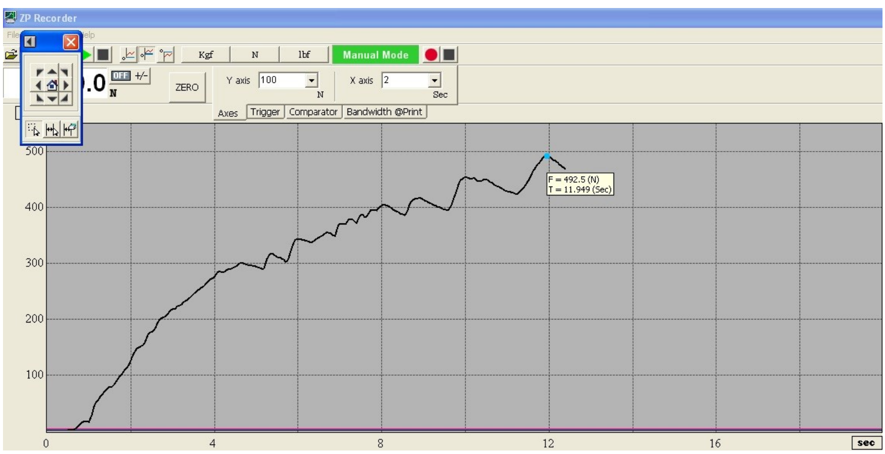

Fig. 7. Evoloution of force in function of time of biocompatible thermoplastic dental prototype in the incisive region

The results is radically changing in parts made from photosensitive resins. Figure 7 clearly shows the difference between the maximum forces exerted on the thermoplastic models and the photopolymer thermorigids. Between about 330 and 355 N there is a breakage of the models in the incisive area, which is shown in the Fig.8.

Fig.9 demonstrates the breaking of the dental model after reaching the maximum force, the graph showing Hooke's law with the elastic area, the yield area, and finally the rupture area where the force drops suddenly. Both models of photopolymer resins had almost identical behavior in the molar area and the incisive central region, reaching the rupture at about 350 N.

An experimental research was also carried out on the resistance of dental prosthetic models to penetration force. For this purpose, a penetrating pin gauge was used on the same test stand (Fig.10). Of all the investigated materials, plastic deformation was produced only in the dental model of ABS, the other materials having the deformation values in the elastic field. The ABS medical proved to be the most resistant with a deformation of 1.42 mm. At the opposite pole there are photopolymeric resins with deformations over 2.35 mm. The

PETG model has a 2.01 mm deformation. It is worth mentioning that these arrows were measured at the same drive force - 100 N.

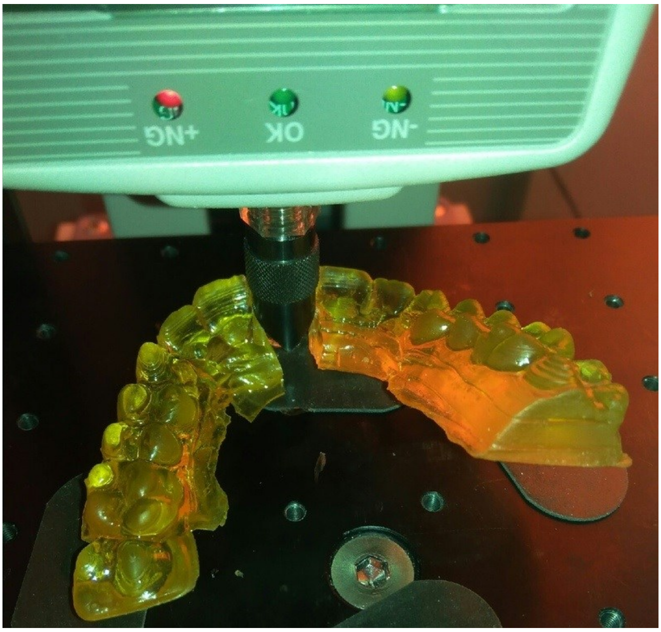

Fig. 8. The breaking of the photopolymer resin dental model.

It can be said that the photosensitive polymeric materials are easier to model and deform, so practicing and simulating surgical procedures on these dental models by specialists seems to be more practical.

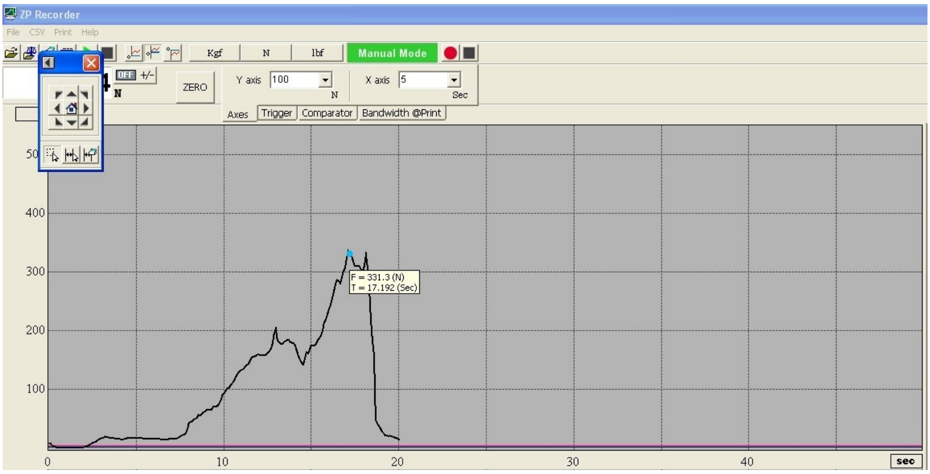

Fig. 9. Evoloution of force in function of time of standard resin dental prototype in the incisive region

Fig. 11 illustrates the comparison between two thermoplastic materials subjected to the penetration test. It can be observed the difference between plastic deformation in the ABS model, where the force drops suddenly and the elastic deformation of the ABS medical model.

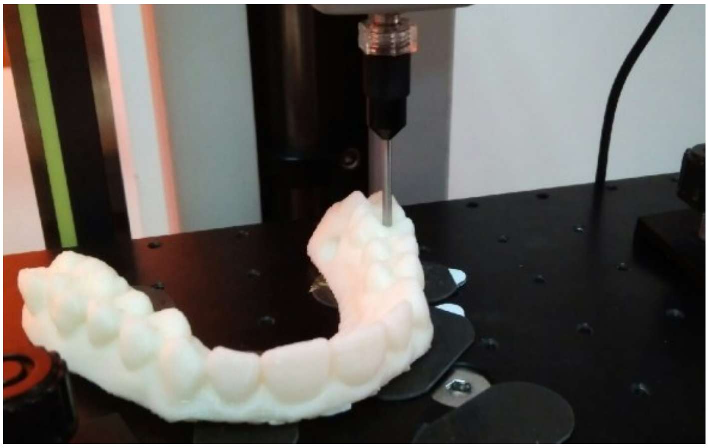

Fig. 10. ABS medical dental model acted with the penetrating pin gauge

Fig. 11. Results of force in function of time of ABS (top) and ABS medical (bottom) prosthetic dental models tested with penetrating pin gauge

4 Conclusions

Dental prostheses are consistently subjected to very complex and unpredictable mechanical loads, which is why their study becomes essential in order to obtain prosthetic works with the desired performance. In this study, the authors performed 5 prosthetic dental models using two different additive technologies - Fused deposition modeling and Digital light processing. For the first technology ABS, ABS for medical use and PETG reinforced with carbon were used. The other technology used two diffused resins - standard and industrial. All dental prosthetic models were tested on a force transducer in two different areas - the molar area and the central incisor in order to determine how the material deforms acting on the prosthetic elements with some combined forces - compression and shear. As expected, the thermoplastic parts are more mechanically resistant, ABS demonstrating its utility in many engineering applications. The biocompatible material proved to be equally resistant, which in optimal printing conditions could even serve as temporary prostheses. At PETG reinforced with carbon prototypes, maximum deformations are obtained. In the prosthetic models of the photopolymer resin it was obtained a rupture in the central incisive area at about 350 N. Also, the dental prototypes were subjected to a penetration force, most of the models deforming in the elastic domain. Overall, from the mechanical point of view, the most resistant material after the study proved to be ABS medical, but from the point of view of the quality of the resulting surfaces, the photocurable resins give better results than those realized by thermoplastic extrusion.

These materials can serve as models for future dentures due to its properties. Instead, those in thermoplastic materials are more resistant to mechanical loads, but they can still be used as a teaching aid for future specialists. Due to the special development of these additive technologies in the medical field, future research aims at the study of new materials, especially the realization and testing of biocompatible resin from photopolymer specially designed for dental applications. The behavior of the models to the other types of mechanical stresses will also be investigated.

References

1. P. Berce, N. Balc, C. Caizar, R. Pacurar, A. Radu, S. Bratean, I. Fodorean, *Tehnologii de Fabricatie Prin Adaugare de Material Si Aplicatiile Lor* (Editura Academiei Romane, Bucuresti, 2014)
2. A. R . Spanu, V. Constantin, IJOMAM, **2**, 7- 11 (2017)
3. E. Moraru, D. Besnea, O. Dontu, G. I. Gheorghe, V. Constantin, IJOMAM, **3**, 66-71 (2018)
4. G. Ionascu, L. Bogatu, A. Sandu, D. Duminica, RRPMOM **15** (27), 417-424 (2005)
5. E. Moraru, O. Dontu, D.Besnea, V. Constantin, Study and realization of prosthetic dental models by additive technologies, IOP Conf. Ser.: Mater. Sci. Eng **444** (4), 042017
6. N. Mohan, P. Senthil, S. Vinodh, N. Jayanth, Virt. Phys. Prot **12**(1), 1-13 (2017)
7. E. Moraru, D. Besnea, A. Spanu, V. Constantin, IJOMAM **3** (4), 329-338 (2018)
8. D. T. Ngo, A. Kashani, G. Imbalzano, K. T. Q. Nguyen, D. Hui, Composites Part B **143**, 172-196 (2018)
9. E. Moraru, O. Dontu, A. Petre, D. Vaireanu, F. Constantinescu, D. Besnea, J. Opt. Adv. Mat **20** (3-4), 208-213 (2018)
10. D. Besnea, C. Rizescu, D. Rizescu, C. D .Comeaga, R. Ciobanu, E. Moraru, Study of deflection behavior of 3D printed leaf springs, IOP Conf. Ser.: Mater. Sci. Eng **444** (4):042008