DOI 10.52209/2706-977X_2024_1_53 IRSTI 55.13.17 UDC 316.343.653

Investigating the Time Spent on Manufacturing Parts of Complex Geometry Using Additive and Traditional Technologies

Zhetessova G.S.[1], Škamat Je.S.[2], Tattimbetova G.B.[3], Mateshov A.K.[4]
[1,3,4] Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
[2] Vilnius Gediminas Technical University, Vilnius, Lithuania
*corresponding author

Abstract. The research objective is to conduct a comprehensive analysis of the time spent on the production of parts of complex geometry using additive and traditional technologies. In modern industrial production, especially in the field of mechanical engineering, the manufacture of parts with complex shapes is becoming more and more in demand. These parts often have a high degree of complexity and require precise and efficient processing. The use of additive and traditional technologies in the production of parts can present various advantages and disadvantages, including production speed, manufacturing quality and overall time costs. However, there is insufficient research comparing the time costs of these two production methods, especially in the context of manufacturing parts of complex geometry. This work aims to fill this knowledge gap by analyzing and comparing the time spent on manufacturing parts using additive and traditional technologies. The results of this research can be useful for both the scientific community and industrial enterprises, helping them make informed decisions when choosing production technology for specific tasks.

Keywords: additive technologies, 3D printing, prototyping, milling, model.

Introduction

Prototyping is an integral part of product pre-production. Prototyping allows you to obtain valuable technical information, conduct a marketing research of a new product on the market, check some functional properties of the CAD model and the future product, and much more. Before starting mass production of a product, it is necessary to produce one, and sometimes even several versions of prototypes. In the latter case, this leads to additional costs, but they cannot be avoided when working with new or unfamiliar materials, designing products of complex geometric shapes or individual loaded, load–bearing parts - in practice, it is necessary to find out the real shrinkage characteristics of plastic, assess the possibilities of maintaining dimensional tolerances, etc. The above applies equally to two groups of prototypes: exact facsimile copies of products (for evaluating appearance and other applications) and technological (obtained in an experimental injection mold to evaluate the process and some properties of castings [1]).

Various technologies can be used to manufacture master models for casting (hereinafter referred to as parts) having a complex geometric shape:

– machining;
– photopolymerization;
– stereolithography;
– laser sintering of powder materials;
– layered application of molten polymer filament;
– gluing (lamination) of layers;
– casting into elastic silicone molds;
– low pressure casting;
– creating solid - state objects using printers;
– production of models from foamed plastics;
– casting of prototypes in experimental molds.

This article discusses in more detail two manufacturing technologies for such parts: milling on a CNC machine and 3D printing.

The rapid proliferation of Additive Manufacturing (AM) in the last 50 years has seen the developing manufacturing sector integrated into design and modelling as a rapid prototyping technique [2]. 3D printing (Three Dimension Printing, 3DP) technology is a rapid prototyping technology, also known as additive manufacturing technology. It is a technology based on digital model files, using powdered plastics, metals or bondable materials to build objects by layer-by-layer printing [3]. Compared with the traditional processing and manufacturing technology that removes materials, 3D printing technology is a brand-new manufacturing technology. With the maturity and promotion of computer-aided design (CAD) technology, 3D printing technology is becoming more and more perfect [4]. The ability to fabricate complex parts in one machine and job, has businesses determined to establish AM as a certified end-user product manufacturing technique. AM research and company integration of the technologies has progressed AM from rapid prototyping to rapid tooling and now to a future in Direct Manufacturing [5].

The additive technology market consists of segments of equipment, materials, services and software. According to forecasts of world experts, the global market for additive technologies will reach $41.6 billion by 2027, and 3D printing services will be in high demand [6] (Fig. 1).

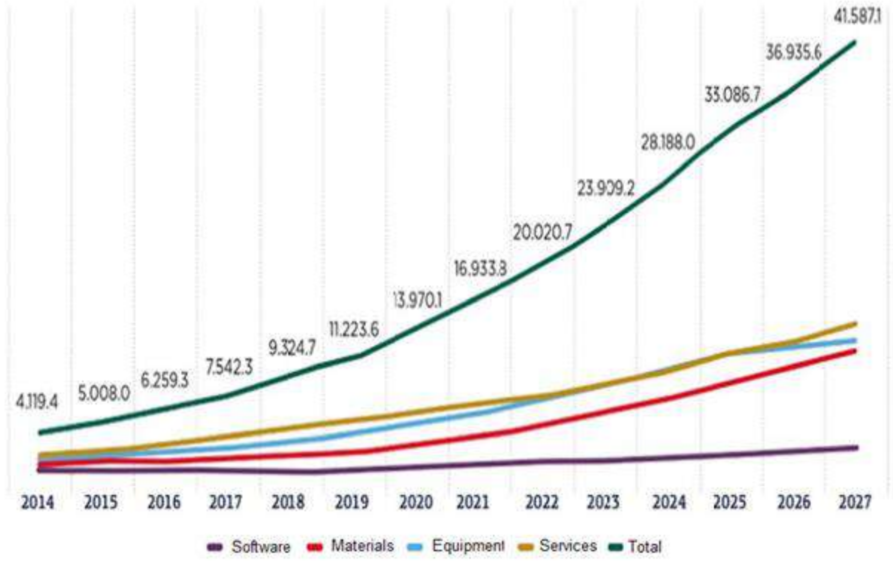

Fig. 1. – Dynamics and forecast of the total volume of the additive technologies market (by application areas), billion dollars. Source: SmarTech Publishing

1. Methods and experimental research

During the experiments, general methods of scientific cognition were used: analysis and synthesis of information on the research topic; methods of mathematical modeling in the analysis of experimental results; experiment planning; 3D modeling of parts and their manufacture on a 3D printer with maintenance of the required technological parameters, as well as calculation of time costs for the production of parts using additive and traditional technologies.

The process of manufacturing a part using additive (3D printing) and traditional (milling) technologies can be presented in the following sequence of works (Table 1)

Table 1. Stages of manufacturing a part of complex geometry

No.	Stages	Traditional technologies (milling)	Additive technologies (3D printing)
1	Designing	Creating a model	Creating a model
2	Postprocessing	Creating a blank Development of the technological process Tool Selection Code generation Check	Exporting a 3D model to STL format G-code generation
3	Production preparation	Preparation of the machine Setting up Preparation of the tool Debugging	Preparing a 3D printer
4	Production	Milling	3D printing
5	Post-production processing	Finishing (on demand)	Finishing (on demand)

The rational use of time in the process of creating parts allows you to optimize the entire production cycle. This may include improving design processes, reducing hardware setup time, and optimizing the execution time of operations.

We will experimentally calculate the time spent on creating a pump body using additive technologies. To begin with, a three-dimensional model is created in a special Siemens NX software module. The result of designing a 3D model is shown in Fig. 2. The resulting file is exported to STL format. STL is a graphical standard for representing model data for rapid prototyping systems. It is based on the method of three-dimensional triangulation of the model surface, which is carried out by triangles and can be smoothed by geometric shapes of a higher order, thereby achieving high accuracy and reproducibility of the synthesized surface [7].

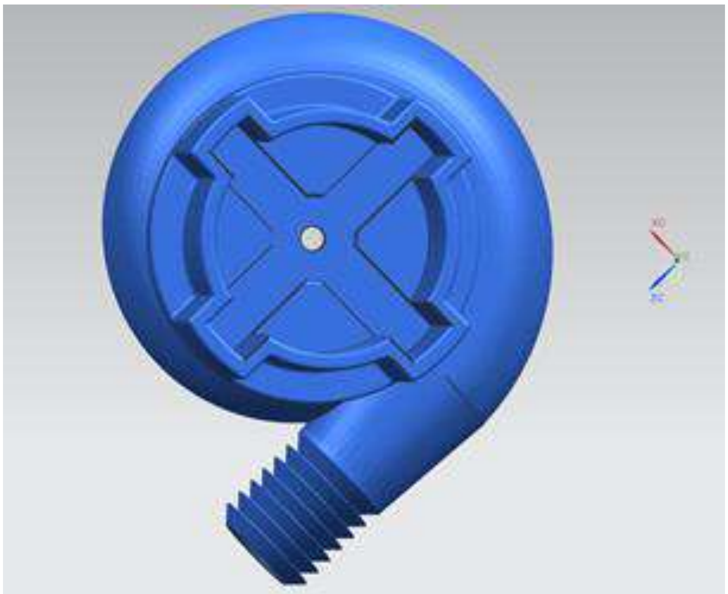

Fig. 2. – 3D model of the pump housing in Siemens NX

In the next step, using the Polygon software, the two-dimensional fragments, in turn, are converted into a G-code that controls the movement of the print head and printing conditions such as temperature and speed [8]. In addition, at this stage, the optimal parameters for the direct printing process of the product are determined. According to the received G-code, the approximate printing time of the product with dimensions 57 x 41 x 60 mm is 2 hours and 12 minutes (Fig. 3).

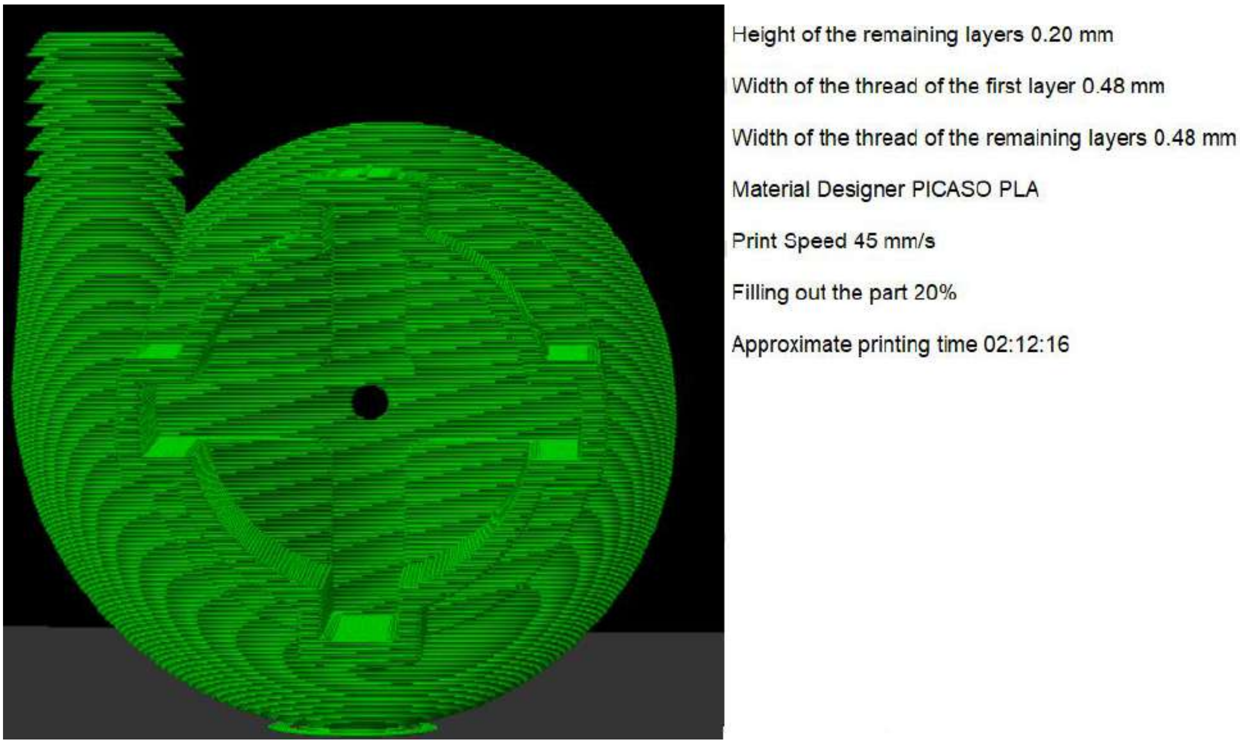

Fig.3. – Setting up a print job

The part was printed on a Designer Classic 3D printer based on the laboratory of the Abylkas Saginov Karaganda Technical University. Designer Classic is a 3D printer using FFF technology (fused filament fabrication). Typical feedstock materials for FFF are thermoplastics or thermoplastic-matrix composites in the form of filaments having a tightly controlled diameter of 1.75 or 2.85 mm, depending on the printing hardware [9]. As illustrated in Fig. 2, the filament is fed into the printhead by the action of two counter-rotating gears. The core of the printhead is the liquefier, where the feedstock material is heated and melted. The filament at the liquefier's entrance works like a piston and pushes the melt out of the print nozzle. While the extrudate is being deposited on the base platform, the printhead moves on a X–Y gantry following a computer-controlled toolpath defined by the G-code, so that the extrudate draws the cross section of the part. When the first layer is completed, the base platform moves downward along the Z (growth) direction (or, vice versa, the printhead moves upward), and a second layer is added on top of the previous one. The process is then repeated layer by layer until completion of the desired 3D geometry [10]. The technical specifications of the 3D printer are shown in Table 2.

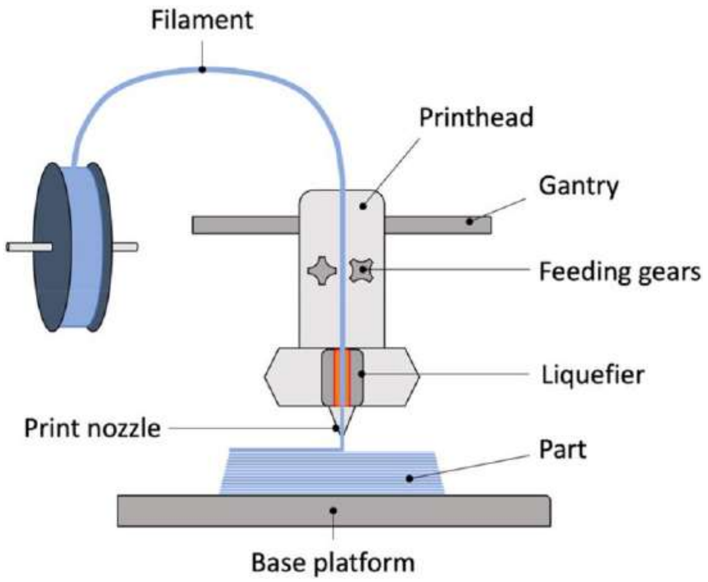

Fig. 4. – Schematic representation of an FFF printer

Table 2. Technical specifications of the Designer Classic 3D printer

№	Name of the parameter	Value
1	Printing technology	Fused Filament Fabrication (FFF)
2	Printing area, mm	201 x 201 x 210
3	Printing speed, cm^3/h	Up to 100
4	Minimum layer thickness, mm	0.01 mm
5	Diameter of the plastic thread, mm	1.75±0.1
6	Nozzle diameter, mm	0.5 mm (0.2 – 0.8 mm)
7	Printing material	PLA, PVA, ABS, PETG, TPE, SEBS etc.
8	Printing temperature, ºC	Up to 250
9	Platform temperature, ºC	150
10	Software	Polygon X

In the process of manufacturing a part on a 3D printer, the following time costs were experimentally recorded for the entire production process (Table 3).

Table 3. Numerical values of time spent during the manufacture of a part by 3D printing

No.	Name of the parameter	Value
1	Creating a digital model, min	60
2	Exporting a 3D model to STL format, min	3
3	G-code generation, min	3
4	Preparing the 3D printer for operation, min	40
5	3D model printing, min	132
6	Finishing of the part, min	60
	Total, min	298

If 100% of the total time spent from the beginning of the creation of the digital model to the finishing of the part is taken into account, then the distribution of time costs has the form shown in Fig. 5.

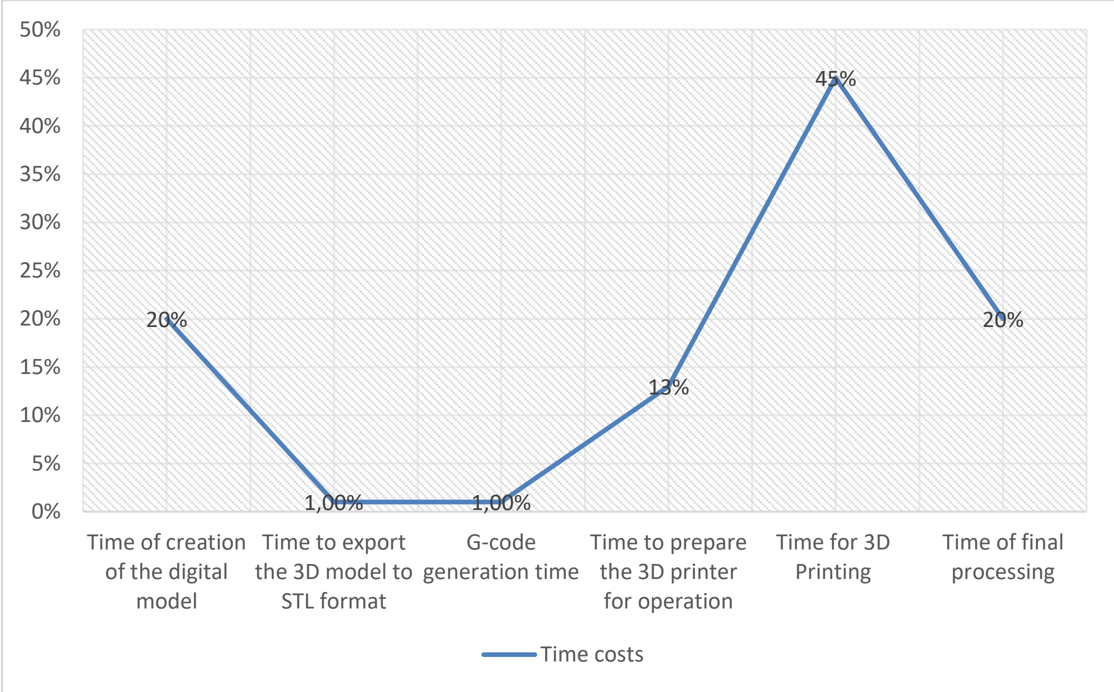

Fig. 5. – Time spent on the process of manufacturing a part by 3D printing

According to Fig. 5, the longest stage in the manufacture of a part is the stage of direct 3D printing of the part.

To conduct a comparative analysis of time costs, we will also consider the manufacture of a part in the traditional way – by milling on a CNC machine.

As can be seen from Table 1, the milling process on a CNC machine includes several important steps:

– Development of the control program;

– Preparation of the CNC machine;

– Manufacturing of the part.

For milling on a CNC machine, the same digital model was adopted, which is shown in Fig. 2. Next, it is necessary to develop a control program for the CNC. Currently, there are 2 ways to write control programs for CNC machines:

1. The manual method.

2. Development of control programs using automated CAD/CAE/CAM systems.

The manual method of developing a control program is impractical when developing a program for manufacturing parts of complex geometry.

To calculate the time to create programs to start the milling process on a CNC machine, we will use the Standard Time standards for preparing control programs for CNC machines using a computer (hereinafter – standard). According to the standard, the manufactured part belongs to the group of complexity of technological operations – 6.

Before programming, it is necessary to develop a technological process for processing a part on a CNC milling machine, which includes the following types of work:

– studying the drawing of the part, linking the projected technological operation with the functionality of the machine;

– choosing the optimal variant of the technological operation;

– selection of the basing scheme, technological equipment, cutting, measuring and auxiliary tools;

– drawing up and drawing a sketch of the processing and adjustment scheme with the calculation of tool departures;

– rationing of the technological operation;

– development of operational technology;

– control of technological preparation, standard control [11].

Based on the data in Table 3 [11], 14.07 hours are spent to develop the technological process of processing a part belonging to the complexity group 6.

Next, it is necessary to encode information for input into the CNC system (CP for a CNC milling machine), which includes the following types of work:

- construction of a mathematical model of the workpiece;

- building a technological model of the projected operation;

- development of the CP;
- CP control.

Based on the data in Table 7 [11], 3.41 hours are spent to encode information, 0.53 hours are spent to control the control program (Table 12 [11]). The total time spent on CNC programming is 18.01 hours.

According to table 14 [11], it takes 5.2 hours to debug the control program on a CNC machine. Debugging includes the following types of work:

- verification and control of compliance of the machine setup and the developed technological documentation (selection and installation of cutting, measuring and auxiliary tools, installation of the device and the workpiece);
- working out the control program on the machine outside the part and making the necessary changes;
- processing of the part in frame-by-frame mode, monitoring and making necessary changes [11].

As a result of computer modeling of milling in NX [12], it was found that the average milling time on a CNC machine of the part under study is 235 minutes (on both sides), quality control is 30 minutes. The part is not subjected to final processing

In the process of manufacturing a part on a CNC machine, the following time costs were analytically recorded for the entire production process (Table 4). If we take the total time spent from the beginning of the design of the model to the finishing of the part as 100%, then the distribution of time costs has the form shown in Fig. 6.

Table 4. Numerical values of time spent during the manufacture of a part by milling

No.	Parameter	Value
1	Model design, min	60
2	CNC programming, min	1081
3	Machine preparation, min	312
4	Milling of the workpiece, min	235
5	Quality control, min	30
6	Finishing of the part, min	0
	Total, min	1718

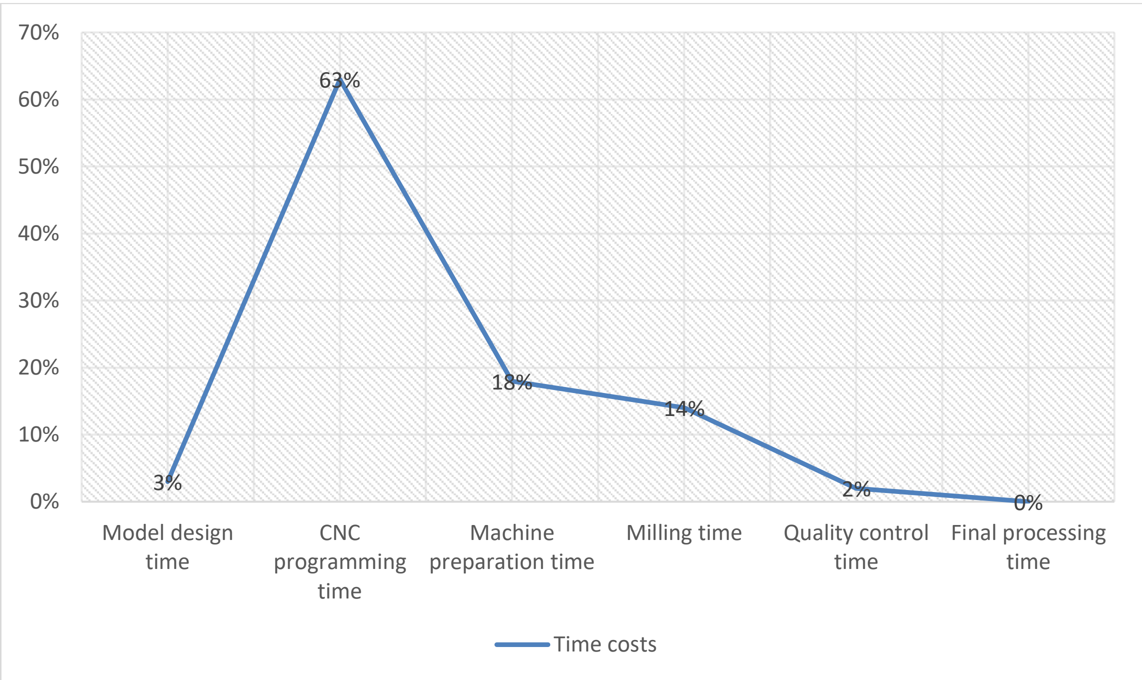

Fig. 6. – Time spent on the process of manufacturing a part by milling

According to the data shown in Fig. 6, the longest stage in the manufacture of a milling part is the programming stage of the control program for a CNC machine.

When using 3D printing to manufacture a part, the main work is done by the designer and the operator of the 3D printer. While the milling process requires qualified employees: a designer, a technologist, an adjuster and a machine operator. This means that choosing milling instead of 3D printing requires additional labor costs for qualified specialists, which may affect the economic side of the issue.

Conclusions

As a result of the analysis of empirical and analytical data, it was found that the most time-consuming operations are the following:

- in the process of 3D printing, the main amount of time (45% of the total process time) is spent directly on the printing process of the part;
- in the milling process, the largest share of time (63% of the total process time) is occupied by the development of a control program for a CNC machine.

The study showed that the preparation and completion time of the milling process (1718 minutes) exceeds the time spent on the 3D printing process (298 minutes) by 5.76 times. This is due to the fact that the main efforts during milling are aimed at developing a control program and initial setup of the machine, which makes the use of milling unprofitable in conditions of single and repair production.

References

[1] Melloy R.A. Konstruirovaniye plastmassovykh izdeliy dlya lit'ya pod davleniyem / per. s angl. yaz. pod. red. V.A. Braginskiy, Ye.S. Tsobkallo, G.V. Komarova – SPb.: Professiya, 2006. - 512 s.

[2] Gao, W., et al., The status, challenges, and future of additive manufacturing in engineering. Computer-Aided Design, 2015. 69. - P. 65-89.

[3] Guan Yunqin. Application of 3D printing technology in 3D modeling course [J]. Quality Education in West China, 2018 (6): 169

[4] Kianoush Haghsefat, Liu Tingting. 3D Printing and traditional manufacturing technology analysis and comparison

[5] Gausemeier, J., et al., Thinking ahead the Future of Additive Manufacturing–. Future Applications, 2011.

[6] Novikov S. V., Ramazanov K. N. Additive technologies: state and prospects : textbook [Electronic resource] / Ufa State University. aviac. tech. Ufa University: UGATU, 2022.

[7] P.P. Serebrenitsky. Rapid prototyping technologies // Rhythm. – 2008, № 6 (36). – p. 27

[8] C.K. Chua, C.H. Wong, W.Y. Yeong, 4 – software and data format, in: Standards, Quality Control, and Measurement Sciences in 3D Printing and Additive Manufacturing, Academic Press, Elsevier, London, UK – San Diego, CA, United States – Cambridge, MA, United States – Kidlington, Oxford, UK, 2017, pp. 75–94.

[9] L. Koester, H. Taheri, L.J. Bond, D. Barnard, J. Gray, Additive manufacturing metrology: state of the art and needs assessment, AIP Conf. Proc. 1706 (2016).

[10] L.S. Moura, G.D. Vittoria, A.H.G. Gabriel, E.B. Fonseca, L.P. Gabriel, T.J. Webster, E.S.N. Lopes, A highly accurate methodology for the prediction and correlation of mechanical properties based on the slimness ratio of additively manufactured tensile test specimens, J. Mater. Sci. 55 (2020) 9578–9596.

[11] Typical time standards for the preparation of control programs for CNC machines using a computer: approved The Central Bureau of Labor Standards of the USSR State Committee. – Moscow, 1991. – 43 p.

[12] Vedmid P.A., Sulinov A.V. Programming processing in NX CAM. – M.: DMK Press, 2014. – 304 p.: ill. ISBN 978-5-97060-143-3

[13] Savelyeva N.A., Zhetessova G.S., Ibatov M.K., Nikonova T.Yu., Reshetnikova O.S., Berg A.S., Berg A.A., Yassakov Yu.D. Prerequisites for developing a technological preparation database of small- and medium-scale machine-building industries //Material and mechanical engineering technology

Information of the authors

Zhetessova Gulnara Santaevna, d.t.s., professor, Karaganda Abylkas Saginov Karaganda Technical University
e-mail: zhetesova@mail.ru

Škamat Jelena, d.t.s., associate professor, Vilnius Gediminas Technical University
e-mail: jelena.skamat@vilniustech.lt

Tattimbetova Gulim Bolatovna, doctoral student, Karaganda Abylkas Saginov Karaganda Technical University
e-mail: tattimbetova@mail.ru

Mateshov Arman Karievich, Senior lecturer, Karaganda Abylkas Saginov Karaganda Technical University
e-mail: makashka_m@mail.ru