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POSSIBILITIES OF OBTAINING COMPLEX GEOMETRIES USING ADDITIVE MANUFACTURING WITH LIQUID PHOTOPOLYMERS

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Abstract: *Additive DLP printing technology is an additive manufacturing process based on the use of ultraviolet light for the solidification of liquid polymeric resins sensitive to this radiation and the obtaining in a short time and with a high surface quality of parts with complex geometries with numerous applications in the medical area, micromechanics, microfluidic or moulding. In the paper are presented the advantages of this technology regarding the obtaining of functional prototypes with complex geometries made of different materials including applications in the biomedical field, the obtaining of master moulds for injection process, models for medical prosthetics, hearing aids, dental restorations, microfluidic models, emphasizing the fact that the prototypes are used for demonstrative models or functional testing with high surface quality and precision.*

Key words: *Additive manufacturing, advanced manufacturing process, DLP technology, photopolymeric resins, functional prototypes*

1. INTRODUCTION

The current 3D printing systems have a vast flexibility regarding the use of a varied range of materials leading to the increasingly pronounced growth of the fields of applicability. Most of the additive manufacturing processes with liquid raw material use a certain radiation source to which the liquid is sensitive to strengthen its surface pointwise or surface to surface, the solidification being achieved due to the photopolymerization reaction resulting on the upper surface of the liquid during the impact with the radiation source. The main type of radiation used is ultraviolet light, which causes a chemical reaction and changes the properties of the polymeric material used in these types of additive technologies. After all these photochemical reactions and consolidation of a layer, the part is immersed with a new section thickness and a new cross section of the part is processed until the part is built on its entire volume. Being the first additive technology recognized worldwide, photopolymerization technologies have always represented an interest from scientists over the years with the aim of improving the process and finding new important uses for society [1–6].

SLA (Stereolithography) technology [7] and DLP (Digital Light Processing) technology are representative additive manufacturing methods in the category of processes using photosensitive liquid raw material, the latter being a more accessible option, but also often faster than printers using SLA technology due to the specific mechanism and configurations of processing and scanning layers through a complete image of them [8]. Applications of DLP technology can be identified in several branches such as dentistry [9], medical modeling [10] and jewelry [11] or other types of functional or visual prototypes and other applications [12].

This effective technology for manufacturing three-dimensional objects with diverse and complex geometries fits perfectly into the current research issue for expanding applications in biomedical or precision engineering [4, 9, 13–15], in the paper the authors addressing these aspects in which 3 areas will be discussed and developed in which DLP technology can be applied with examples of obtained parts, experimental stands made in which structures executed by DLP technology are found and at the same time the properties of the resulting surfaces are evaluated and compared with another rapid prototyping technology – Fused Deposition Modelling (FDM) – another additive manufacturing method with multiple applications [16 –19].

2. DESCRIPTION OF THE DLP (DIGITAL LIGHT PROCESSING) PROCESS

The DLP printing technology used for the execution of the structures in this work is based on the interaction of ultraviolet light with the surface of liquid raw material with special properties for materializing three-dimensional objects by additive methods with high precision due to specific execution mechanisms. They consist of a set of microoptical systems consisting of a matrix of mirrors that have the role of performing a spatial modulation of light in a short time.

Fig.1 presents the principle scheme of DLP 3D printing technology [9] [20], where the main components of the manufacturing system can be identified.

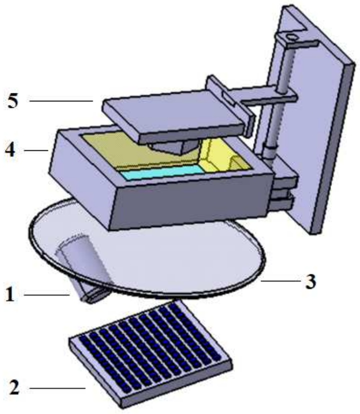


Fig.1. Principle sketch of DLP process: 1 - UV source; 2- DLP micromirror matrix; 3 - lens; 4 – vat with liquid photopolymer; 5 – work platform**.**

The process starts as usual typical of additive technologies from a CAD file obtained by design or scanning, which is then processed into special software to cut the model into several layers and generate future trajectories of the printing mechanism, this information being subsequently transmitted to the 3D printing equipment before the actual execution begins. During processing by DLP technology, UV light is modulated and directed using the aforementioned special optical system, according to the information received from the slicing software on the surface of the photopolymer liquid located in the construction platform. Ultraviolet light interacting with the surface of the liquid photopolymer triggers specific chemical reactions, inducing successive solidification of the treated layers according to the trajectories generated by the program. Since the optical system consisting of matrices of micromirrors exposes an entire cross section, the printing speed of a layer is invariable for any geometric complexity to achieve. Structures with more sophisticated geometries may require the generation of additional special sacrificial zones to support future layers, which are then removed when construction is completed, and in order for the component made to have the most compliant properties, it is recommended that it be subsequently processed by an additional post-photopolymerization in special UV stations. In the following will be presented 3 examples of important applications developed by authors in which structures obtained by DLP technology can be used.

3. EXPERIMENTAL RESEARCH

Due to its undoubted advantages as precise executions using high-performance optical systems at a relatively low price and energy consumption or 3D printing speed compared to other similar technologies in the field, DLP technology has quickly integrated into new contemporary applications.

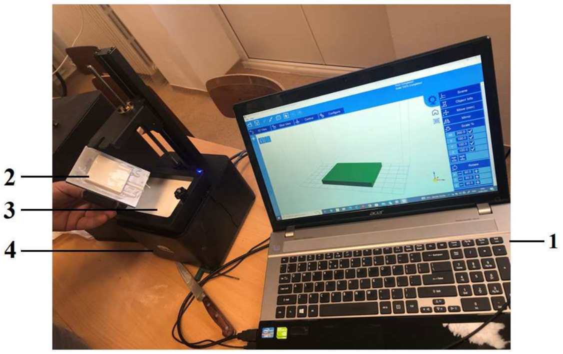


Fig.2. DLP 3D printer Duplicator 7 overview**:** 1 – PC; 2 – obtained part; 3 – photopolymeric resin vat; 4 – DLP 3D printer

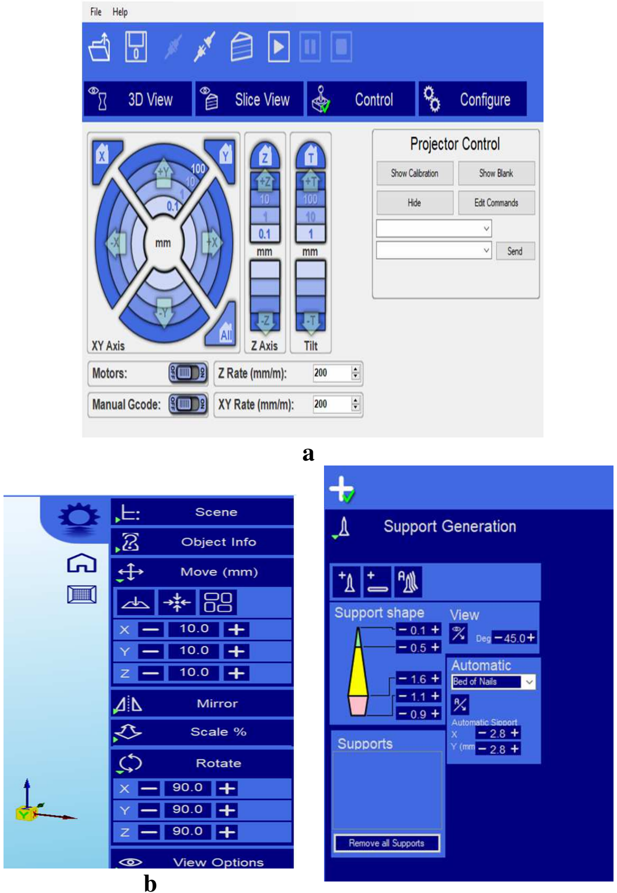
In total, 3 different areas of applicability of DLP technology were discussed and developed:

- Medical – dental field by executing a mandibular arch model starting from a virtual file generated by digital intraoral scanning [21] and the ENT domain by physically implementing a physical ear model.
- Microfluidic field by implementing two microchannel systems that can be used for different purposes of circulation and direction of special liquids, also creating an experimental stand for testing them.
- Molding field [22] by realization of some injection forms. In addition, molds made by DLP technology were compared with those obtained by FDM technology in terms of surface quality resulting from the plastics injection process.

The equipment used was the DLP Wanhao Duplicator 7 printer, and as a material a photopolymer liquid from the printer manufacturer [23]. More details on the DLP process, equipment and materials used can be found in the papers [4, 9, 24]. In Fig. 2 it can be seen the 3D printing system (4) that is connected to the calculation unit (1), and it can be observed also the finalized component (2) extracted from the photopolymer liquid (3) at the completion of construction.

Fig.3 shows the interface of the Creation Workshop program used to configure the slicing of layers, generate trajectories and other printing parameters to be considered, where sections can be seen with the program interface for calibration and positioning (Fig.3a), scaling, moving and rotating operations (Fig.3b) and the part of the program dealing with the generation of sacrificial layers (Fig.3c).

In the following subsections, each application will be addressed with more details – Medical applications, Microfluidics and for casting/injection moulding.



Motors:
Manual Gcode:
Z Rate (mm/m): 200
XY Rate (mm/m): 200

Move (mm): X 10.0, Y 10.0, Z 10.0
Rotate: X 90.0, Y 90.0, Z 90.0

Deg 45.0
Automatic: Bed of Nails
Automatic Support X 2.8, Y (mm) 2.8

a

b

c

Fig.3. Creation Workshop software capabilities: a – Calibration and positioning; b – Scaling, moving and rotating; c – generating supports

3.1. Medical applications

The first application approached in the paper refers to the realization of anatomical models, namely – personalized dental prosthetic model obtained by intraoral digital scanning and an anatomical ear model. They represent an application with great perspective of use in the medical field due to the possibilities of modern medical scanning/imaging systems. The manufacturing of the model can also be realized of materials that are not biocompatible, in order to obtain an implant of biocompatible material using an intermediate phase by manufacturing a mold in which the implant itself will be casted or to use this physically prototype as study model for a certain medical device or anatomical organ. Fig. 4 shows the steps of obtaining an ear model [25] for casting a cochlear implant from biocompatible material and obtaining a mandibular dental model obtained by computer scanning.

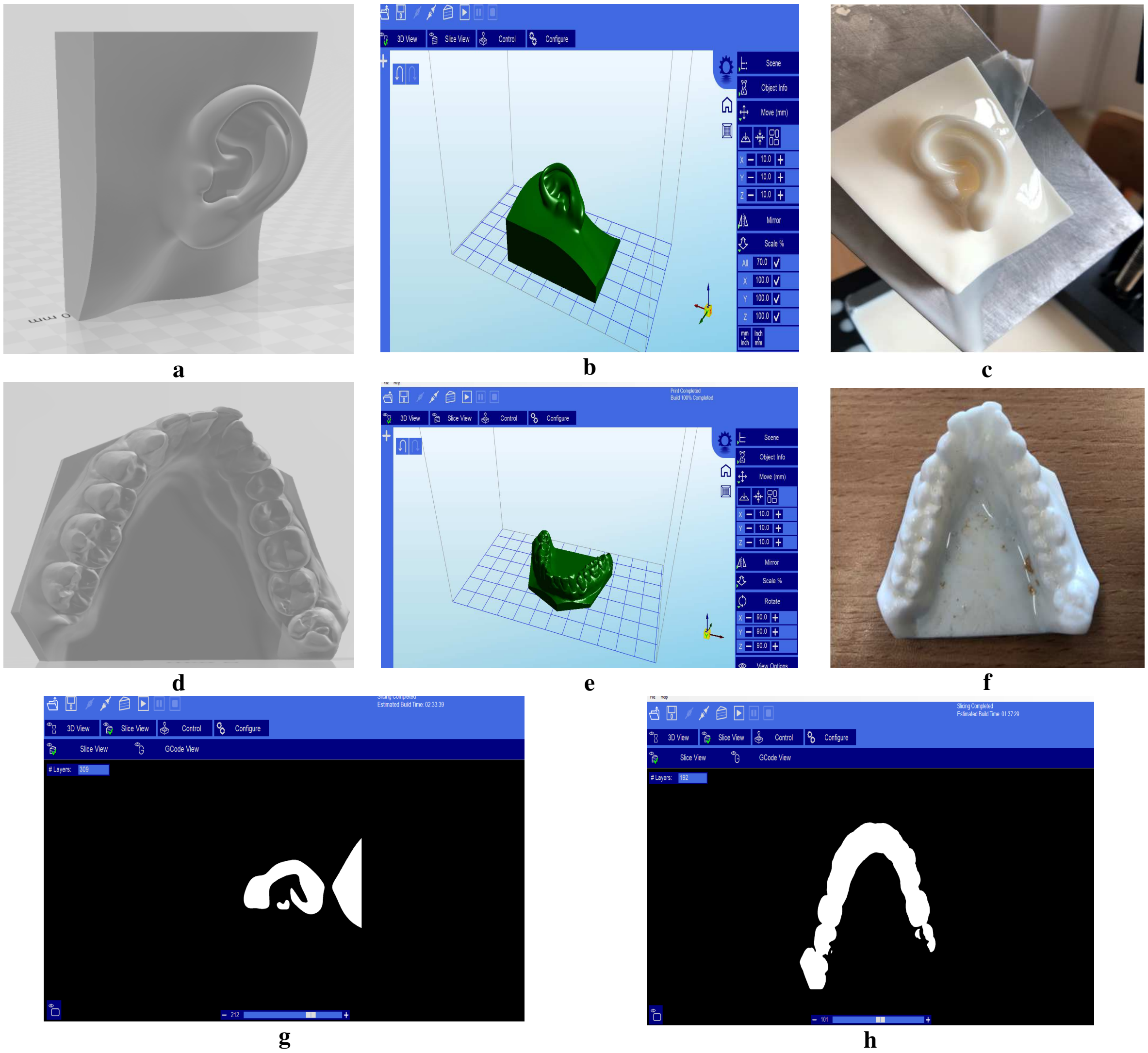


Fig. 4. Models obtained by DLP technology with uses in medicine: a – STL ear model; b – positioning the STL ear model on the virtual work platform; c – ear model obtained; d – STL mandibular arch model; e – positioning the STL mandibular arch model on the virtual work platform; f – mandibular arch model obtained; g, h – slice simulation of ear and mandibular arch models

3.2. Microfluidic application

If during the execution of a structure by thermoplastic extrusion (FDM technology) a mechanical joining of the layers takes place according to the processed digital model and this method not being able to ensure the tightness of the walls, the structure being porous even with 100% infill, in DLP technology a chemical bond is achieved by layered solidification of photopolymers due to specific chemical reactions leading to obtaining parts with a high density and with a water and air tightness without changes in mechanical properties depending on orientation. These properties make it possible to microfabricate complex microfluidic models and molds with possible applications in precision engineering, medical field and microelectronics. In Fig.5 are presented two CAD models and the stages of obtaining microfluidic models on the DLP 3D printer, and in Fig.6 is presented the experimental stand made for their testing.

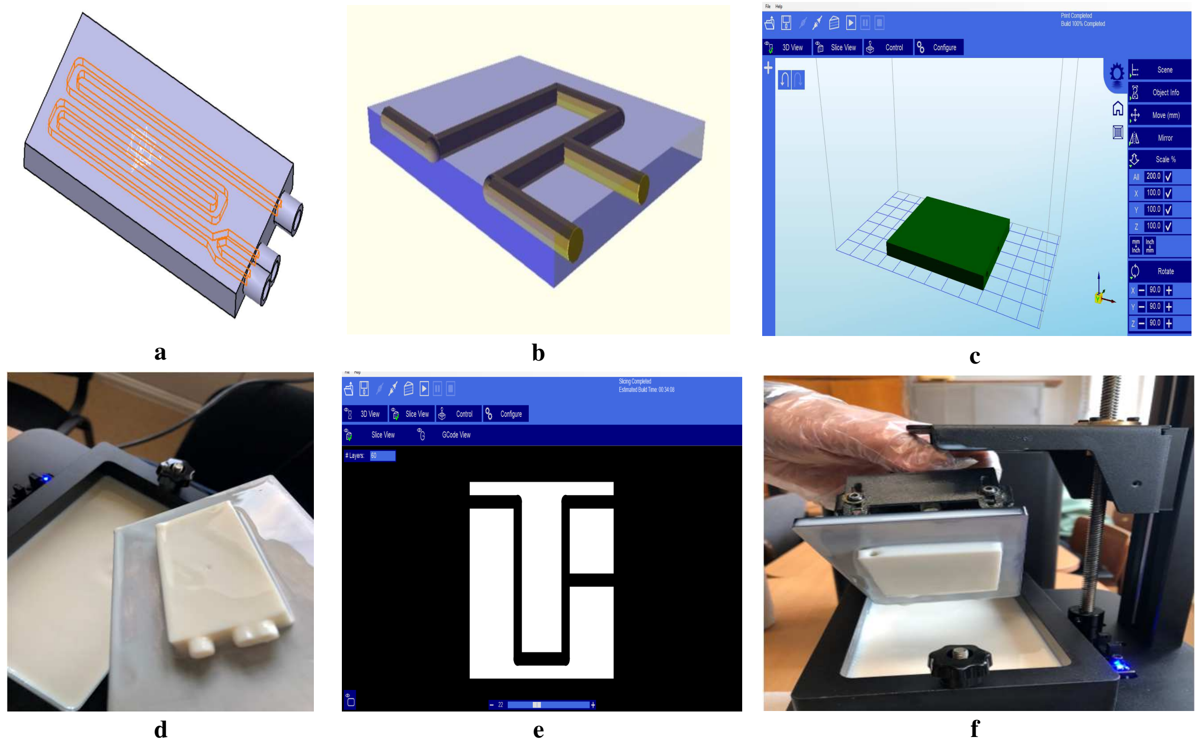


Fig.5. Microfluidic models obtained by DLP technology with uses in precision engineering: a, d – Microfluidic model 1 designed and realized; b, f – microfluidic model 2 designed and realized; c, e – microfluidic model 2 in the printer program

3.3. Casting models

The emergence and development of AM technologies has offered and offers a much faster, cheaper and sometimes more accurate alternative for manufacturing all types of models and cores, from a very wide range of materials, starting from a virtual 3D model of them, without the need for classical equipment and technologies used in the manufacture of these parts, which sometimes have a unique or very small series character.

Fig.7 shows the casting steps in molds made by DLP technology using Zhermack material, which is a basic and catalyst biocomponent, the elements are weighed and measured in a ratio of 1:1. The rubber models obtained have excellent long-term stability, high dimensional stability, high mechanical strength and precision in reproduction.

Fig. 8 shows comparatively the result of casting in molds made by DLP and FDM technology, observing also at macro scale [22]. In order to highlight the possibilities of obtaining experimental model parts by casting on molds obtained by DLP technology, a comparison was made with the same model of casting from the same Zhermark material, images of the surfaces of the 2 pieces resulting from casting were captured on a mold made by the FDM process (Fig. 9) with the help of an electron microscope.

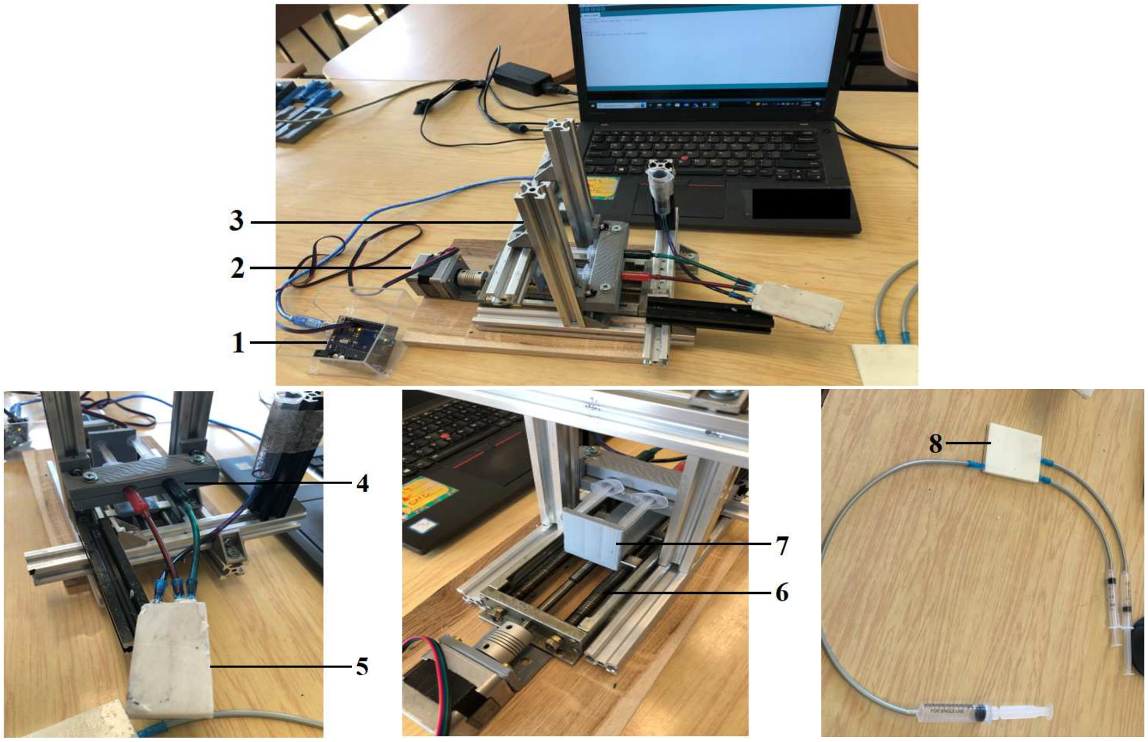
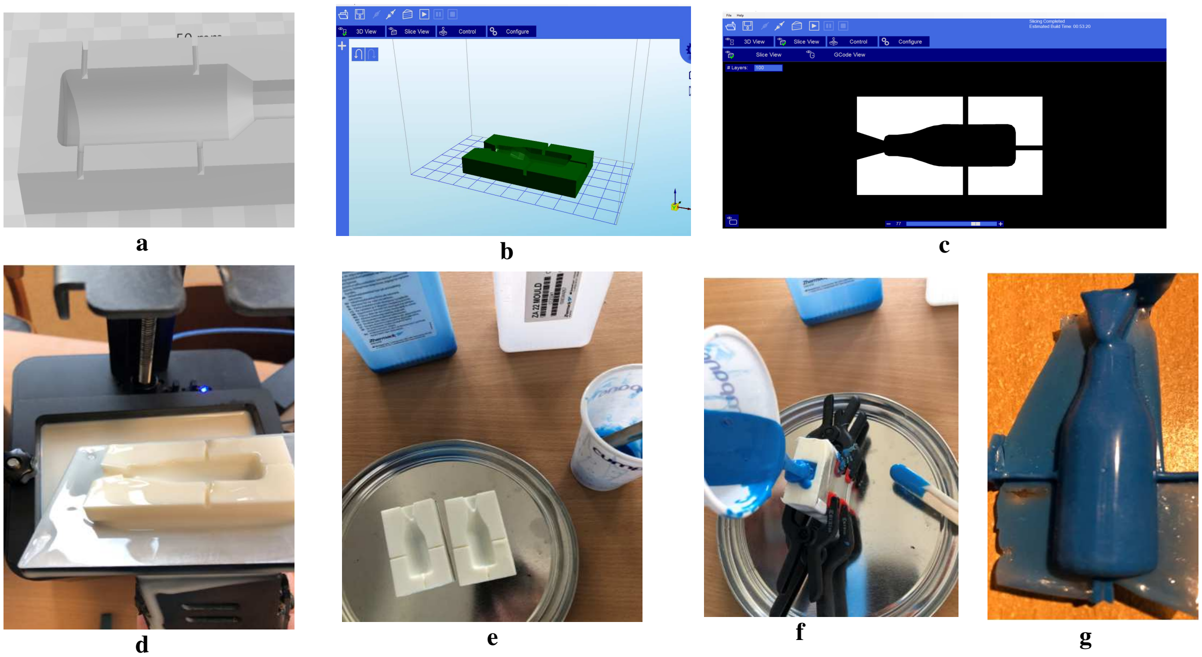


Fig.6. Experimental test stand for microfluidic models: 1 – Arduino board; 2 – stepper motor; 3 – aluminium profile frame; 4 – syringe holder; 5 – microfluidic model 1; 6 – screw nut mechanism; 7 - pusher wall piston syringes; 8 – microfluidic model 2



a b c

d e f g

Fig.7. Obtaining molds for casting by DLP process: a – STL mould model; b – Mould model in the slicer program; c – simulation of layer processing of mould model; d – DLP realized mould model; e – half moulds before casting; f – casting process; g – result of casting

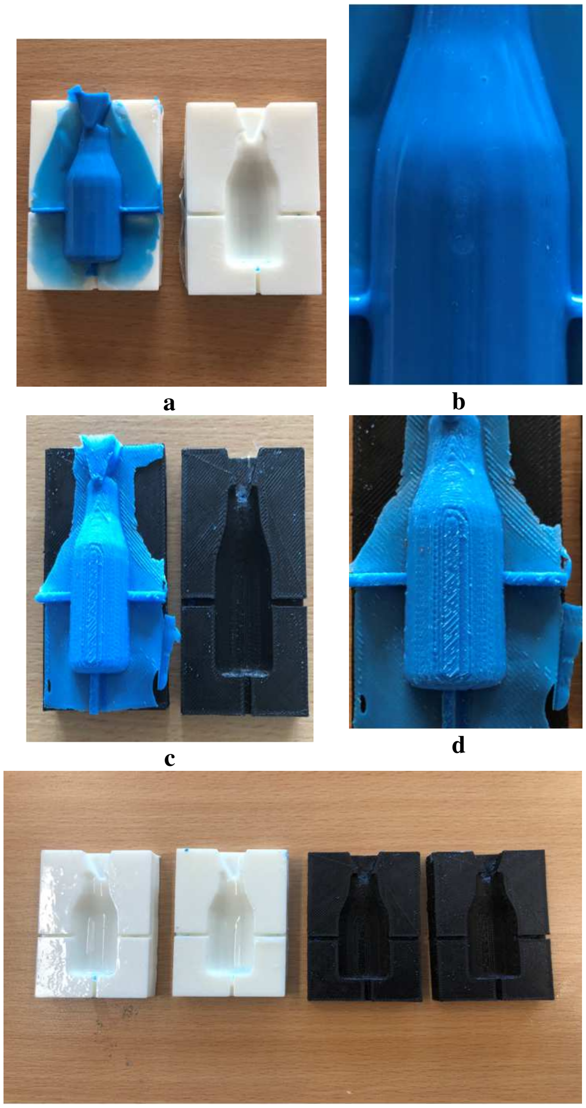
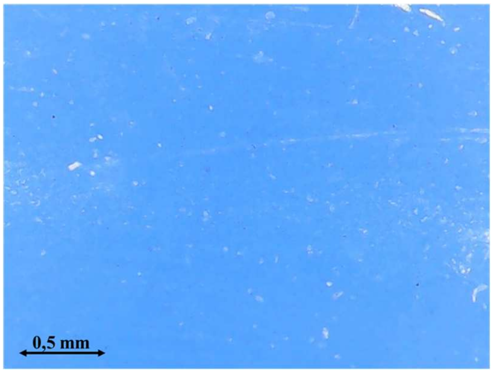
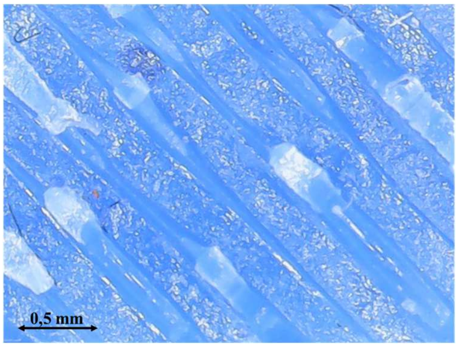

a b c d e

Fig.8. Comparison of moulds obtained by DLP and FDM process: a – Result of casting in moulds realized through DLP process; b – detail of casting result for casting in DLP realized moulds; c – result of casting in moulds realized through FDM process; d – detail of casting result for casting in FDM realized moulds; e – master mold realized by DLP (left) and FDM (right)

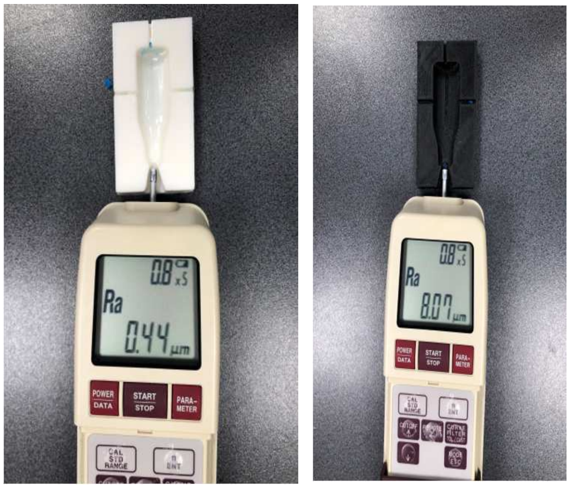


a



b

Fig.9. Microscopic image of the surface of the part obtained from moulding obtained by additive technologies: a – through DLP technology; b - through FDM technology



a b

Fig.10. Measuring the surface roughness of moulds obtained by additive technologies: a – DLP; b – FDM

Also, the surface roughness of the two types of semi-molds obtained by DLP and FDM process was determined using the roughness measuring equipment SJ 201-P (Fig. 10) [26]. Following a series of an experimental determinations, the average values of the parameter R_a (arithmetic mean deviation of the surface profile) were established for the 2 molds obtained by DLP technology (0.42 µm) and FDM technology (8.25 µm).

4. CONCLUSIONS

In recent times, FDM technologies and stereolithography have gained popularity in 3D printing are used to produce high-performance products. Because FDM technology is affordable, it is widely used in offices and educational institutions, however, their applications are limited compared to vat photopolymerization technology where 3D printers are useful for creating products with better surface quality. The development of photopolymers with desired properties such as chemical, mechanical composition, concentrations and biocompatible materials will be useful in creating complex products and thus increase application areas.

The process presents the prospect of complex functional prototypes in a short time, in particular a new microproduction concept is being developed, focusing on the development of new microfluidic models, jewelry and watchmaking industry, design elements as well as applications in medicine with cochlear implants, and small errors (± 0.1...0.15) mm in parts printed by this technology make it acceptable.

Three different research directions were presented in the paper in which DLP (Digital Light Processing) additive technology can be successfully implemented in cutting-edge fields: medical, precision engineering and microproduction by making microfluidic models, casting molds in unique series and small series. DLP creates a chemical bond by linking photopolymers through layers, which leads to obtaining very dense structures, and the resistance characteristics do not change depending on the orientation of the three-dimensional model. Among the fields that can benefit from the advantages of DLP technology (especially fine and precise surfaces) are electronics, the field of dental technology, microfluidics or the use for making master molds for the injection molding industry.

After evaluating the quality of the surfaces and the surface parameters for the master molds made by the two additive technologies, the clear superiority of the DLP technology compared to the FDM technology was observed in terms of average roughness (the average values for the arithmetic mean deviation of the surface profile of 0.42 μm for DLP mold and 8.25 μm for FDM mold were established).

Apart from the problems addressed in this paper, the authors also presented other aspects regarding the use and evaluation of additive technologies in previous papers [4, 9, 21, 22, 24].

In the future, it is desired to develop applications using DLP technology and to conduct further research into dimensional accuracy and other mechanical characteristics of the obtained structures.

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Posibilități de obținere geometrii complexe prin tehnologii aditive cu lichide fotopolimerice

Tehnologia aditivă de printare DLP reprezintă un proces de fabricație aditivă bazat pe utilizarea luminii ultraviolete pentru solidificarea unor rășini polimerice lichide sensibile la aceasta radiație și obținerea într-un timp scurt și cu o calitate superioară a suprafețelor unor piese cu geometrii complexe cu numeroase aplicații în zona medicală, micromecanică, microfluidică sau matrițe/forme de turnare. În articol sunt prezentate avantajele acestei tehnologii privind obținerea de prototipuri funcționale cu geometrii complexe din diferite materiale inclusiv cu aplicații în domeniul biomedical, obținerea de matrițe master pentru turnarea prin injecție, modele în protetica medicală, proteze auditive, restaurări dentare, modele microfluidice, evidențiind faptul că prototipurile sunt folosite pentru modele demonstrative sau testare funcționala având calitatea suprafețelor și precizie ridicată.

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