Acta Tecnología - International Scientific Journal about Technologies
Volume: 10 2024 Issue: 2 Pages: 65-71 ISSN 2453-675X

https://doi.org/10.22306/atec.v10i2.201 *Received: 09 May. 2024; Revised: 26 June 2024; Accepted: 28 June 2024*

Comparison of mechanical properties polyamide materials produced by different additive technologies

Miroslav Kohan
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letna 1/9, 042 00 Kosice, Slovak Republic, EU, miroslav.kohan@tuke.sk (corresponding author)
Viktoria Rajtukova
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letna 1/9, 042 00 Kosice, Slovak Republic, EU, viktoria.rajtukova@tuke.sk
Tomas Balint
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letna 1/9, 042 00 Kosice, Slovak Republic, EU, tomas.balint@tuke.sk
Jozef Zivcak
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letna 1/9, 042 00 Kosice, Slovak Republic, EU, jozef.zivcak@tuke.sk
Radovan Hudak
Technical University of Kosice, Faculty of Mechanical Engineering, Department of Biomedical Engineering and Measurement, Letna 1/9, 042 00 Kosice, Slovak Republic, EU, radovan.hudak@tuke.sk

Keywords: SLS Technology, MJF Technology, PA, mechanical properties, orientation.

Abstract: Additive technology provides several advantages compared to traditional production methods, such as creation of complex geometric shapes with less material consumption. However, the setting of the 3D printing process as well as the positioning of the printed object has an impact on the mechanical properties of the material used. The aim of this study was to compare the mechanical properties of polyamide (PA) material as well as the influence of the orientation of printed objects when using SLS and MJF technology. The SLS technology used the P 396 device (EOS, Germany). An HP Jet Fusion 5200 (HP, USA) was used for MJF technology. In both cases, PA was used to creating experimental samples for mechanical testing. The orientation of the printed samples was 0°, 45° and 90° to the base platform of the 3D printer. The results show by comparing SLS and MJF technologies highest mechanical properties for MJF technology when the position samples were at 90° to the basic platform of 3D printer. Conversely, the lowest mechanical properties were recorded for samples that were positioned at a 45° angle to the base platform of the 3D printer using SLS technology.

1 Introduction

Polyamide (PA) is considered a thermoplastic polymer characterized by low density and good thermal stability. PA material is characterized by good properties such as impact, wear against mechanical forces as well as proportional elongation [1]. However, in general, PA material can be divided into several subgroups (e.g. PA46, PA66, PA12 and PA6) [2]. The designation of the subgroups of the PA material refers to the molecular structure that affects the mechanical properties. The subgroup of materials PA 6 represents harder and tougher materials, while PA 12, on the other hand, represents more flexible and pliable materials. However, the melting temperature of the entire group of these materials represents a temperature range of 220°C to 260°C [3].

Due to the different types of polyamides, the scientific community also studies these materials in terms of mechanical properties. One of them is the study by Hofland et al. [4] where they investigated the parameters of 3D printing of SLS technology on the mechanical properties of printed parts of PA12 material. Among the parameters investigated during the production of samples for mechanical testing were preheating temperature, laser power, scanning distance, scanning speed, layer thickness and orientation of the printed object. The results of mechanical testing for the selected settings of the 3D printing process confirmed that the thickness parameter of the applied layer has the greatest influence on the mechanical properties. The orientation of the printed samples (horizontal = 0°; vertical = 90°) with the same parameters of the 3D printing process were also analysed, while different mechanical properties of the PA material were also recorded in this aspect. A similar study called the effect of printing orientation on the tensile strength of PA12 samples obtained by SLS is described by Jevtic et al. [5]. The results of the study describe that samples oriented vertically during the 3D printing process have a higher modulus of elasticity. The authors also hypothesize that the sintering process is more efficient for samples oriented in a vertical position due to a more uniform trajectory of the laser beam than for samples that were oriented horizontally to the base platform of the 3D printer.

Additive technology, also known as 3D printing, is increasingly entering various fields such as automotive manufacturing [6-8], aerospace industry [9-11], prototyping [12-14], medicine [15-17] or pharmacology [18]. Additive technology currently plays an important role in prototype design. However, it is necessary to realize what is expected from the manufactured prototype and therefore it is important to choose the appropriate type of additive technology during the production of the prototype. Currently, Selective Laser Sintering (SLS) and Multi Jet Fusion (MJF) is often used in the production of prototypes but also in serial production [19]. SLS technology belongs to the general group of additive technology called Laser Powder Bed Fusion (LPBF), which uses a laser to melt plastic grains that have been applied to a platform. Subsequently, the platform is moved lower in the z axis, a new layer of powder material is applied and the laser sinters the material in the required places. This process is repeated until the entire 3D object is created. Selective laser sintering is very popular in the field of plastic 3D printing due to its substantial advantages, such as design freedom, high productivity and low part cost. Unlike some other 3D printing technologies, such as Stereolithography (SLA) or Fused filament fabrication (FFF), SLS and MJF technology does not require any support structures. This enables the creation of very complex patterns [20-22].

The 3D printing process of MJF technology can be divided into the following points. The printer's dispenser applies a thin layer of powder material to the platform. Then the ink head applies a liquid agent, which comes in two variants. The first type (fixing) connects the individual layers together and the second type (detailing) is used to define the exact surface dimensions of the printed parts. A heating unit is used to harden the individual layers, which is activated after the agent is applied. The advantage of this technology is the use of bulk material, which eliminates the creation of supporting structures, which results in the creation of complex structures (like SLS technology). Part of the production process is also the so-called postprocessing, where excess material is removed. Used material can be reused when mixing with new material in 20/80 (new material / used material). MJF technology based on its principles is used for serial production of printed parts as well as prototyping. By comparing SLS and MJF technology, it can be said that these technologies are similar in terms of the input materials used, but SLS technology uses sintering to join individual layers, while MJF uses reagents and heating to join individual layers.

There are several scientific studies comparing SLS and MJF technology. In a study by Rosso et al. [23] investigated an in-depth comparison of PA12 parts produced by SLS and MJF technology. The study analyzed the material properties of PA12 printed samples from PA12 as well as the mechanical behavior of selected structures in tensile and fatigue tests. The results of mechanical tests showed that samples produced by SLS technology appear to be stiffer with lower plastic deformation compared to samples produced by MJF technology. Fatigue tests represent a higher dispersion for samples produced with MJF technology and an increase in fatigue life. A similar study by Xu et. al. [24], which was devoted to the comparison of the SLS and MJF technology processes while evaluating the morphology, thermal and mechanical properties of PA12 parts. The results of the study showed that the PA12 material in powder form using these technologies had approximately elliptical shapes of similar size. In the case of the produced samples, the surface roughness of the samples produced by the MJF technology showed better values than that of the samples produced by the SLS technology. During the printing process with the function of immediate laser cutting, the degree of melting of particles with SLS technology was higher than with MJF technology. The results of the mechanical properties of the printed samples were better with the SLS technology. In terms of time, the printing speed with MJF technology was 10 times higher than with SLS technology.

The aim of the presented work is to compare the mechanical properties of samples produced by two different additive technologies. A difference is assumed between the positions of the samples as well as between the production technologies.

2 Material and methodology

2.1 *Material characteristics*

To compare the individual additive technologies in terms of the mechanical properties of the PA12 material, the material PA 2200 (EOS, Germany) based on PA12 using SLS technology was chosen. In the second case, the MJF technology was chosen using the input material PA12 under the trade name HP 3D HR PA12 (HP, Germany). The selection of materials was chosen based on the technologies used, which use only certified materials from 3D printer manufacturers. The technical specification of the materials is described in Table 1.

Table 1 Specification of materials

	PA2200	**PA12**
Density [g/cm^3]	0.93	1.02
Average grain size [µm]	65	60
Melting point [°C]	176	187
Glass transition [°C]	~ 55	~ 50

2.2 *Samples production procedure*

The design of the experimental samples was implemented in SolidWorks 2019 software (Dassault Systèmes, USA). The design of the proposed sample was based on the valid standard for mechanical testing STN EN SIO 527-2: 2012. Individual variations of the proposed sample are described in Figure 1.

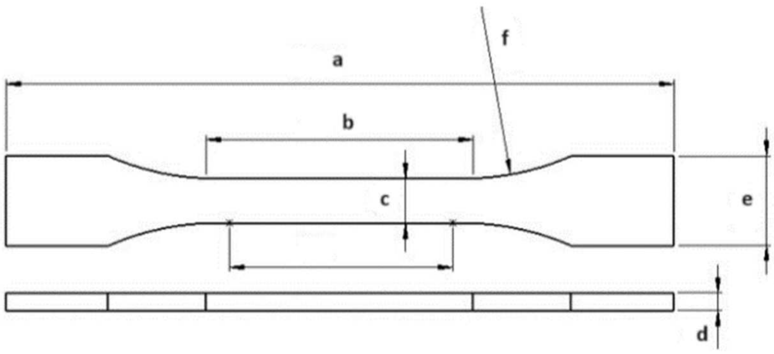

Figure 1 Dimensions of test samples (a:Total length 150 mm; b: Lenght of the narrow parallel part 60 mm; c: Width of the narrow part 10 mm; d: thickness 4 mm; e: Width at the end 20 mm; f: radius 60 mm)

The samples were divided into 3 groups according to the positioning during the 3D printing process (Figure 2). The difference in orientation for individual groups was as follows:

- Group A: position of samples at 0 angle (on the mat), 20 pieces of samples.
- Group B: position of the samples at a 45° angle to the horizontal axis, 20 pieces of samples.
- Group C: position of the samples at a 90° angle to the horizontal axis, 20 pieces of samples.

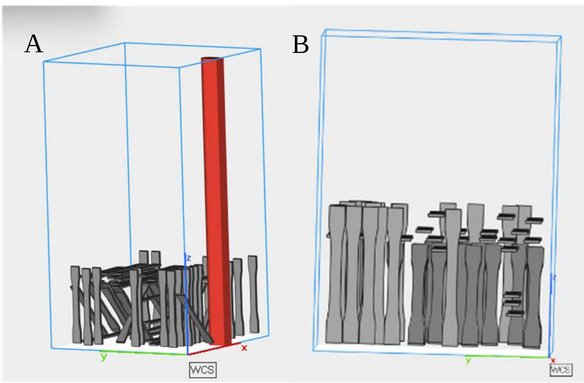

Figure 2 Preparation of samples for EOS and for HP (A: SLS Technology; B: MJF Technology)

The production of experimental samples was carried out using two technologies. One of them was the SLS technology behind the EOS P396 device (EOS, Germany). In the second case, MJF technology was chosen for the HP Jet Fusion 5200 device (HP, USA). In both cases of the chosen technology, PA12 material was used. The set parameters of 3D printing are described in Table 2.

Table 2 Parameters of 3D printing process for SLS and MJF technologies

	EOS P396	**HP 5200**
Building speed [m/s]	6	0.014
Layer thickness [mm]	0.12	0.08
Sintering energy source	Heating lamp	Energy
Powder mixture	50:50	20 fresh:80 recycled
Powder melting point [°C]	187	176

2.3 *Mechanical testing*

Mechanical tensile testing was performed on 120 samples (Figure 3). The samples were divided into 3 test groups (Group A: sample position at 0°; Group B: sample position at 45°; Group C: sample position at 90°). An Inspekt Table (Hegewald & Peschke, Nossen, Germany) with a measuring range of 5 kN was used for mechanical testing. The tensile testing speed was set at 2 mm/min. The relative elongation was measured on RTSS extensometer (Limess, Germany) while the initial length was 50 mm. The distance between the clamping jaws was 115 mm.

A
B

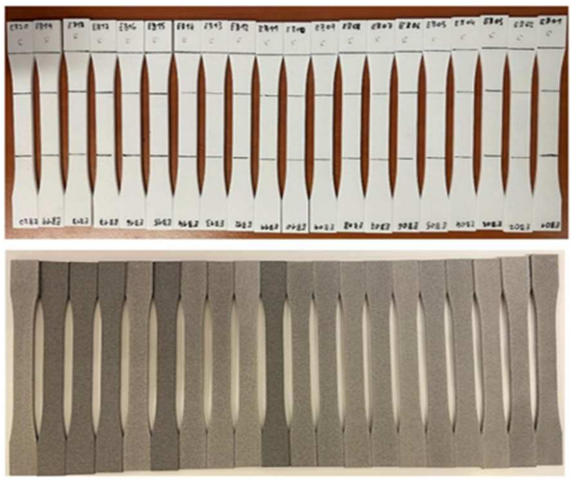

Figure 3 Produced samples for mechanical testing (A: samples produced by SLS Technology; B: samples produced by MJF Technology)

3 Results and discussion

3.1 *Comparison of mechanical properties of PA material based on sample position*

The investigated parameters of the mechanical properties of PA material based on the positioning of the sample were ultimate strength (Rm) and Young's modulus of elasticity (E). In Figure 4 individual groups of samples are graphically represented and compared.

When SLS technology was used, the average Rm value for sample group A was 43.52 ± 1.65 MPa, for sample group B at 40.86 ± 0.57 MPa and for sample group C at 42.63 ± 0. 47 MPa. Comparing the average values of the Rm parameter, differences were found at the level of 2.66 MPa (group A versus group B). By comparing the same parameter between sample groups A and C, differences were detected at the level of 0.89 MPa. From this, it can be concluded that the positioning of the experimental samples at a zero angle (on the base platform of the 3D printer) shows the best mechanical properties of the samples made of PA material. Conversely, the lowest Rm was recorded for samples that were positioned at a 45° angle during the 3D printing process. The analysis of parameter E using SLS technology showed average values for sample group A at a value of 1464 ± 78.4 MPa, for sample group B at a value of 1425.49 ± 44.41 MPa and for sample group C at a value of 1465.85 ± 34, 97 MPa. By comparing the average values of the parameter E, differences were recorded at the level of 38.51 MPa in favor of the samples that were positioned at a zero angle to the base platform of the 3D printer. When comparing groups, A and C, these differences in average values were recorded at the level of 40.36 MPa.

When using the MJF technology, specifically for the parameter Rm, the average values were recorded for the sample group A at a value of 42.66 ± 1.67 MPa, for group B the value was 42.67 ± 1.63 MPa and for group C the value was 45.25 ± 1.1 MPa. In this case, the best mechanical properties of the samples were achieved with group C (position of the samples 90° to the basic platform of the 3D printer). The differences in mean Rm values were 2.59 MPa (group C versus A). A similar result was recorded when comparing the average values between sample groups C and B (2.58 MPa). The analysis of parameter E using MJF technology showed average values for sample group A at a value 1453.2 ± 43.35 MPa, for samples group B at a value of 1523.03 ± 37.34 MPa above for sample group C at a value of 1559.1 ± 99.8 MPa. The highest differences of these average values were observed between sample groups A and C (105.9 MPa). It is evident from the results that the position of the experimental samples below 90° to the basic platform of the 3D printer shows the highest values of the E parameter.

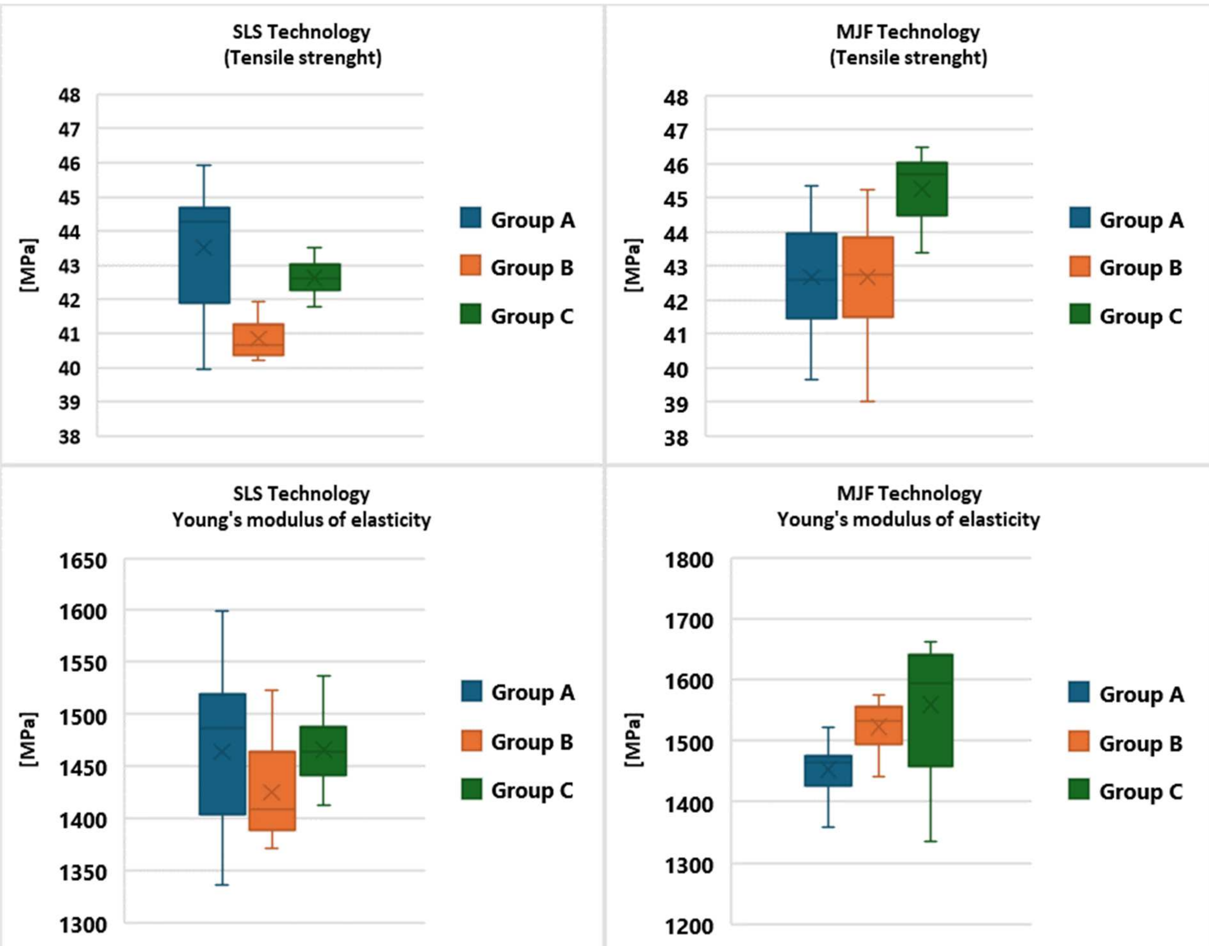

Figure 4 Comparison of mechanical properties of experimental samples at different positions during the 3D printing process

3.2 Comparison of mechanical properties of PA material based on production technology

The comparison of the mechanical properties of the PA material based on the production technology was performed on the parameters Rm and E. In Figure 5 are a graphic representation and comparison of individual production technologies.

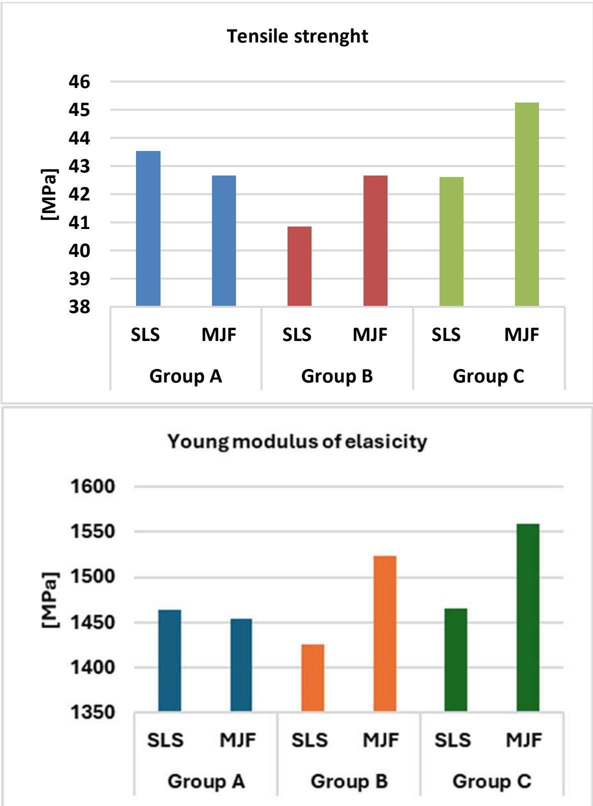

Figure 5 Comparison of mechanical properties of experimental samples based on production technology

Comparing SLS and MJF technologies in terms of Rm, certain differences were noted, while in sample group A this difference was at a value of 0.86 MPa, in sample group B at a value of 1.81 MPa and in sample group C at the level of 2.62 MPa. By comparing the average values of the Rm parameter, it can be concluded that the production SLS technology has better mechanical properties if the printed sample was positioned at a zero angle to the basic platform of the 3D printer. However, for the remaining sample positions (45° and 90°), the Rm values were higher for the MJF technology. Comparing the technologies when examining the parameter E, similar results were achieved, but with higher levels of difference. By comparing the average values of the parameter E, it can be concluded that the production SLS technology has better mechanical properties for samples that were produced at a zero angle to the basic platform of the 3D printer (difference at the level of 10.8 MPa). However, for samples that were printed at 45° and 90° angles to the base platform, these values of the parameter E were significantly lower compared to the MJF technology. The difference in this case was at the level of 97.54 MPa for group B and 93.25 MPa for group C samples.

4 Conclusion

In this study, we used SLS and MJF technology to investigate the mechanical properties at different positions of printed objects on the ideal position in terms of parameters Rm and E. The results showed that when comparing SLS and MJF technologies, the highest mechanical properties were recorded when MJF technology was used while positioning the sample at a 90° angle to the base platform of the 3D printer. Conversely, the lowest mechanical properties were recorded for samples that were positioned at a 45° angle to the base platform of the 3D printer using SLS technology. The study also demonstrated that additive technology and its correct setting and position of printed objects is possible to regulate the mechanical properties of manufactured parts.

Acknowledgement

This publication is the result of the project implementation Research and development of intelligent traumatological external fixation systems manufactured by digitalisation methods and additive manufacturing technology (Acronym: SMARTfix), ITMS2014+: 313011BWQ1 supported by the Operational Programme Integrated Infrastructure funded by the European Regional Development Fund. This research was supported by project KEGA 050TUKE-4/2022 Additive manufacturing in medicine - creation of multimedia material and tools to support teaching in biomedical engineering. This research was supported by project VEGA 1/0599/22 Design and biomechanical analysis of personalized instruments for arthroscopic applications.

References

[1] UNAL, H., MIMAROGLU, A.: Friction and wear performance of polyamide 6 and graphite and wax polyamide 6 composites under dry sliding conditions, *Wear*, Vol. 289, No. June, pp. 132-137, 2012. https://doi.org/10.1016/j.wear.2012.04.004

[2] GILBERT, M.: *Aliphatic Polyamides*, Brydson's Plastics Materials, Elsevier, pp. 487-511, 2017. https://doi.org/10.1016/B978-0-323-35824-8.00018-9

[3] COUSSENS, B., RULKENS, R.: Effect of amide distribution in polyamide isomers on their melting points, *Journal of Applied Polymer Science*, Vol. 135, No. 9, 2018. https://doi.org/10.1002/app.45837

[4] HOFLAND, E.C., BARAN, I., WISMEIJER, D.A.: Correlation of Process Parameters with Mechanical Properties of Laser Sintered PA12 Parts, *Advances in Materials Science and Engineering*, Vol. 2017, pp. 1-11, 2017. https://doi.org/10.1155/2017/4953173

[5] JEVTIĆ, I., GOLUBOVIĆ, Z., MLADENOVIĆ, G., BERTO, F., SEDMAK, A., MILOVANOVIĆ, A., MILOŠEVIĆ, M.: Printing orientation influence on

tensile strength of PA12 specimens obtained by SLS, *Journal of Mechanical Science and Technology*, Vol. 37, No. 11, pp. 5549-5554, 2023. https://doi.org/10.1007/s12206-023-2306-4

[6] VASCO, J.C.: *Chapter 16 - Additive manufacturing for the automotive industry*, Editor(s): Juan Pou, Antonio Riveiro, J. Paulo Davim, In: Handbooks in Additive Manufacturing, Additive Manufacturing, Elsevier, pp. 505-530, 2021. https://doi.org/10.1016/B978-0-12-818411-0.00010-0

[7] MOHANAVEL, V., ASHRAFF ALI, K.S., RANGANATHAN, K.: The roles and applications of additive manufacturing in the aerospace and automobile sector, *materialstoday: Proceedings*, Vol. 47, part 1, pp. 405-409, 2021. https://doi.org/10.1016/j.matpr.2021.04.596

[8] LUNIYA, T., CHIMATA, G.: *Extending the Life of Classic Cars, the Additive Manufacturing Way*, In: Volume 2A: Advanced Manufacturing, American Society of Mechanical Engineers, 2021. https://doi.org/10.1115/IMECE2021-70355

[9] NAJMON, J.C., RAEISI, S., TOVAR, A.: *Review of additive manufacturing technologies and applications in the aerospace industry*, In: Additive Manufacturing for the Aerospace Industry, Elsevier, pp. 7-31, 2019. https://doi.org/10.1016/B978-0-12-814062-8.00002-9

[10] KALENDER, M., KILIC, S.E., ERSOY, S., BOZKURT, Y., SALMAN, S.: *Additive Manufacturing and 3D Printer Technology in Aerospace Industry*, In: 9th International Conference on Recent Advances in Space Technologies (RAST), IEEE, 2019, pp. 689-694, 2019. https://doi.org/10.1109/RAST.2019.8767881

[11] FU, X.X., LIN, Y.X., YUE, X.J., XUNMA, HUR, B., ZHENG YUE, X.: *A Review of Additive Manufacturing (3D Printing) in Aerospace: Technology, Materials, Applications, and Challenges*, In: TANG, Dalai, ZHONG, Joni a ZHOU, Dalin (ed.), Mobile Wireless Middleware, Operating Systems and Applications, EAI/Springer Innovations in Communication and Computing, Cham: Springer International Publishing, 2022, pp. 73-98, 2022. https://doi.org/10.1007/978-3-030-98671-1_6

[12] BOCHNIA, J., KOZIOR, T.: Methods of Prototyping Process Using Modern Additive Technologies, *Solid State Phenomena*, Vol. 223, pp. 199-208, 2014. https://doi.org/10.4028/www.scientific.net/SSP.223.199

[13] ROBINSON, D.K.R., LAGNAU, A., BOON, W. P.C.: Innovation pathways in additive manufacturing: Methods for tracing emerging and branching paths from rapid prototyping to alternative applications, *Technological Forecasting and Social Change*, Vol. 146, pp. 733-750, 2019. https://doi.org/10.1016/j.techfore.2018.07.012

[14] GIBSON, I., ROSEN, D., STUCKER, B.: *Additive Manufacturing Technologies*, New York, Springer New York, 2015. https://doi.org/10.1007/978-1-4939-2113-3

[15] KUMAR, A., KUMAR, D., FAISAL, N., SHARMA, A., KUMAR ANSU, A., GOYAL, A., SAXENA, K.K., PRAKASH, C., KUMAR, D.: Application of 3D printing technology for medical implants: a state-of-the-art review, *Advances in Materials and Processing Technologies*, Vol. 10, No. 2, pp. 357-372, 2023. https://doi.org/10.1080/2374068X.2023.2193788

[16] ARIF, Z.U., KHALID, M.Y., NOROOZI, R., HOSSAIN, M. et al. Additive manufacturing of sustainable biomaterials for biomedical applications, *Asian Journal of Pharmaceutical Sciences*, Vol. 18, No. 3, pp. 1-36, 2023. https://doi.org/10.1016/j.ajps.2023.100812

[17] BAHATI, D., BRICHA, M., EL MABROUK, K.: Vat Photopolymerization Additive Manufacturing Technology for Bone Tissue Engineering Applications, *Advanced Engineering Materials*, Vol. 25, No. 1, 2023. https://doi.org/10.1002/adem.202200859

[18] MUHINDO, D., ELKANAYATI, R., SRINIVASAN, P., REPKA, M.A., ASHOUR, E.A.: Recent Advances in the Applications of Additive Manufacturing (3D Printing) in Drug Delivery: A Comprehensive Review, *AAPS PharmSciTech*, Vol. 24, No. 2, pp. 1-22, 2023. https://doi.org/10.1208/s12249-023-02524-9

[19] LIPSON, H., KURMAN, M.: *Fabricated: the new world of 3D printing; [the promise and peril of a machine that can make (almost) anything]*, Indianapolis, Wiley, 2013.

[20] RAZAVIYE, M.K., TAFTI, R.A., KHAJEHMOHAMMADI, M.: An investigation on mechanical properties of PA12 parts produced by a SLS 3D printer: An experimental approach, *CIRP Journal of Manufacturing Science and Technology*, Vol. 38, No. August, pp. 760-768, 2022. https://doi.org/10.1016/j.cirpj.2022.06.016

[21] CHAROO, N.A., BARAKH ALI, S.F., MOHAMED, E.M., KUTTOLAMADOM, M.A., OZKAN, T., KHAN, M.A., RAHMAN, Z.: Selective laser sintering 3D printing – an overview of the technology and pharmaceutical applications, *Drug Development and Industrial Pharmacy*, Vol. 46, No. 6, pp. 869-877, 2020. https://doi.org/10.1080/03639045.2020.1764027

[22] KUSHWAHA, A.K., RAHMAN, M.H., SLATER, E., PATEL, R., EVANGELISTA, CH., AUSTIN, E., TOMPKINS, E., MCCARROLL, A., RAJAK, D.K., MENEZES, P.L.: *Powder bed fusion–based additive manufacturing: SLS, SLM, SHS, and DMLS*, In: Tribology of Additively Manufactured Materials, Elsevier, pp. 1-37, 2022.

https://doi.org/10.1016/B978-0-12-821328-5.00001-9

[23] ROSSO, S., MENEGHELLO, R., BIASETTO, L., GRIGOLATO, L., CONCHERI, G., SAVIO, G.: In-depth comparison of polyamide 12 parts manufactured by Multi Jet Fusion and Selective Laser Sintering, *Additive Manufacturing*, Vol. 36, pp. 1-13, 2020. https://doi.org/10.1016/j.addma.2020.101713

[24] XU, Z., WANG, Y., WU, D., ANANTH, K.P., BAI, J.: The process and performance comparison of polyamide 12 manufactured by multi jet fusion and selective laser sintering, *Journal of Manufacturing Processes*, Vol. 47, No. November, pp. 419-426, 2019. https://doi.org/10.1016/j.jmapro.2019.07.014

Review process

Single-blind peer review process.