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The impact of 3D printing assumptions and CNC machining conditions on the mechanical parameters of the selected PET material

P. Krawulski*, T. Dyl

Faculty of Marine Engineering, Gdynia Maritime University,
ul. Morska 81-87, 81-225 Gdynia, Poland

* Corresponding e-mail address: p.krawulski@wm.umg.edu.pl

ORCID identifier: https://orcid.org/0000-0002-7093-6627 (P.K.)

ABSTRACT

Purpose: This article focuses on a comparative analysis of the technology of additive shaping and multi-axis CNC machining. The authors examine the impact of 3D printing assumptions and CNC machining conditions on the strength of the selected PET material used to produce machine elements on the example of a shaft-type element. The purpose of the study is to identify a better production method.

Design/methodology/approach: The analysis was carried out by producing six samples of different diameters and lengths from the same thermoplastic material (ethylene terephthalate) by both 3D printing (FDM) and CNC machining. The resulting samples were subjected to a static compression test, for which a universal testing machine by Zwick & Roell 100 kN was used. The following factors during the production of elements were compared: the difficulty of preparing the project, the time of execution, the cost of execution, the accuracy of the execution and the properties of the elements made.

Findings: Elements made by CNC machining have higher compressive strength and yield strength, as well as lower relative expansion and relative shortening. Those produced by CNC machining are created as a monolith (semi-finished product), and the printed elements are incrementally shaped layer by layer. During the strength test, the spaces between the layers decrease, which in turn causes an increase in relative shortening and a decrease in strength properties.

Research limitations/implications: Further research is planned on the analysis of manufacturing technology using incremental shaping technology (e.g. change of filling density, change of filling type, change of material) compared to CNC machining.

Practical implications: In the conducted tests, a universal method was used, which can be translated into a comparative study of elements made of other materials.

Originality/value: The research carried out allowed for the initial assessment of the use of PET material for the production of machine elements through 3D printing and CNC machining.

Keywords: 3D printer, FDM method, CNC machining, Mechanical properties, Polymers

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MATERIALS MANUFACTURING AND PROCESSING

1. Introduction

In the engineering, food, petrochemical, automotive, aviation and shipbuilding industries, products with complex shapes and special functional and operational properties are used. In many cases, it is important to look for modern technological solutions for the production of components used in the construction of machines in shipbuilding and aviation. In particular, it is important to use durable and reliable design solutions in these industries. The so-called 3D printing technologies and CNC-controlled multi-axis machining in production deserve special attention [1].

Incremental shaping is known as 3D printing, which can be represented as layering by a layer of material, leading to the fabrication of a real 3D model object [2]. The main advantage of this manufacturing method is the ability to produce parts and products of any shape from a wide variety of materials. The technologies most often used in this method are [3]: FDM, SLA, SLS, and DMLS.

Incremental shaping technologies and processing with the use of Computerized Numerical Control (CNC) allow the production of a wide range of products from engineering materials (metal, ceramics, polymers and composites) [4]. CNC machine tools allow for greater automation of subtractive processes compared to conventional turning or milling methods. It is possible by using post-processors that allow for error compensation, coding and monitoring of tool wear. In CNC devices, microelectronics is used to collect and transmit information within the machine tool environment [5]. Modern manufacturing technologies are used in industry, inter alia, shipbuilding, and aviation (fragments of the fuselage, drive components, clutch inserts) [6].

Not all designs delivered for production can be made using CNC machine tools. Sharp angles and internal radii require a lot of experience from the technologist to be done correctly. It happens that the complexity of the product requires a redesign, which extends the production process and increases costs. Another limitation in the case of CNC machine tools is the complexity of the manufacturing process [7]. In the case of CNC machine tools, the problem is that the product is made of one solid piece. An important problem in machining is that making the entire element in one operation is impossible. 3D printing allows designers to produce parts with more complex shapes and structures inside the element unattainable with other production methods [8].

The aim of the research was to conduct a comparative analysis of the manufacturing technology by CNC machining and 3D printing technology (FDM) on the example of a shaft-type element. It consisted of comparing the following factors during the production of elements: the difficulty of preparing the design, time of execution, accuracy of execution and properties of the elements made.

2. Materials and experiments

The thermoplastic material poly(ethylene terephthalate) (PET) was tested. The samples were made using the EMCO Concept TURN 60 machine tool (Fig. 1) [9] and the Original Prusa i3 MK3S 3D printer (Fig. 2) [10]. The static compression test was performed on a universal testing machine by Zwick & Roell 100 kN (Fig. 3) [11]. A testing machine that meets the requirements of PN-ISO 5893:2015-12 [12].

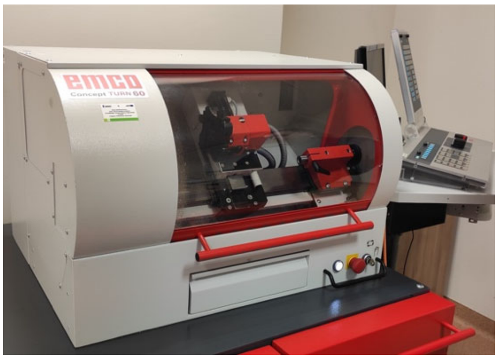

Fig. 1. EMCO Concept Turn 60 machine tool

Hardened steel compression plates are used to apply the load so that the load is transmitted coaxially in the range of 1:1000 and transmitted through polished surfaces parallel to each other. The load indicator is equipped with a mechanism to indicate the total compressive load exerted on the fitting.

Micrometres with an accuracy of 0.01 mm were used to measure the depth, width and length (Fig. 4).

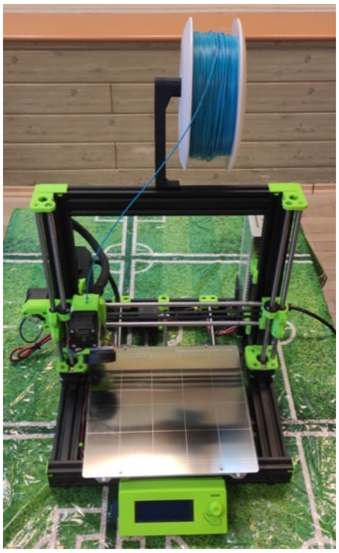

Fig. 2. Original Prusa i3 MK3S 3D printer

Fig. 3. Universal testing machine Zwick Roell 100 kN

Fig. 4. Set of micrometres

The samples were designed in Autodesk Inventor 2021. In PrusaSlicer, for technological reasons, the following conditions and parameters of 3D printing have been set for elements printed on a 3D printer: filling 100%, nozzle temperature 230°C, bed temperature 70°C, printing speed 25 mm/s, layer thickness 0.2 mm, cooling speed 15%. The following parameters were assigned during the production of samples on a CNC machine: spindle speed 1500 rpm, longitudinal feed speed 0.1 mm/rev, and transverse feed speed 0.05 mm/rev.

Samples for the static compression test were prepared in accordance with the standard PN-EN ISO 604:2006P [13].

With both CNC machining [14] and 3D printing (FDM) technology [15], the following six elements were made of the same material (Fig. 5): a shaft with a diameter of ⌀22 mm and a length of 25 mm, a shaft with a diameter of ⌀22 mm and a length of 40 mm, a shaft with a diameter of ⌀ 22 mm and 50 mm long, shaft ⌀18 mm in diameter and 25 mm long, shaft ⌀18 mm in diameter and 40 mm long, shaft ⌀18 mm in diameter and 25 mm long.

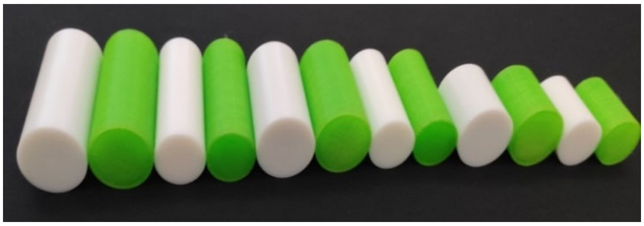

Fig. 5. Samples made by CNC machining and 3D printing technology

The article presents the results of tests determined in the static compression test. The yield strength, relative shortening and relative expansion were determined.

3. Results

The execution time of individual manufacturing processes (machining, 3D printing technology) is presented in Table 1.

Properties of elements manufactured by CNC machining and 3D printing technology, determined based on the performed compression test, are presented in the Table 2, Table 3, Table 4 and Table 5.

Figure 5 shows a diagram of the relationship between the geometrical parameters and the compressive strength of samples made of PET material. The chart shows that the compressive strength value during CNC technology in each case of the shaft size is more than twice as high as the 3D

Table 1.
Lead time for individual shaft manufacturing processes using CNC machining and 3D FDM printing technology

Process	CNC machining	3D printing
Preparing the project, min	38	28
Time of execution of the working movement, min	15	431
The total time of making the elements, min	33	431
Operator working time, min	71	28

Table 2.
Compressive strength

Element	Compressive strength R_c, MPa	
	CNC machining	3D printing
Sample 1 ⌀18x25	102.60	41.58
Sample 2 ⌀18x40	102.11	41.84
Sample 3 ⌀18x50	99.67	40.55
Sample 4 ⌀22x25	109.23	41.40
Sample 5 ⌀22x40	105.05	41.23
Sample 6 ⌀22x50	103.77	41.93

Table 3.
Yield point

Element	Yield point R_{ec}, MPa	
	CNC machining	3D printing
Sample 1 ⌀18x25	99.91	32.76
Sample 2 ⌀18x40	94.97	30.71
Sample 3 ⌀18x50	94.38	29.13
Sample 4 ⌀22x25	102.02	34.79
Sample 5 ⌀22x40	96.06	33.62
Sample 6 ⌀22x50	94.82	31.57

Table 4.
Relative contraction

Element	Relative contraction A_{ck}, %	
	CNC machining	3D printing
Sample 1 ⌀18x25	1.48	3.42
Sample 2 ⌀18x40	1.95	4.43
Sample 3 ⌀18x50	2.46	4.34
Sample 4 ⌀22x25	1.00	3.75
Sample 5 ⌀22x40	1.63	3.58
Sample 6 ⌀22x50	1.60	3.97

Table 5.
Relative expansion

Element	Relative expansion Z_c, %	
	CNC machining	3D printing
Sample 1 ⌀18x25	2.36	2.07
Sample 2 ⌀18x40	2.09	2.81
Sample 3 ⌀18x50	2.34	2.68
Sample 4 ⌀22x25	1.75	2.41
Sample 5 ⌀22x40	2.05	2.75
Sample 6 ⌀22x50	2.39	3.33

printing technology. The highest compressive strength value in CNC machining technology was observed for the sample with dimensions of ⌀22x25 mm and the lowest for the sample of ⌀18x50 mm. In 3D printing technology, the highest value was observed for the ⌀22x50 mm sample, while the lowest was for the ⌀18x50 mm sample.

Figure 6 shows the graph between the geometrical parameters and the yield point of samples made of PET material. The chart shows that the compressive strength value during CNC technology isthree times higher in each case than that of 3D printing technology. The highest value of the yield point in the CNC machining technology was

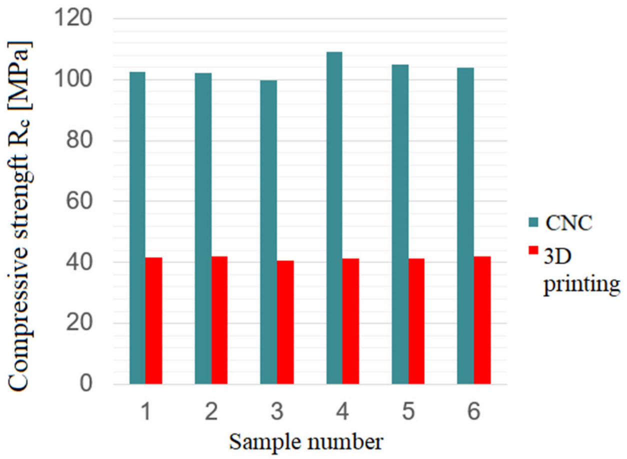

Fig. 5. Compressive strength diagram

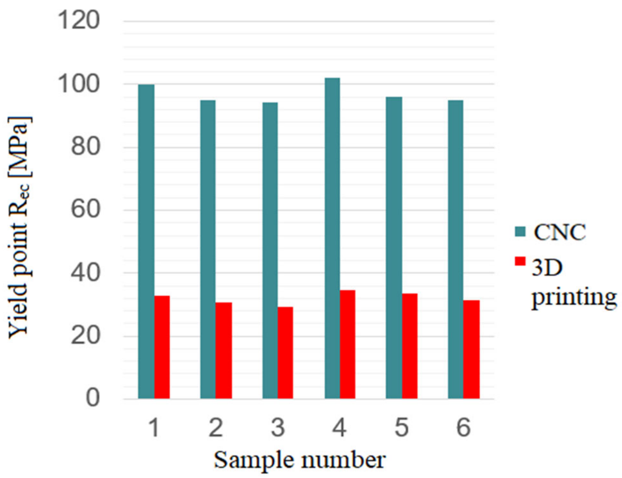

Fig. 6. Yield point diagram

observed for the sample ⌀22x25 mm, and the lowest for the sample ⌀18x50 mm. In the 3D printing technology, the highest value was observed for the ⌀22x25 mm sample, while the lowest for the ⌀18x50 mm sample.

Figure 7 shows the graph between the geometrical parameters and the relative contraction of samples made of PET material. The highest value of relative contraction in CNC machining technology was observed for the sample ⌀18x50 mm, and the lowest for the sample ⌀22x25 mm. In 3D printing technology, the highest value of relative shortening was observed for the ⌀18x40 mm sample, while the lowest for the ⌀18x25 mm sample.

Figure 8 shows the graph between the geometrical parameters and the relative expansion of samples made of PET material. The highest value of relative expansion in CNC machining technology was observed for the sample

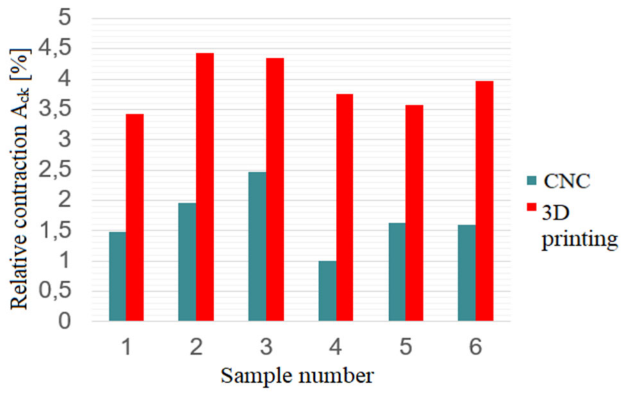

Fig. 7. Relative contraction diagram

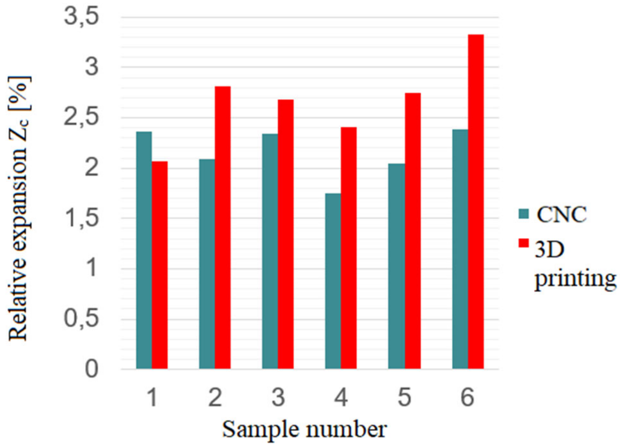

Fig. 8. Relative expansion diagram

⌀18x25 mm, and the lowest for the sample ⌀22x25 mm. In 3D printing technology, the highest value of relative expansion was observed for the ⌀22x50 sample, while the lowest for the ⌀18x25 mm sample.

4. Conclusions

The conducted research allowed for an initial assessment of the use of PET material for the production of machine elements through 3D printing and CNC machining.

Based on the strength tests carried out, it can be concluded that the elements made by CNC machining have higher compressive strength and yield strength, as well as lower relative expansion and relative shortening. It can be concluded that despite the parts being made of the same material, the values are divergent. This is mainly because the elements produced by CNC machining technology are made as a monolith (semi-finished product), and the printed elements are incrementally shaped with 100% filling (layer by layer). During strength tests, the spaces between the layers decrease, which in turn causes an increase in relative shortening and a decrease in strength properties.

Parts made with CNC machining technology are characterized by greater accuracy and better strength properties than elements made with additive technology.

Further research is planned on the analysis of manufacturing technology using additive shaping technology (3D printing, changes in filling density during printing and changes in the type of filling) compared to CNC machining.

References

[1] S.S. Crump, A system and a method building three-dimensional objects in a layer-by-layer manner via fused deposition modeling, US5121329A, 1989.

[2] A. Su, S.J. Al'Aref, Chapter 1 – History of 3D Printing, in: S.J. Al'Aref, B. Mosadegh, S. Dunham, J.K. Min (eds), 3D Printing Applications in Cardiovascular Medicine, Academic Press, Cambridge, USA, 2018, 1-10. DOI: https://doi.org/10.1016/B978-0-12-803917-5.00001-8

[3] J. Huang, Q. Qin, J. Wang, A review of Stereolitography: Processes and Systems, Processes 8/9 (2020) 1138. DOI: https://doi.org/10.3390/pr8091138

[4] Basics of CNC machining, Rea Publisher, 2013.

[5] M. Borkowski, Comparative analysis of technology for manufacturing machine elements by incremental shaping and CNC machining, Gdynia, 2022 (in Polish).

[6] C.K. Chua, K.F. Leong, 3D printing and additive manufacturing: principles and applications – fifth edition of rapid prototyping, World Scientific Publications, 2016.

[7] How to quadruple the production costs of a single model (in Polish). Available from: https://atmat.pl/cnc-vs-druk-3d (Access in: 20.12.2022)

[8] 3D printing and CNC machining - comparison of technologies in the production of tooling (in Polish). Available from: https://centrumdruku3d.pl/case-study-druk-3d-i-obrobka-cnc-porownanie-technologii-w-produkcji-oprzyrzadowania/ (Access in: 20.12.2022)

[9] Manual for the EMCO Concept TURN 60 CNC machine tool.

[10] Prusa i3 MK3S 3D printer manual.

[11] Universal testing machine manual Zwick & Roell 100 kN.

[12] PN-ISO 5893:2015-12. Equipment for testing rubber and plastics - Tensile, bending and compression tests (constant traverse speed).

[13] PN-EN ISO 604:2006. Plastics Determination of compression properties (in Polish).

[14] 3D printing and CNC machining - comparison of technologies in the production of tooling (in Polish). Available from: https://obrobkametalu.tech/druk-3d-i-obrobka-cnc-porownanie-technologii-w-produkcji-oprzyrzadowania/ (Access in: 12.01.2023)

[15] P. Siemiński, G. Budzik, Incremental techniques. 3D printing. 3D printers, OWPW, Warsaw, 2015 (in Polish).