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THE INFLUENCE OF THE MODEL MATERIAL LAYER THICKNESS IN THE ADDITIVE PROCESS ON SELECTED STRENGTH PARAMETERS

WPŁYW GRUBOŚCI WARSTWY MATERIAŁU MODELOWEGO W PROCESIE PRZYROSTOWYM NA WYBRANE PARAMETRY WYTRZYMAŁOŚCIOWE

***Summary**: The subject of the research is to analyze the influence of the elementary thickness of the model material layer in the additive process on the tensile and torsional strength of the manufactured elements. The FFF (Fused Filament Fabrication) thermoplastic modeling technique was used to produce standard research samples. The selected model material was the commonly used PET material. Test models were developed in the CAD (Computer Aided Design) environment. The additive process was developed in dedicated tool software by defining the layer thicknesses at levels of 0.2 and 0.3 mm, respectively. The produced series of FFF samples were subjected to tests In a static tensile test and a static torsional test. The results determined in the strength tests were subjected to comparative analysis.*

***Keywords**: thermoplastic modeling technique, PET material, CAD (Computer Aided Design) environment, the additive process, the tensile and torsional strength, static tensile test, static torsional test, the strength tests*

Streszczenie: Przedmiotem badań jest analiza wpływu grubości elementarnej warstwy materiału modelowego w procesie przyrostowym na wytrzymałość na rozciąganie i skręcanie wytwarzanych elementów. Do wytworzenia standardowych próbek badawczych wykorzystano technikę modelowania tworzywem termoplastycznym FFF (ang. *Fused Filament Fabrication*). Wybranym materiałem modelowym było powszechnie wykorzystywane tworzywo PET. Modele testowe opracowano w środowisku CAD (ang. *Computer Aided Design*). Proces przyrostowy opracowano w dedykowanym oprogramowaniu narzędziowym definiując grubości warstwy na poziomach odpowiednio 0,2 i 0,3 mm. Wytworzone serie próbek FFF poddano badaniom w statycznej próbie rozciągania i statycznej próbie skręcania. Wyznaczone w przedmiotowych próbach wytrzymałościowych wyniki poddano analizie porównawczej.

Słowa kluczowe: technika modelowania tworzywem termoplastycznym, tworzywo PET, środowisko CAD (*Computer Aided Design*), proces przyrostowy, wytrzymałość na rozciąganie i skręcanie, statyczna próba rozciągania, statyczna próba skręcania, próby wytrzymałościowe

Introduction

Additive manufacturing is currently widely used in many industries, including automotive and aerospace, and in other areas such as medicine, architecture, art, education, and the interior design and household goods industries [1, 5, 10]. Due to the high accuracy of CAD model mapping, additive techniques are also used in the process of implementing new elements of various types of structures into production [3]. The selection of the appropriate additive technique is determined by many factors, such as the dimensions of the model, surface quality, dimensional and shape accuracy, or the type of bench tests planned to be performer [1, 3, 5, 10]. Additive techniques are commonly used, the model material of which is thermoplastics. These include the FFF technique employed at the stage of the present research [1, 5, 7, 8, 9, 10].

The application of additively manufactured models in real systems requires knowledge of the model material properties – precise values of strength parameters. The situation is similar when analyzing stress distribution using experimental tests – elastooptics and numerical tests – finite element method (FEM). Here, too, the actual strength parameters of the material are necessary [2, 4, 6].

The technical data sheets provided by the manufacturers of model materials do not take into account, for individual parameters, including strength, individual conditions of the additive process, which include, among others, the thickness of the elementary layer of the material. Additionally, most of the data sheets contain only selected parameters, where, for example, torsional strength is not provided [2, 4, 6]. Research work to date has mostly included the analysis of basic material and strength parameters in the area of model materials used based on standard samples. There are few studies that would take into account torsional strength, which is so important in the case of additively manufactured elements, especially for additively processed thermoplastics. This is a key parameter for a number of parts, including machine shafts, clutches, gear hubs, etc. [2, 4, 6].

The research included the development and production of standard test models for static uniaxial tension and torsion tests and analysis of individual strength parameters on dedicated test stands. The models were made using the FFF technique from thermoplastic PET with the change of the elementary layer thickness in the incremental process, i.e. 0,2 and 0,3 mm.

CAD Test Models

CAD models of the samples were developed based on dedicated standards – defined dimensional and shape conditions. The tensile sample was a type 1A shape standardized in the PN-EN ISO 527-2 series with a measuring section length of 80 mm and a thickness limited to 4 mm. The torsion sample was a shaft with a diameter of 20 mm and a measuring length of 100 mm, terminated on both sides with dedicated grips with a cross-section dictated by the test stand assembly system [2, 4, 6]. CAD models of the samples are shown in Figure 1.

CAD models of the research samples were used to develop the FFF additive manufacturing process for the selected model material – thermoplastic PET filament.

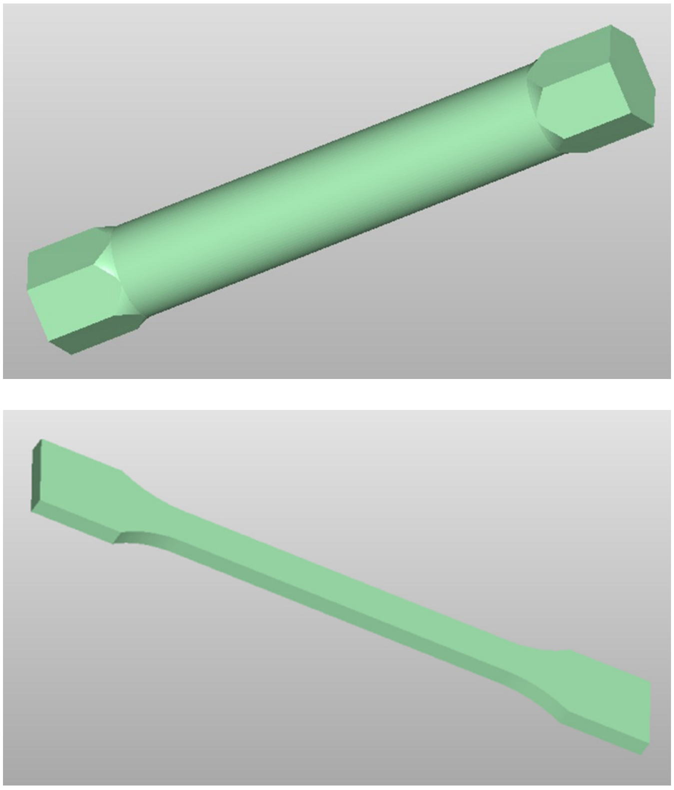


Fig. 1. CAD models of research samples

Developing an incremental process

CAD models of samples for strength tests were used in the process of developing the additive manufacturing procedure using the FFF technique. Based on the solid models, a dedicated STL (Standard Triangulation Language) format was generated, i.e. a triangle mesh describing the individual surfaces of a given solid. STL is the leading format used by most 3D printers - on its basis, it is possible to generate an executive procedure for the manufacturing equipment – data regarding the production of subsequent elementary layers of the model [1, 5, 10]. The FFF process was developed in dedicated Prusa Slicer tool software. After importing the models to the virtual work platform, they were replicated in individual series, their position in relation to the printing module was optimized and individual process parameters were defined. In addition to the elementary layer thickness, appropriately defined for one set of 0.2 mm and the other 0.3 mm, all other parameters were set, i.e. primarily the filling – at the level of 90% with a standard grid at an angle of 45°, the support structure – only on the table and other outlines, compact layers, individual speeds, etc. The virtual build plate with a set of sample models and the calculated FFF process data at 0.2 mm layer thickness – in the Prusa Slicer software window – are shown in Figure 2.

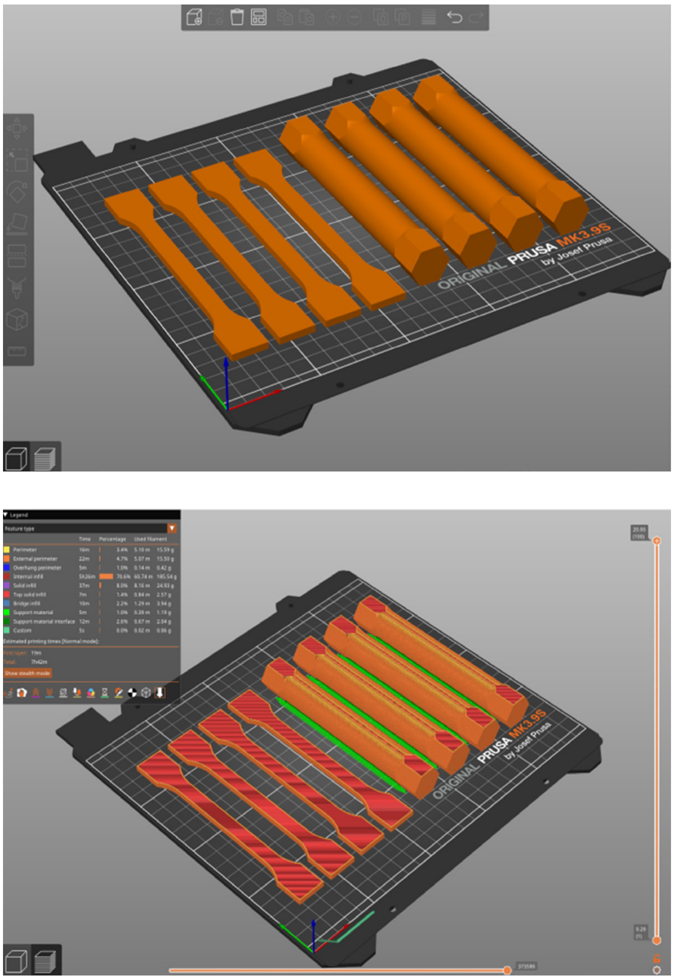


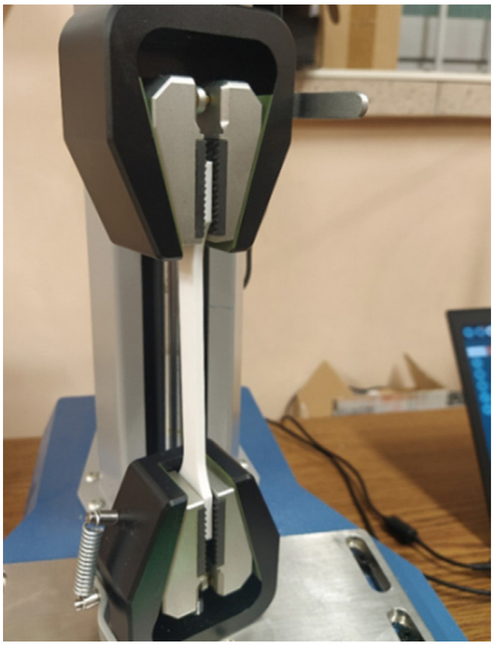
Fig. 2. Prusa Slicer software – FFF process development

Physical models of the samples were produced using the Original Prusa MK3S printer from PET model material – a polymer that is widely used in modern industry due to its high strength, resistance to mechanical and chemical damage, and durability [1, 5, 10].

The samples were subjected to strength tests using the Mecmesin Multitest-Dv machine and an original test stand for analyzing torsional strength of the Department of Mechanical Engineering of the Rzeszów University of Technology.

Samples for strength tests placed in dedicated holders of the measuring equipment are shown in Figure 3.

Strength tests were carried out for two series of research models – with an elementary layer thickness of the model material of 0.2 and 0.3 mm, 4 samples in each set.



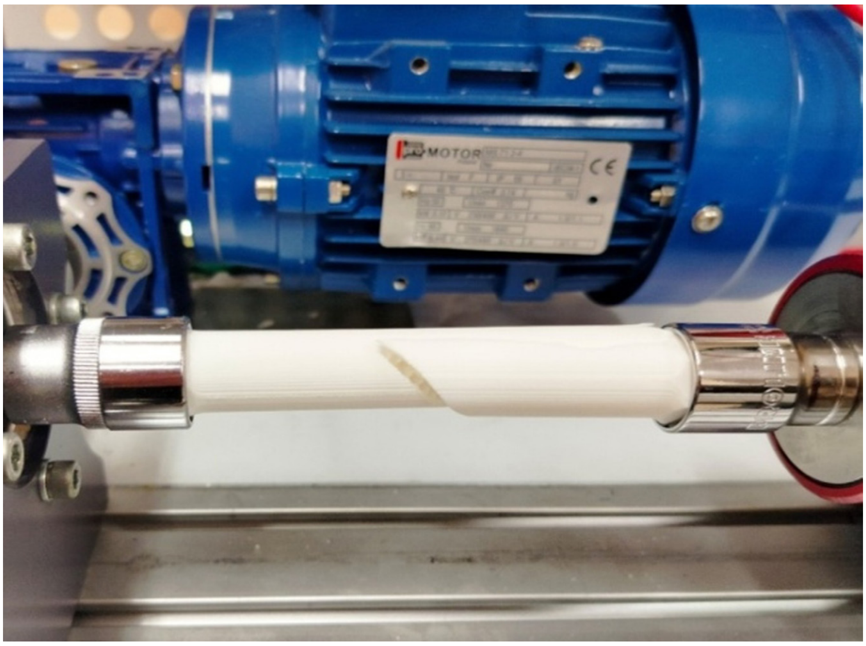


Fig. 3. Samples for strength tests in measuring equipment holders

Development of strength test results

The results of individual strength tests in static uniaxial tension were prepared in the form of stress-strain diagrams – Figure 4 and 5, as well as summary comparative tables – Table 1 and 2.

The results of individual strength tests in static torsion were prepared in the form of graphs of the dependence of the torque on the torsion angle – Figure 6 and 7 and collective comparative tables – Table 3 and 4.

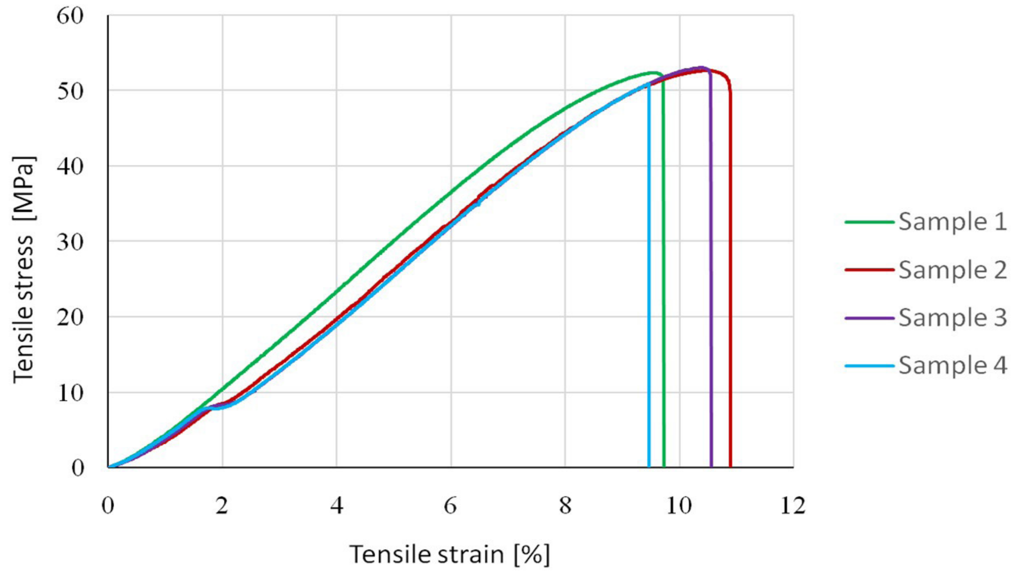


Fig. 4. Stress-strain graph for tensile samples with a layer thickness of 0.2 mm

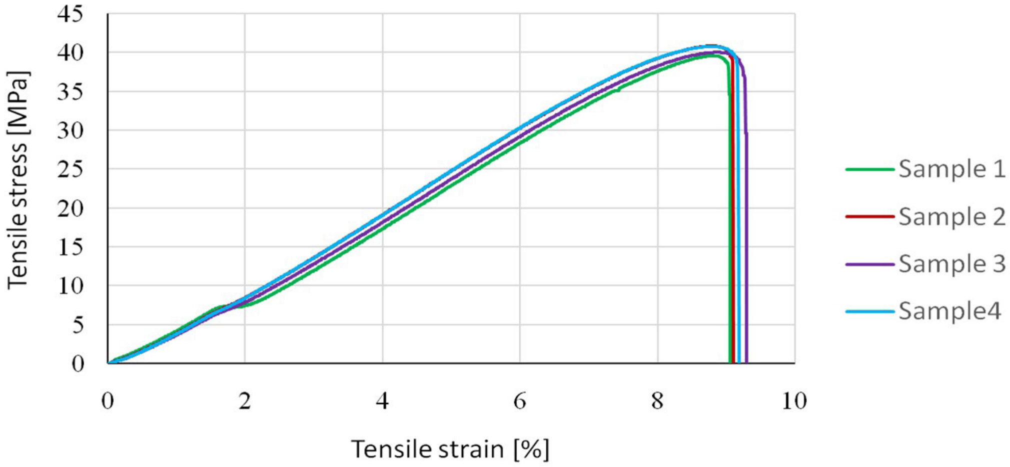


Fig. 5. Stress-strain graph for tensile samples with a layer thickness of 0,3 mm

Table 1. Summary of the static tensile test results for the maximum tensile stress

Sample	Layer thickness 0.2 mm			Layer thickness 0.3 mm		
	Maximum tensile stress [MPa]			Maximum tensile stress [MPa]		
	For the sample	Average value	Standard deviation	For the sample	Average value	Standard deviation
1	52.3	52.2	0.9	39.6	40.3	0.5
2	52.6			40.8		
3	53.0			40,0		
4	50.9			40.7		

Table 2. Summary of the static tensile test results for the maximum tensile strain

Sample	Layer thickness 0.2 mm			Layer thickness 0.3 mm		
	Maximum tensile stress [MPa]			Maximum tensile stress [MPa]		
	For the sample	Average value	Standard deviation	For the sample	Average value	Standard deviation
1	9.7	10.2	0.6	9.1	9.2	0.1
2	10.9			9.1		
3	10.6			9.3		
4	9.5			9.2		

Table 3. Summary of the results of the static torsion test for the maximum torsion torque

Sample	Layer thickness 0.2 mm			Layer thickness 0.3 mm		
	Maximum torsion torque [Nm]			Maximum torsion torque [Nm]		
	For the sample	Average value	Standard deviation	For the sample	Average value	Standard deviation
1	40.1	40.25	0.20	28.3	28.28	0.34
2	40.5			27.6		
3	40.4			28.8		
4	40.0			28.4		

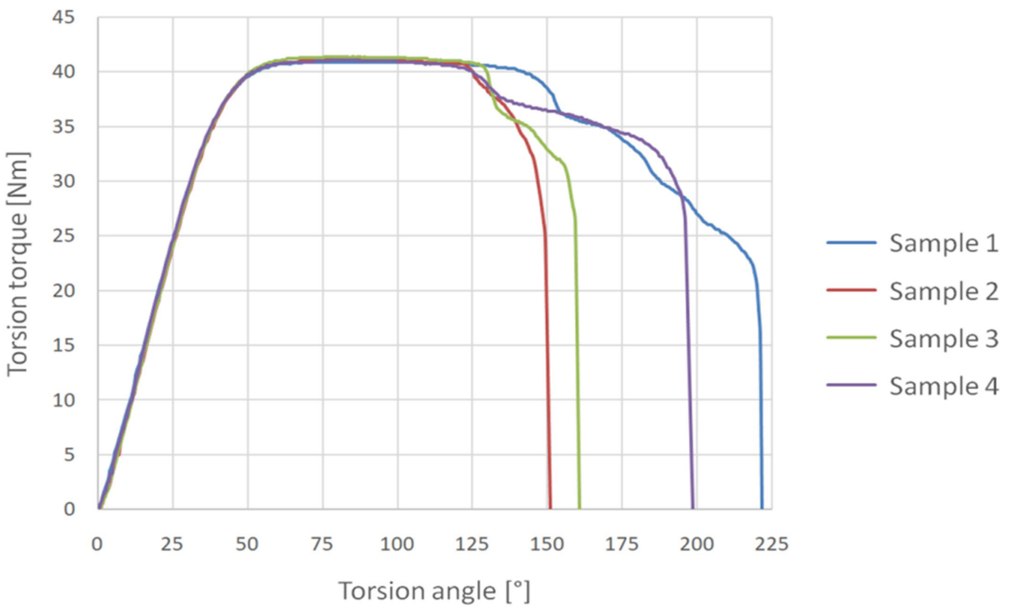


Fig. 6. Graph of the dependence of the torque on the torsion angle for samples with a layer thickness of 0.2 mm

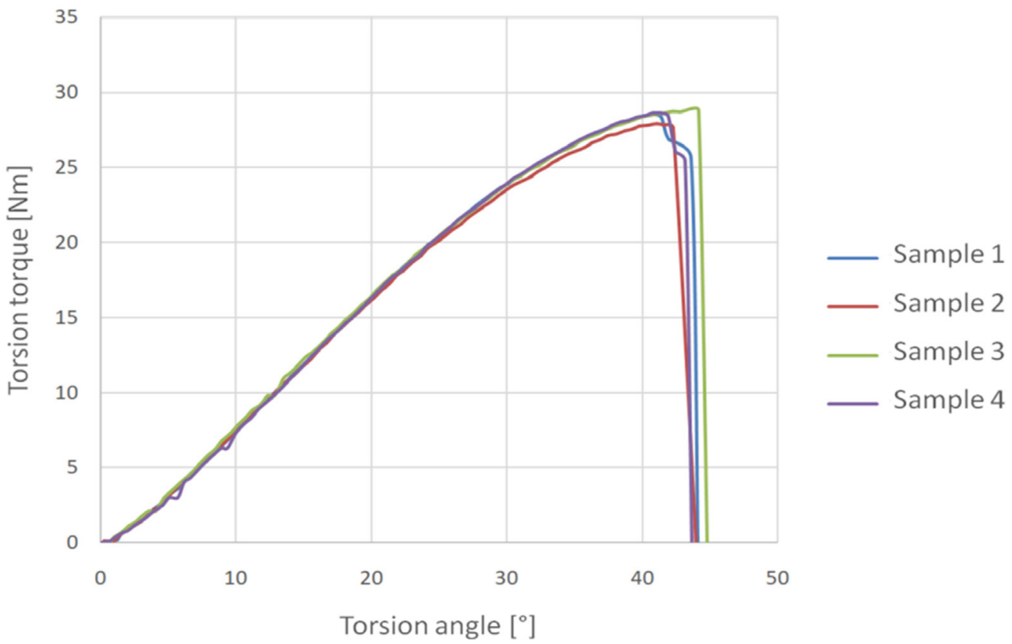


Fig. 7. Graph of the dependence of the torque on the torsion angle for samples with a layer thickness of 0.3 mm

The results of the strength tests for key parameters of the static tensile and torsion tests clearly indicate greater strength of the test models printed using the FFF technique with an elementary thickness of the PET model material layer at a defined level of 0.2 mm.

Final conclusions

The performed research work provided new knowledge on the actual values of strength parameters of PET thermoplastic formed in the FFF process. In the light of the achievements published in the literature so far, the analysis conducted constitutes a separate approach to a specific problem. The results in question supplement the previous material data in the area of the influence of changes in the printing process parameters on the selected mechanical properties of thermoplastic material commonly used in additive manufacturing techniques. It should be emphasized that the research work carried out constitutes a representative fragment of the study, which fully takes into account additional different model settings in the workspace of the manufacturing equipment. The results determined in the static uniaxial tensile test and static torsion test indicate higher strength values for the research sample models printed using a layer thickness of 0.2 mm. For the maximum tensile stress, the difference is over 23%, and for the tensile strain less than 10%. Similarly, higher torsional strength was determined for the samples with a layer thickness of 0.2 mm. The maximum torsion torque is higher in the variant in question by almost 30% than the maximum torsion torque determined for the 0.3 mm variant. On the other hand, the angle of torsion at sample fracture was determined at a level almost 70% higher for the 0.2 mm variant.

Of course, in the case of the target application of models in a load system requiring lower strength, it is advisable to print in the 0.3 mm layer thickness variant due to the economic factor. The printing time of the series of research models with a defined layer thickness of 0.3 mm was by 20% shorter than for the 0.2 mm variant. The level of material consumption was determined at a similar level for both variants.

The determined strength test results can be used in the process of determining the application area of additively manufactured parts using the FFF technique from thermoplastic PET material. Additionally, in the test process, the values of torsional strength parameters were determined, which are not provided by the manufacturers of model materials, but are necessary for parts such as machine shafts, clutches, gear hubs and many others loaded with torsion torque.

Bibliography

[1] Badiru A.B., Valencia V.V., Liu D., Additive Manufacturing Handbook. Product Development for the Defense Industry, CRC Press, 2020.

[2] Bernaczek J., Dębski M., Gontarz M., Grygoruk R., Józwik J., Kozik B., Mikulski P., Analysis of Torsional Strength of Pa2200 Material Shape Additively with the Selective Laser Sintering Technology, Advances in Science and Technology Research Journal 2023, 17(2) 12–24.

[3] Bernaczek J., Budzik G., Dziubek T., Przeszłowski Ł., Wójciak K., Dimensional-Shape Verification of a Selected Part of Machines Manufactured by Additive Techniques, Advances in Science and Technology Research Journal 2023, 17(1) 46–57.

[4] Bernaczek J., Dębski M., Gontarz M., Kiełbiscki M., Magniszewski M., Przeszłowski Ł., Influence of torsion on the structure of machine elements made of polymeric materials by 3D printing, POLIMERY 2021, 66, 5, 298-304.

[5] Budzik G., Woźniak J., Przeszłowski Ł., Druk 3D jako element przemysłu przyszłości. Analiza rynku i tendencje rozwoju. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów, Poland 2022.

[6] Budzik G., Magniszewski M., Oleksy M., Oliwa R., Bernaczek J., Torsional strengh testing of machine elements manufacture by incremental technology from polymeric materials POLIMERY 2018, 63, 11-12, 830-832.

[7] Gao X., Kuang X., Li J., Qi S., Su Y., Wang D., Fused filament fabrication of polymer materials: A review of interlayer bond, Additive Manufacturing 2021, 37, 101658.

[8] Gunasekaran J., Sevvel P., Solomon I. J., A review of the various processing parameters in FDM, Materials Today: Proceedings 2021, 37, 509-514.

[9] Senkerik V., Bednarik M., Janostik V., Analysis of Extrusion Process Parameters in PLA Filament Production for FFF Technology. In: Manufacturing Technology, 2024, Vol. 24, No. 2, pp. 265–271.

[10] WOHLERS REPORT, 3D Printing and Additive Manufacturing: State of the Industry. Annual Worldwide Progress Report 2018.