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# ADDITIVE MANUFACTURING OF FUNCTIONAL PARTS BASED ON MATERIAL EXTRUSION TECHNOLOGY

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**Abstract:** This paper presents the advantages and the process of making of complex functional parts using additive manufacturing technology. Design and manufacturing of components were performed at the Laboratory for Technology of Plasticity and Processing Systems at the Faculty of Mechanical Engineering in Banja Luka. The parts were designed using SolidWorks and Catia software packages. Then, CatalystEX and Simplify3D software packages were used to process the CAD model and to prepare it for 3D printing, which included defining of the process parameters, generating layers and support. Functional parts were produced on 3D printers based on the principle of material extrusion. The results of this study show that additive manufacturing technology, specifically technology based on material extrusion, enables very fast production of complex functional parts, with high accuracy and much lower costs and development time compared to conventional technologies.

**Keywords:** additive manufacturing, material extrusion, functional parts, CAD design.

## 1. INTRODUCTION TO ADDITIVE MANUFACTURING

Additive Manufacturing (AM) Technologies emerged as a new and innovative technology based on Rapid Prototyping (RP) which overcomes the shortcomings of traditional methods of prototyping. This terminology is under the jurisdiction of the F42 Committee on Additive Manufacturing Technologies and of F42.91 Subcommittee on Terminology, through a mutual agreement with ASTM International (ASTM) standards development process, and the Society of Manufacturing Engineers (SME), available from ISO Standard [1].

A key feature of AM is that it enables generating physical models directly from computer data - CAD, without using tools and accessories, layer by layer, significantly reducing the time needed for prototyping and increasing chances for the placement of quality and successful products.To ensure effective implementation of AM Technology, the F42 Committee established classification in seven main groups as follows: Material Extrusion – Fused Deposition Molding (FDM), Material Jetting, Binder Jetting, Sheet Lamination, Vat Photopolymerization, Powder Bed Fusion and Directed Energy Deposition [1].

Materials play a key role in the AM process. According to the type of AM technology used in certain AM processes, Table 1 gives the selection of materials and the field of application of AM processes.

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*Table 1. Selection of AM processes according to typical materials and field of application*

| Process | Typical materials | Application |
|---|---|---|
| **Material Extrusion** – Fused Deposition Modeling (FDM) | Polymer (ABS, PP, PC, PPS, ASA, ), Composite, Wax, WPC | Prototypes, Casting Patterns, Soft Tooling, Functional Parts |
| **Material Jetting** Multi-jet modeling (MJM) | Polymer (ABS, PP, Acrylic, Rubber), Wax | Prototypes, Casting Patterns, Soft Tooling |
| **Binder Jetting** Powder bed and inkjet head, plaster based 3D printing | Composite Gypsum, Ceramic, Sand, Metal, Polymer | Functional Parts, Prototypes, Casting Patterns, Soft Tooling |
| **Sheet Lamination** Laminated object manufacturing (LOM), ultrasonic consolidation | Paper, Metal (Steel, Aluminium, Titanium, Copper) | Functional Parts, Prototypes, Casting Patterns, Soft Tooling |
| **Vat Photopolymerization** Stereolitography (SLA), digital light procesing | Polymer (Epoxy, ABS, PP), Compostie Gypsum, Ceramic, Wax | Prototypes, Casting Patterns, Soft Tooling |
| **Powder Bed Fusion** Thermal energy selectively fuses regions of a powder | Metal (Alloy Steel, Aluminium, Titanium), Ceramic, Polymer (ABS, PP, PA, PA-Glass filled), Composite, Rubber, Silicate | Functional Parts, Prototypes, Casting Patterns |
| **Directed Energy Deposition** Focused thermal energy is used to fuse materials – Laser metal deposition (LMD) | Metal (Alloy Steel, Aluminium, Titanium) | Functional Parts |

These new techniques of AM are called 3D printing (3D printing-Synonym for additive manufacturing), additive fabrication, or free-form fabrication. AM enables the realization of the first preliminary model of something, especially machines or some element of the product, from which other forms or versions are developed or copied. Modern access to AM technology implies functional and design aspect of the prototype model.

Benefits of Additive Manufacturing according to [2,3,4,5,10,14] are: innovation, part consolidation, lower energy consumption, less waste, reduced time to market, lightweighting, agility of manufacturing operations. Otherwise, selection of AM technology in development and conquering new or improving existing products is predominantly influenced by three key factors: quality, costs and time.

## 2. MATERIAL EXTRUSION TECHNOLOGY

Production of functional elements is based on Material Extrusion - Fused Deposition Modeling (FDM) technology in the Laboratory for Plasticity at the Faculty of Mechanical Engineering in Banja Luka. In this additive manufacturing process, the wax or plastics is extruded through a nozzle which follows the cross-section of a part, forming the geometry of the part, layer by layer. The material is usually supplied in the form of wire, while some manufacturers use systems that are filled with plastic pellets from the pellet reservoir. The nozzle contains resistance heaters to heat and keep material at a temperature above the melting point, allowing the flow of material and forming layers.The plastic hardens immediately after leaving the nozzle and forms the next layer. When the layer is done, the platform descends and the nozzle starts with the inflection of the next layer. The layer thickness and vertical accuracy depends on the diameter of a nozzle. They use different types of materials including ABS plastic, polyamide, polycarbonate, polyethylene, polypropylene and melted wax [3, 4, 5, 6, 14]. As it is getting ready for printing, the machine that controls the FDM process where the algorithm is developed, accumulates all the factors and steps that lead to the most appropriate options for making an object and enabling better orientation of user. This technology uses software that controls the orientation of an object and the forming of layers. Except the main material, the FDM system uses a supporting material used as support for the overhang and the holes, passing through separate nozzles.

The scheme of forming prototypes layers using FDM method is shown in Figure 1.1. a) and b) shows the 3D printers: Dimension Elite (left) and Leapfrog Creatr XL (right) at the Faculty of Mechanical Engineering Banja Luka, which are used for the development of functional elements.


a) b)

*Figure 1. a) Scheme of Material Extrusion –FDM procedure 1-Build material filament, 2- Support material filament, 3-Extrusion head, 4-Drive wheels, 5-Liquifiers, 6-Extrusion nozzles, 7-Part, 8-Part supports, 9-Foam base, 10-Build platform, 11-Support material spool, 12-Build material spool and b) 3D printers: Dimension Elite (left) and Leapfrog Creatr XL (right), Faculty of Mechanical Engineering in Banja Luka.*

## 3. DEVELOPMENT OF FUNCTIONAL PARTS – CASE STUDIES

The main characteristics of the 3D printers used as well as their experimental parameters are given in Table 2.

The procedure of development of functional parts using material extrusion technology consisted of the following procedures:

– Product design in a CAD software package,

– Conversion of CAD odel sin STL format that 3D printer recognizes,

– Transfer of STL files to the computer that controls the three-dimensional printer,

– Processing of STL files within the CatalystEXand Simplify3D in which all the parameters for the required model are set and adjusted,

– Creating a three-dimensional model using additive technology and

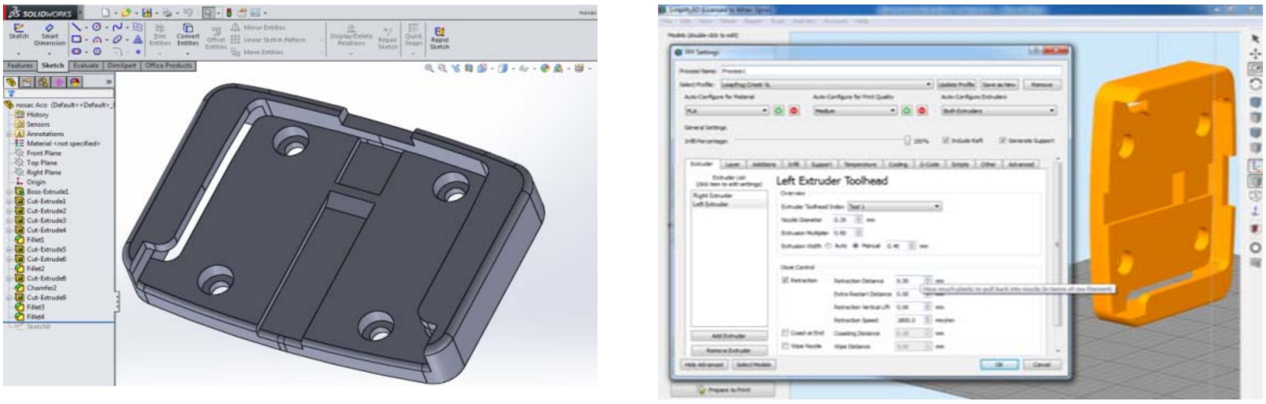
– Further processing of created prototypes.

*Table 2. Specification and experimental process parameters of 3D printers*

| Machine | **Creatr XL (LeapFrog)** | **Dimension Elite (Stratasys)** |
|---|---|---|
| Type of extruder | Double extruder | Double extruder |
| Build volume | 230x270x600 mm | 203 x 203 x 305 mm |
| Material | ABS, PLA, PVA, Nylon | ABS plus |
| Support material | HIPS | Default |
| Layer thickness | 0,2 mm | 0,254 mm |
| Model interior | 100 % fill density | Solid |
| Process temperature | 60 °C (heated plate) | Default |
| Extruder temperature | 195 °C | Default |
| Raft | Included | Default |
| Price | ≈ 5 000 $ | ≈ 30 000 $ |

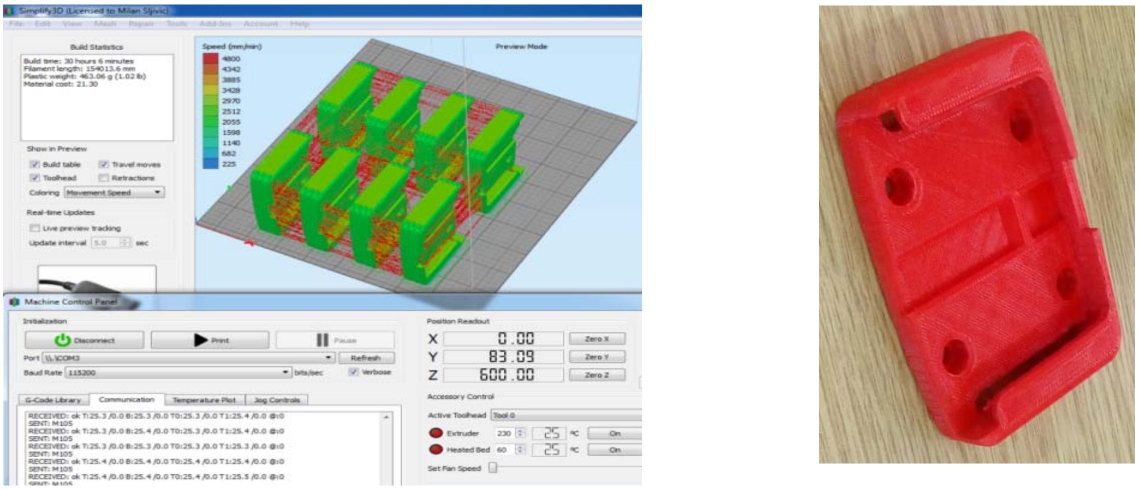
### 3.1. Development of protective cover

The above mentioned procedure was fully implemented in the development of a protective cover. The element was designed in SolidWorks software package, Figure 2a). After the model was transferred to a computer that controls the operation of the 3D printer and the generated model was loaded, operating parameters were adjusted within the Simplify3D software, Figure 2 b). Choices of orientation of the model and the best position on the working platform, processing layers and support as well as the layout of models on a 3D printer platform „Leapfrog Creatr XL“ are given in Figure. 3 a), and Figure 3 b) shows the finished element.



a) b)

*Figure 2. a) Design in SolidWorks, b) Setting the operating parameters in the Simplify3D software*



a) b)

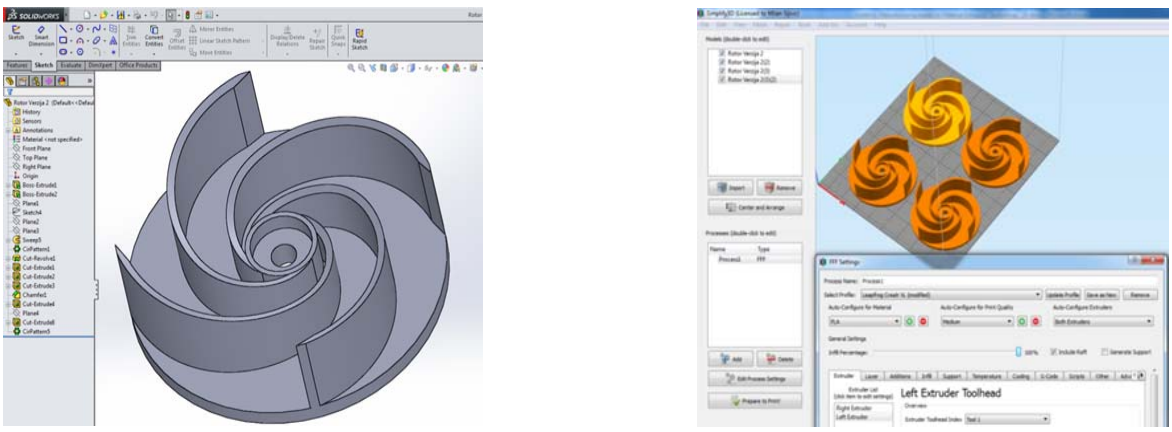
*Figure 3. a) Schedule of models on a 3D printer platform (8 pieces), b) 3D printed element*

There are 8 pieces of functional elements on a single platform of a 3D printer, made from a PLA polymer. The main parameters that define the optimal production are:

- Build time: 30 hours 6 minutes
- Plastic weight: 463.06 g
- Material cost: 21.30 € .

### 3.2. Development of a rotor for vacuum cleaner

Four elements made from ABS polymer are printed on this platform, Figure 4 a) and Figure 4b.



a) b)

*Figure 4. a) Design in SolidWorks, b) Setting the operating parameters in the Simplify3D software*

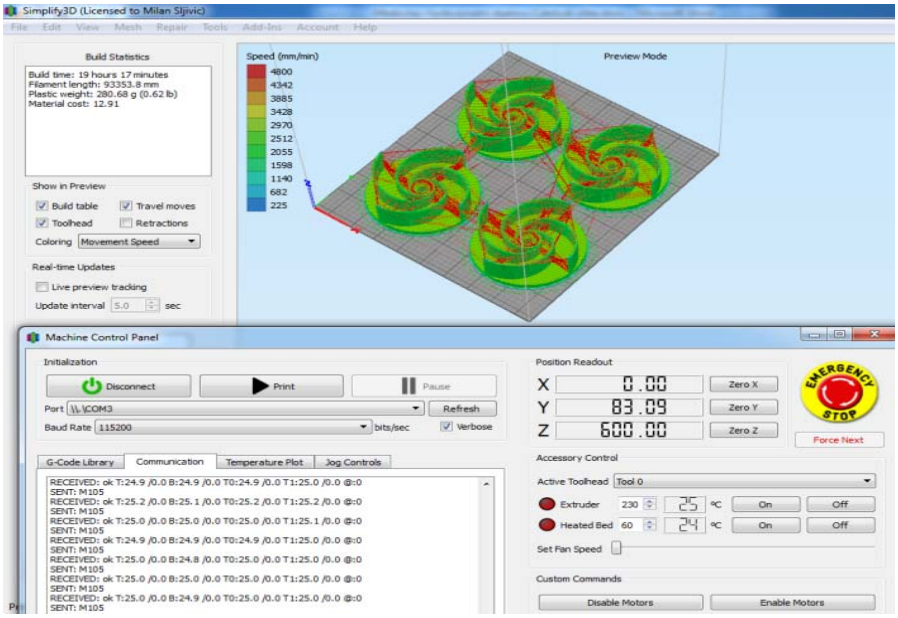


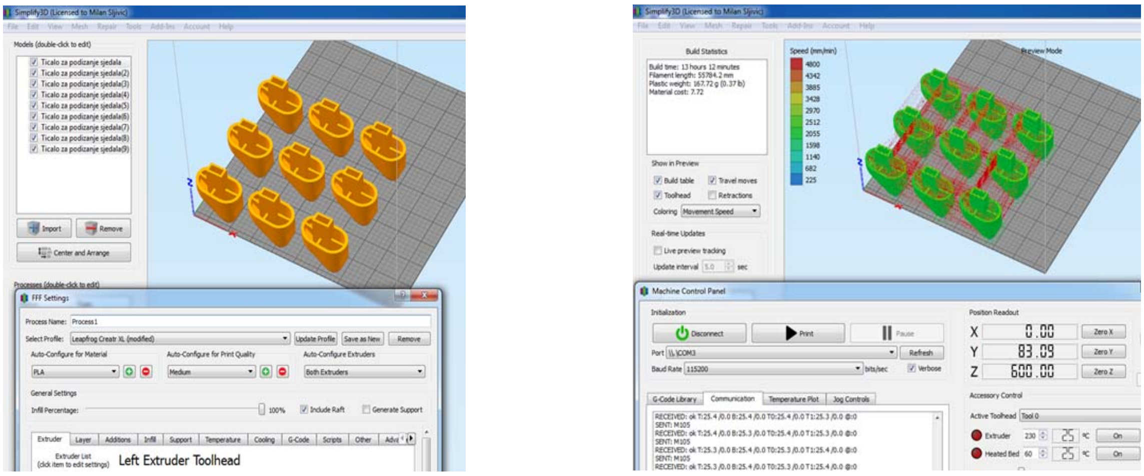

*Figure 5. Schedule of models on 3D printer platform (4 pieces)*

The main parameters that define the optimal production are:

- Build time: 19 hours 17 minutes
- Plastic weight: 280,68 g
- Material cost: 12,91 €

### 3.3. Development of a holding cap

Polymer ABS material is selectively dispensed through a nozzle, and there are 9 pieces printed on a 3D printer platform, Figure 6 a) and b).



a) b)

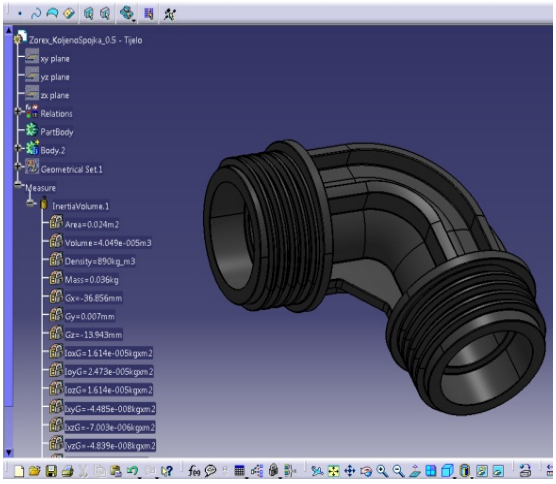
*Figure 6. a) Setting the operating parameters in the Simplify3D software,*
*b) Schedule of models on 3D printer platform (9 pieces)*

The main parameters that have been achieved in making a holding cup are:

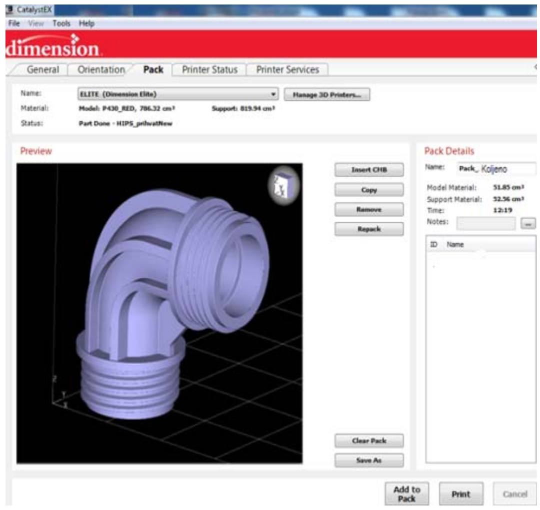
- Build time: 13 hours 12 minutes
- Plastic weight: 167.72 g
- Material cost: 7.72 €.

### 3.4. Development of a water supply knee

The water supply knee is done using ABS plus polymer, designed in CATIA and operating parameters are adjusted in CatalystEX, *Figure. 7 a) and b).*




a)




b)

*Figure 7. a) Design in CATIA b) Schedule of models on a 3D printer platform (1 piece)*

There is one functional part on a 3D printer platform. The following parameters are realized:

- Build time: 12 hours 19 minutes
- Plastic weight: 104.41 g
- Material cost: 17.66 €

## 4. CONCLUSION

The case studies of development of functional parts confirmed the full justification of the use of additive manufacturing technology. The factors that affect the development and production of advanced components, namely quality, costs and time, as indicators of the success of application of AM technology are above the conventional method. Limiting factors are the type of material and the number of pieces per time unit. AM based on material extrusion technology can produce only functional parts based on polymers. In the cases given above, the following polymers were used: ABS, ABS plus and PLA, which meet technical requirements for manufactured parts.

This shows that the development and production of functional parts using AM technology in the industry is facing justified expectations and challenges.

## 5. ACKNOWLEDGMENT

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## 6. REFERENCES

[1] ASTM International Designation: F2792-12A; Standard Terminology for Additive Manufacturing Technologies, DOI: 10.1520/F2792-12A

[2] I. Gibson et al., *Additive Manufacturing Technologies*, Springer Science+Business, Media New York 2015, DOI 10.1007/978-1-4939-2113-3_2

[3] Wohlers Report 2014: *3D Printing and Additive Manufacturing State of the Industry Annual Worldwide Progress Report*, Wohlers Associates, INC. Colorado 80525 USA

[4] Quadrennial Technology Review 2015, Chapter 6: Innovating Clean Energy Technologies in Advanced Manufacturing, Additive Manufacturing. Available at: http://energy.gov/sites/prod/files/2015/11/f27/QTR2015-6A-Additive%20 Manufacturing.pdf

[5] EOS: Global Presence, *Additive Manufacturing Meets Industrial production – a Paradigm Shift*, Available at: http://www.aita3d.it/wp-content/uploads/dlm_uploads/2015/03/Convegno-29-gennaio_EOS.pdf

[6] I. Gibson, D.W. Rosen, B. Stucker, *Additive Manufacturing Technologies (Rapid Prototyping and Direct Digital Manufacturing)*, Chapter 2.6, page 27–28, Springer Science + Business Media, LLC, New York USA, 2010, DOI 10.1007/978-1-4419-1120-9

[7] F. W. Liou, *Rapid Prototyping and Engineering Applications (A Toolbox for Prototype Development)*, Chapter 6. Rapid Prototyping Processes: Liquid-Based, Solid Based, Powder Based; page: 215-, CRC Press, Taylor & Francis Group, 6000 Broken Sound Parkway, USA 2008.

[8] M. Despeisse, S. Ford, *The Role of Additive Manufacturing in Improving Resource Efficiency and Sustainability*, Institute for Manufacturing, University of Cambridge, UK, ISSN 2058-8887, No.3, June 2015

[9] T. Himmer, E. Stiles, A. Techel, E. Beyer, *$PC_{Pro}$a novel technology for Rapid Prototyping and Rapid Manufacturing*, Fraunhofer IWS, Dresden, Germany, http://www.ccl.fraunhofer.org

[10] A. Talić–Čikmiš, A. Durmić, M. Sljivic, M. Stanojevic, *The process of developing conceptual design of a product using rapid prototyping technology*, 18th International Research/Expert Conference,TMT 2014, Budapest, Hungary 10-12 September, 2014

[11] I. Gibson, D.W. Rosen, and B. Stucker, Additive Manufacturing Technologies, DOI 10.1007/978-1-4419-1120-9_2, Springer Science+Business Media, LLC 2010

[12] E. Grenda, Printing the future, The 3d Printing And Rapid Prototyping Source Book, Third Edition,Castle Island Co. Arlington, MA 02474 U.S.A. http://home.att.net/~castleisland/

[13] E. Bassoli, A. Gatto, L. Iuliano, M. Grazia Violante, *3D printing technique applied to rapid casting*, Rapid Prototyping Journal, Vol. 13–3 (2007) 148–155 http://dx.doi.org/10.1108/13552540710750898.

[14] N. Grujović, J. Borota, M. Šljivić, D. Divac, V. Ranković, *Art and design optimized 3D Printing*, 34th International Conference on Production Engineering, Niš, 2011

[15] Pham, Duc, and Stefan S. Dimov, *Rapid manufacturing: the technologies and applications of rapid prototyping and rapid tooling*, Springer Science & BusinessMedia, 2012

[16] C. C. Kai, C. T. Howe, E. K. Hoe, *Integrating rapid prototyping and tooling with vacuum casting for connectors*,The International Journal of Advanced Manufacturing Technology, Vol. 14–9 (1998) 617

[17] D. J. Dippenaar, K. Schreve, *3D printed tooling for vacuum-assisted resin transfer moulding*, The International Journal of Advanced ManufacturingTechnology, 2012, DOI: 10.1007/s00170-012-4034-2

[18] R. Singh, *Mathematical modelling of dimensional accuracy in vacuum assisted casting*, Journal: Virtual and Physical Prototyping, Vol. 7–2 (2012), DOI: 10.1080/17452759.2012.668699

## АДИТИВНА ПРОИЗВОДЊА ФУНКЦИОНАЛНИХ ЕЛЕМЕНАТА БАЗИРАНА НА ТЕХНОЛОГИЈИ ЕКСТРУЗИЈЕ МАТЕРИЈАЛА

**Сажетак**:У раду су презентоване предности као и поступак израде комплексних функционалних дијелова технологијом адитивне производње. Дизајн и израда дијелова извршена је у Лабораторији за технологију пластичности и обрадне системе на Машинском факултету у Бањој Луци. Дијелови су дизајнирани у софтверским пакетима SolidWorks и Catia, а затим је у софтверским пакетима CatalystEX и Simplify3D извршено процесирање CAD модела и припрема за 3D штампу која обухвата дефинисање процесних параметара, генерисање слојева и потпора. Функционални дијелови израђени су на 3D штампачима заснованим на принципу екструзије материјала. Резултати овог истраживања показују да технологије адитивне производње, конкретно технологије екструзије материјала, омогућавају израду комплексних функционалних дијелова веома брзо, високе тачности и прецизности и са значајно мањим трошковима и временом израде у поређењу са конвенционалним технологијама израде.

**Кључне ријечи**: адитивна производња, екструзија материјала, функционални дијелови, CAD дизајн.