Istraživanja i projektovanja za privredu
ISSN 1451-4117
DOI:10.5937/jaes0-51243
www.engineeringscience.rs

publishing

Journal of Applied Engineering Science
Vol. 22, No. 4, 2024
Original Scientific Paper
Paper number: 22(2024)4, 1237, 739-745

STRENGTH STUDY OF MACHINE TOOL BEDS WITH CURVILINEAR STIFFENERS FROM POLYMER CONCRETE

Berg Alexandra[1], Nurzhanova Oxana[1]*, Berg Andrey[1], Zharkevich Olga[1], Nikonova Tatyana[1], Yurchenko Vassiliy[1], Taimanova Gulnara[2]

[1] Abylkas Saginov Karaganda Technical University, Mechanical Engineering and Standardization, Department of Technological Equipment, Karaganda, Kazakhstan
[2] Al-Farabi Kazakh National University, Faculty of Physics and Technology, Department of Thermal Physics and Technical Physics, Kazakhstan

** nurzhanova_o@mail.ru*

This study addresses enhancing the strength of metal-cutting machine tool beds made from polymer concrete by optimizing the internal cross-section design through spiral stiffeners. Key factors influencing the bed's strength include the composite preparation technology, the mixing speed (600 - 800 rpm), and duration (3 - 4 minutes). A strong correlation exists between spiral pitch, mixing speed, mixing time, and the bed's strength.

Keywords: strength, helix, curved ribs, stiffness, composite

1 INTRODUCTION

The main challenge for mechanical engineering in the period of Industry 4.0 is to integrate new materials, technologies and digital innovations into production processes. Increased strength metal cutting machines are better integrated with monitoring systems, predictive analytics and other digital solutions to optimize production processes. Also, strength-enhanced machine tools are able to withstand the stresses of adaptive technologies such as self-adjusting tools and intelligent control systems. This improves product quality and reduces production costs, contributes to the creation of efficient competitive equipment and does not require large investments.

Machine tool beds are responsible elements in the production of high-quality parts in machine building.

Nowadays, machine tool beds are made of cast iron [1, 2] and composite materials, so-called polymer concretes [3, 4]. Machine elements made of steel and cast iron do not meet the requirements, as they have low vibration resistance and cannot maintain dimensional stability for a long time [5, 6]. Machine elements made of polymer concrete have the following advantages over the traditionally used cast iron: increased vibration resistance, increased rigidity, reduced deflection, high damping capacity, and corrosion resistance [7, 8, 9, 10].

The design forms of connecting the guides to the bed walls can significantly affect the balance of elastic movements of the machine tool, as well as the natural stresses in the castings due to non-uniform cooling of the bed walls and guides [11]. The beds of metal-cutting machine tools, as a rule, are made of two walls with partitions. Usually the walls have a T-shaped, and the partitions have a T- or U-shaped cross-section. In the lower part of the walls, as well as at the level of the upper end of the partitions, there are flanges, which increase the rigidity of the walls [12].

Currently, there is a tendency to reduce the material intensity of structures [13]. Since the beds of metal-cutting machines have a large weight, it is necessary to reduce their material intensity with a simultaneous increase in the specific strength of structures.

Also important in the selection of polymer concrete composition is the selection of binder elements [14].

In order to obtain improved strength and elastic characteristics of cured polymer concrete, it is necessary first of all to ensure that the mixture is homogeneous [15].

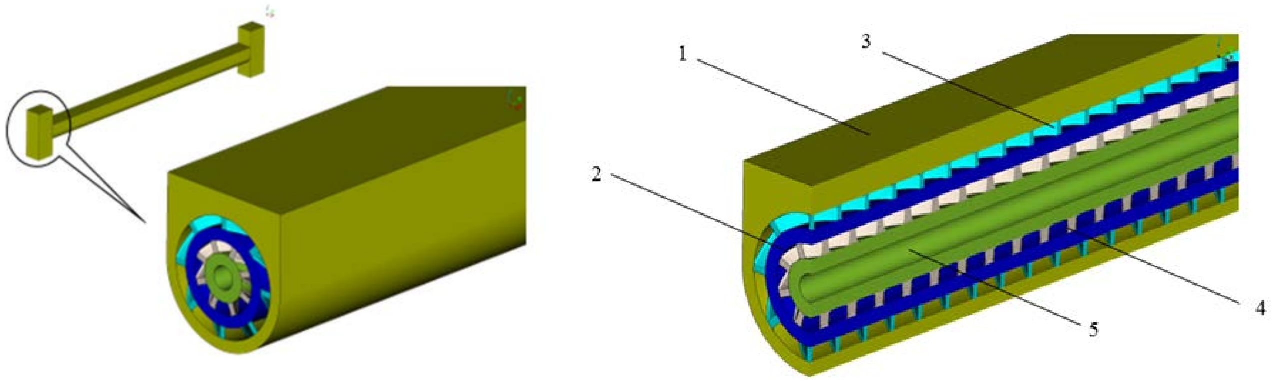
Another important point for obtaining strong beds from polymer concrete is the technology of their fabrication. Adjusting the mixing time of the mixture and the rotation speed of the mixer makes it possible to obtain an easy-moving mixture capable of completely filling the space of the mold without changing the structure [16].

Thus, the purpose of this study is to determine the optimal geometric configuration and technological parameters for manufacturing machine tool beds made from polymer concrete to maximize strength and performance in metal-cutting machine tools.

2 MATERIALS AND METHODS

2.1 Modeling of the research object

Figure 1 shows the developed bed of a metal cutting machine made of polymer concrete with curvilinear stiffeners [17].

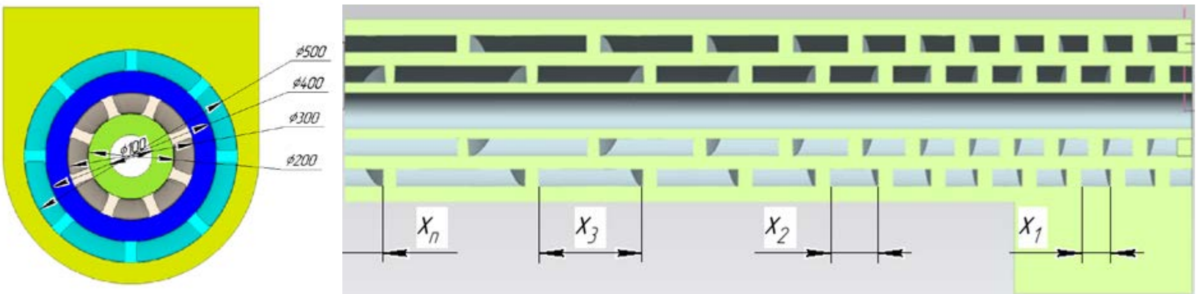


1 - structural profile of the bed; 2 - longitudinal cylinder 1; 3 - curved stiffening rib 1, 4 - curved stiffening rib 2, 5 - longitudinal cylinder 2

Fig. 1. Bed design with curvilinear stiffeners

The structural profile of the bed (1) with an internal cavity is formed by two longitudinal cylinders of different diameters (2, 5), paired with transverse curvilinear stiffeners (3, 4), twisted along the axis in the form of a spiral.

Geometric dimensions of the bed of a metal-cutting machine made of polymer concrete with curvilinear stiffeners are shown in Figure 2.



x1, x2, …xn – helix pitch

Fig. 2. Geometric dimensions of the bed of a metal-cutting machine tool

The developed geometry of the metal-cutting machine bed is able to increase the resistance of the structural profile to longitudinal bending and torsional loading. The proposed design of the metal-cutting machine bed on the basis of curvilinear stiffeners provides greater rigidity and resistance to vibrations. The use of polymer concrete, as the main component of manufacturing of long parts, allows to significantly increase the stability of the load-bearing system of the machine tool and as a consequence increases the accuracy of machining in 1.5 - 2 times. The specified technical result is achieved due to the location of a spiral with variable pitch inside the bed profile.

2.2 Modeling of the research object

The composition for polymer concrete was used for the experiment, the elements of which are summarized in Table 1.

Table 1. Composition of polymer concrete №15 [18]

Constituents	Composition consumption	Composition consumption	
		%	kg/m^3
Sand: quartz gabbro	0,14 – 1,25	31,0 – 55,0	1145 – 1165
Filler	0,14	26,5 – 27,5	560 – 580
Epoxy resin ED - 20	–	8 – 9	170 – 190
Furan resin	–	8 – 9	170 – 190
Polyethylene polyamine	–	3,2 – 3,6	68 – 76

Mechanical properties of polymer concrete (composition №15) are given in Table 2.

Table 2. Main mechanical parameters (composition №15) [18]

Parameter	Value
Tensile strength, MPa	$R_m = 120$
Yield strength, MPa	$Rp_{02} = 90$
Roughness	$R_z = 200$

2.3 Research Methods

To evaluate the strength of the polymer concrete bed, a full-factor experiment was conducted with a plan: N=2k, where k – number of factors, 2 – number of levels [19].

Correlation analysis was used to determine the relationship between the strength of the polymer concrete bed and the rotational speed of the working oragan, the mixing time of the polymer concrete mixture components and the spiral pitch inside the bed section.

To assess the relationship between factor and response, the linear correlation coefficient was calculated [20]:

$$r_{xy} = \frac{\overline{xy} - \overline{x}\overline{y}}{s(x)s(y)} \quad (1)$$

where s(x), s(y) – standard deviations for y and xi;

x¯, y¯- arithmetic mean values of factors and response.

The average approximation error was calculated by the formula [21]:

$$A = \frac{\sum\left|\frac{\varepsilon}{Y}\right|}{n} \cdot 100\% \quad (2)$$

where ε - absolute approximation error;

Y – response value;

n – number of experiments.

The machine tool beds from polymer concrete were subjected to simulated loading conditions to assess their performance under typical operational stresses. The spiral stiffeners were modeled with variable pitches to determine the effect on load distribution and bed rigidity.

3 MATERIALS AND METHODS

3.1 Investigation of the influence of speed mode on the strength of polymer concrete bed

The rotation frequency of the mixer's working body provides effective distribution of polymer concrete mixture components with their uniform placement in the entire volume. This allows to obtain polymer concrete with guaranteed characteristics. As a result of the experiment, it was found that the optimum is considered the rotation frequency of the working body of the mixer 600 - 800 r / min.

At these speeds, the mixed mass is thrown to the walls of the container and "blown out". During subsequent casting, not all bubbles are released from the mixture during vibration compaction, and, consequently, the live section of the samples decreases [22].

After statistical processing of the experimental results, the regularity of the influence of the rotation frequency of the mixer working body (n) on the strength of polymer concrete (σ) was obtained (Figure 3).

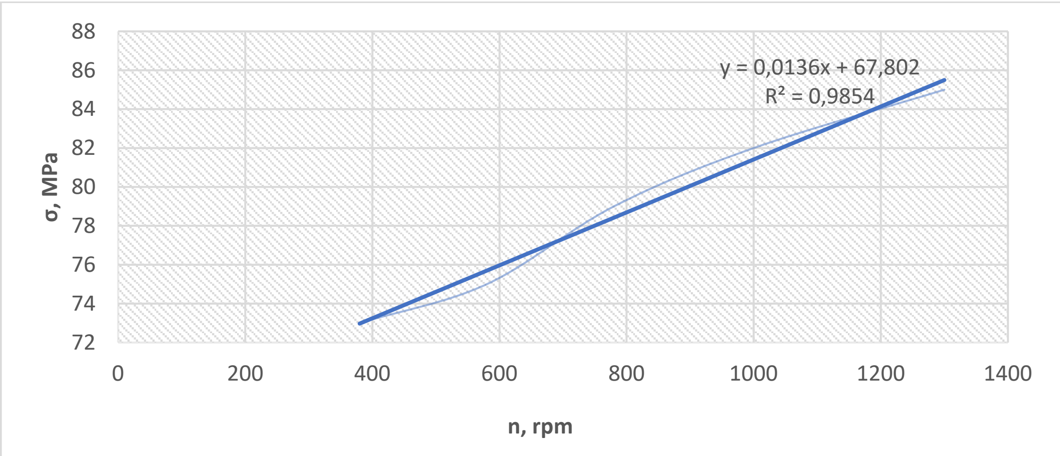


Fig. 3. Dependence of the rotation frequency of the mixer on the strength of polymer concrete

The analysis of the obtained regularity allows us to conclude that the strength of polymer concrete increases in proportion to the increase in the rotation frequency. This is explained by homogenization of the mixture, which provides isotropy of the hardened polymer concrete. However, to obtain the required strength of polymer concrete at stresses of 75...80 MPa, a rotation frequency of 600...900 rpm is sufficient. In this case, the safety factor of the bed is 1.6.

Further increase of rotation frequency will lead to overconsumption of electric power and increase the cost of polymer concrete.

Technological processes for mixing polymer concrete components for metal-cutting machine beds are important for scalability of production, when moving from laboratory experiments to industrial production. This implies maintaining the quality of the material while increasing production volumes.

3.2 Influence of mixing time of components on strength characteristics of polymer concrete

One of the most important factors affecting the quality of polymer concrete mixture is mixing time. Taking into account the difference in the characteristics of the starting materials, it should be sufficient for uniform placement of all components in the volume of the mixture. This will ensure its homogeneity, which in turn makes it possible to rationally place it in the molds without the formation of internal voids (sinks) that remove the strength of hardened polymer concrete. According to the results of statistical processing of the mixing time of polymer concrete mixture (t), Figure 4 shows the regularity of influence on the strength of hardened polymer concrete (σ).

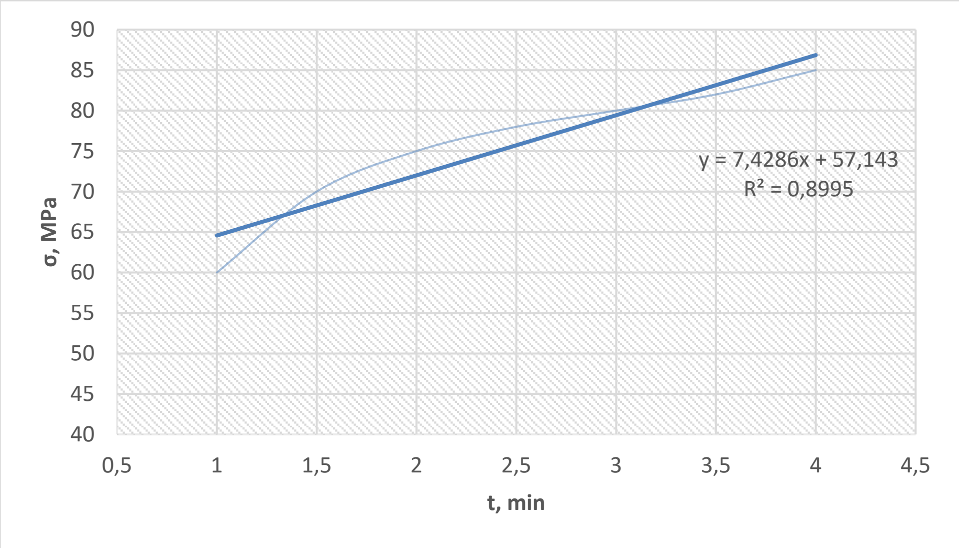


Fig. 4. Dependence of cured polymer concrete strength on mixing time of components

Analysis of experimental results showed that mixing time of 3 ÷ 4 min is quite enough to achieve the required strength of polymer concrete for the manufacture of profiles of beds. Further mixing time does not lead to a significant increase in strength, so it is irrational to increase it [23].

Compliance with technological mode (mixing time) at all stages of the production of polymer products (from mixing to curing) is a guarantee of high quality of the finished product.

3.3 Influence of bed spiral pitch on strength characteristics of polymer concrete bed

Due to the variable spiral pitch in the cross-section of the polymer concrete bed, it is possible to strengthen the structure in dangerous sections by reducing the pitch of the turns and increasing the pitch in places where the bed is not subjected to loads and does not experience stress.

Figure 5 shows the dependence of the polymer concrete bed strength (σ) on the spiral pitch inside its cross-section (l).

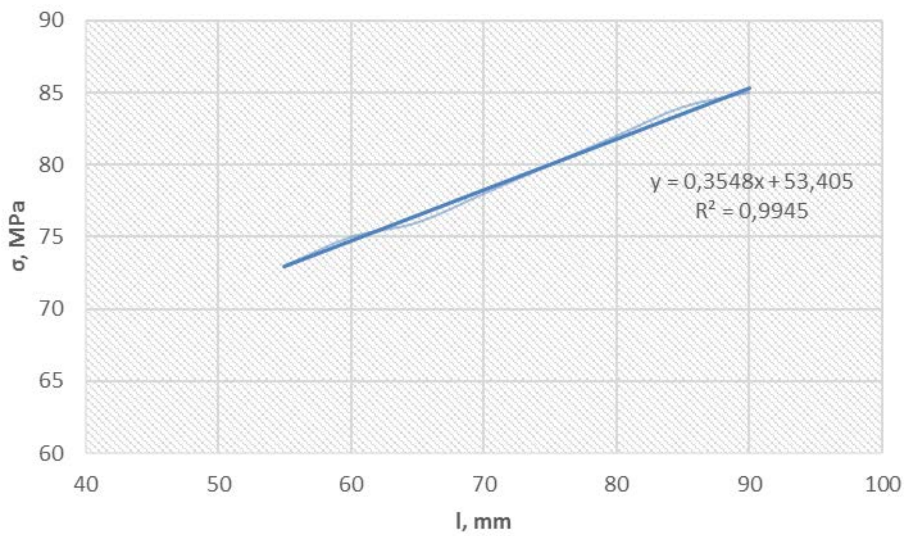


Fig. 5. Regularity of influence of spiral pitch on the strength of polymer concrete bed

The greater the spiral spacing between the stiffeners, the greater the strength of the machine bed.

3.4 Mathematical model of dependence of geometrical parameters and technological parameters of polymer concrete bed fabrication

Based on the obtained experimental data, a mathematical model (regression equation) was built using multiple regression. The regression equation describes the degree of influence of the initial parameters of the spiral pitch in the bed body (X1) and technological parameters of polymer concrete production: the rotation speed of the mixer working body and the mixing time of the mixture components on the strength of the polymer concrete bed (response Y). Input data for determining the mathematical model are presented in Table 3.

Table 3. Factor and response parameters

№ experience	Spiral pitch in cross-section, mm (X1)	Rotational frequencies of the mixer working body, rpm (X2)	Mixing time, min (X3)	Strength, MPa (Y)
1	90	600	2	75
2	85	350	3	73
3	80	750	4	78
4	75	1000	13	82
5	70	650	5	76
6	65	850	6	80
7	60	1300	14	85
8	55	1200	8	84

When conducting correlation analysis, a strong dependence of influencing geometric and technological parameters of polymer concrete bed fabrication on its strength was revealed.

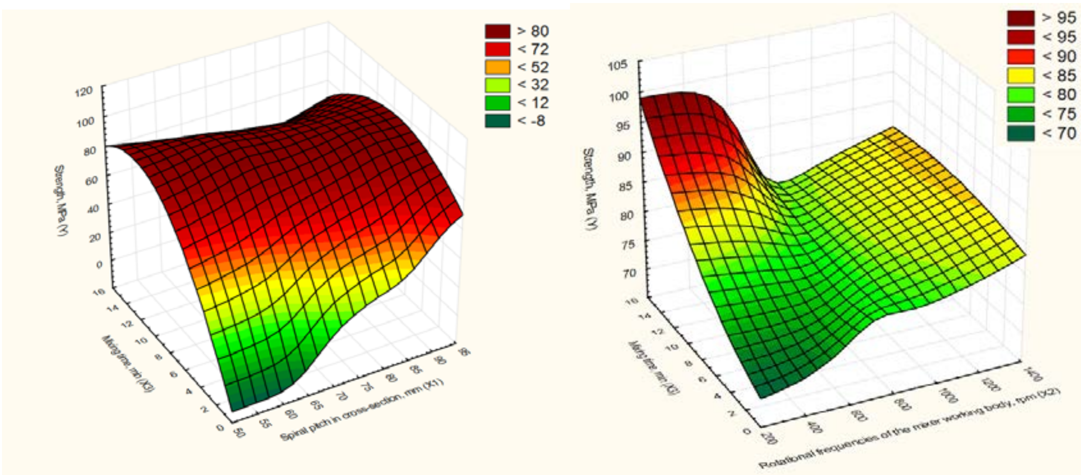
To assess the relationship between the studied parameters, the matrix of pair correlation coefficients R was obtained (Table 4).

Table 4. Matrix of pairwise correlation coefficients

	Y	X_1	X_2	X_3
Y		-0,823244488	0,990531242	0,856073396
X_1			-0,815621809	0,834396255
X_2				0,834396255
X_3				

Analyzing the obtained values of correlation coefficients, it follows that direct strong influence is exerted by factor (X3), inverse strong dependence with factor (X1), and the relationship between factor (X2) on Y is very strong and direct.

Graphically, the relationships between factors X1, X2, X3 and response Y are presented in Figure 4.



a) b)

Fig. 6. Dependence of strength (σ) of polymer concrete bed depending on geometric and technological parameters: a) dependence of Y on X1 and X3; b) dependence of Y on X2 and X3

The relationship between the parameters under study, can be described by the equation:

$$Y = 66,79 + 0,016X_1 + 0,011X_2 + 0,21X_3 \quad (3)$$

The evaluation criteria for reliability and adequacy of the obtained mathematical model are given in Table 5.

Table 5. Criteria for assessing the adequacy and reliability of the mathematical model

Criterion	Criterion value	Adequacy/reliability conditions	Conclusion
Average approximation error, A	1%	1 – 10 %	reliably
Correlation coefficient, R	0,9927	$R \to 1$	strong influence of Xi on Y
Coefficient of determination, R^2	0,9855	$R^2 \to 1$	
Fisher criterion, F	90,41	F > Fkp	adequately

The relationship between the spiral pitch in the cross-section, the rotation frequency of the mixer's working body during the preparation of polymer concrete, the mixing time of the mixture and the strength of the bed is quite strong. The obtained mathematical model is adequate.

The results indicate that increasing the spiral pitch enhances bed strength by improving load distribution along the structure. These findings align with previous studies that highlight the benefits of optimized internal reinforcement geometries in composite materials [15,17,18].

4 CONCLUSIONS

The study concludes that optimal strength for machine tool beds made from polymer concrete is achieved with a mixer rotation frequency of 600-900 rpm, a mixing time of 3-4 minutes, and a spiral pitch of 60-75 mm. This combination maximizes bed rigidity and vibration resistance, which are critical for precision in metal-cutting operations. Future research should explore the long-term durability and fatigue resistance of these optimized designs under operational conditions.

5 ACKNOWLEDGEMENT

The article was prepared within the framework of realization of the grant of NAO “Karaganda Technical University named after Abylkas Saginov” for young scientists, agreement №3 from 07.06.2024.

6 REFERENCES

[1] Kumar, R., Jain, A., Mishra, S. K., Joshi, M., Singh, K., & Jain, R. (2021). Comparative structural analysis of CNC milling machine bed using Al-SIC/graphite, Al alloy and Al-SIC composite material. Materials Today: Proceedings, vol. 51, Part 1, 735-741 DOI: 10.1016/j.matpr.2021.06.219

[2] Kępczak, N., PawłowskI, W., Kaczmarek, Ł. (2015) Cast iron and mineral cast applied for machine tool bed - dynamic behavior analysis. Archives of metallurgy and materials, vol. 60, issue 2, 1023-1029, DOI: 10.1515/amm-2015-0254

[3] Srinivasan, S., Subramanyam, B. (2016) Design and Structural Analysis of CNC Milling Machine Bed with Composite Material. Imperial Journal of Interdisciplinary Research (IJIR), vol. 2, issue 12, 147-151 ISSN: 2454-1362, http://www.onlinejournal.in

[4] Ma, Ya., i Li, F., Wang, L., Wang, G., Kong, L. (2021) Life cycle carbon emission assessments and comparisons of cast iron and resin mineral composite machine tool bed in China, vol. 113, 1143 - 1152 DOI: 10.1007/s00170-021-06656-9

[5] Shukla, A., Singh, D. (2018) Design and analysis of machine tool bed JETIR September 2018, vol. 5, issue 9, 580 – 588 ISSN-2349-5162, www.jetir.org

[6] Cortés F., Castillo, G. (2007) Comparison between the dynamical properties of polymer concrete and grey cast iron for machine tool applications. Materials & Design, 28(5), 1461-1466 DOI: 10.1016/j.matdes.2006.03.012

[7] Haddad H., Kobaisi M. (2012) Optimization of the polymer concrete used for manufacturing bases for precision tool machines, Composites Part B: Engineering, vol. 43, issue 8, 3061-3068, DOI: 10.1016/j.compositesb.2012.05.003

[8] Dunaj, P., Dolata, M., Tomaszewski, J., Majda, P. (2022) Static stiffness design of vertical lathe with steel-polymer concrete frame. The International Journal of Advanced Manufacturing Technology, 121(2), DOI: 10.1007/s00170-022-09391-x

[9] Bedi, R., Chandra, R., Singh, S. Reviewing some properties of polymer concrete (2014) The Indian Concrete Journal, vol. 88, issue 8, 47-68

[10] Jiangmin, D. The new shape forming technology of composite concrete machine tool beds (2010) International conference on mechanic automation and control engineering DOI: 10.1109/MACE.2010.5536583

[11] Murugan S., Thyla, P. (2015) Investigation on dynamic analysis of VMC bed using epoxy composite carbon, Sci. Tech, 7/4, 66-75 ISSN 0974 – 0546, http://www.applied-science-innovations.com

[12] Lia, B., Honga, J., Wanga, Z., Wua, W., Chen, Y. (2012) Optimal design of machine tool bed by load bearing topology Identification with weight distribution criterion Procedia CIRP 3, 626 – 631 DOI: 10.1016/j.procir.2012.07.107

[13] Lucchetta, G., P. Bariani, F. (2010) Sustainable design of injection moulded parts by material intensity reduction. CIRP Annals, 59(1), 33-36 DOI: 10.1016/j.cirp.2010.03.092

[14] Jafari, K., Ta, M., Joshaghani, A., Ozbakkaloglu, T. (2018) Optimizing the mixture design of polymer concrete: An experimental investigation. Construction and Building Materials 167, 185-196 DOI: 10.1016/j.conbuildmat.2018.01.191

[15] Zhetessova G., Nikonova, T., Łukasz G., Berg, A.,Yurchenko, V., Zharkevich, O., Kalinin A. A Comparative Analysis of the Dynamic Strength Properties of the Long Guides of Intelligent Machines for a New Method of the Thermal Spraying of Polymer Concrete Appl. Sci. 2022, 12, 10376. doi.org/ 10.3390/app122010376

[16] Jo, B., Park, S., Kim, D. (2008) Mechanical properties of nano-MMT reinforced polymer composite and polymer concrete. Construction and Building Materials, vol. 22,.14-20 https://doi.org/10.1016/j.conbuildmat.2007.02.009

[17] Berg, A., Nikonova, T., Dandybaev E., Yesyunin, A., Yurchenko V. (2023) Frame of metal cutting machine tool made from polymer concrete with optimized geometry for processing long parts (utility model patent № 8332 of the Republic of Kazakhstan)

[18] Nikonova, T., Gierz, Ł., Berg, A., Turla, V., Warguła, Ł., Yurchenko, V., Abdugaliyeva, G., Zhunuspekov, D., Wieczorek, B., Robakowska, M., Dandybaev E. Comparative analysis of strength fatigue properties and abrasive wear resistance for a new composition of polymer concrete coated with metal alloy powders. Coatings 2023, 13, 586. https://doi.org/10.3390/ coatings13030586

[19] Sherov, K., Mardonov, B., Zharkevich, O., Mirgorodskiy S., Gabdyssalyk R., Smakova N, Akhmedov, K., Imanbaev, Y. (2020) Studying the process of tooling cylindrical gears. Journal of Applied Engineering Science, 18(3), 327–332 DOI: 10.5937/jaes18-23794

[20] Zharkevich, O., Nurzhanova, O., Zhunuspekov, D., Naboko, Ye., Buzauova, T., Abdugaliyeva, G., Mateshov, A., Bessonov, A. (2023) Determination of optimal hardfacing modes for recovering electric motor shafts. Tehnički vjesnik, 30, 3, 951-957 https://doi.org/10.17559/TV-20220719104215

[21] Zharkevich, O., Nikonova, T., Gierz, Ł., Berg, A., Berg, A., Zhunuspekov, D., Warguła, Ł., Łykowski W, Fryczyński K. (2023) Parametric optimization of a new gear pump casing based on weight using a finite element method. Applied Sciences, 13(22), 12154. https://doi.org/10.3390/app132212154

[22] Yelemessov, K., Krupnik, L., Bortebayev, S., Beisenov, B., Baskanbayeva, D. (2020) Polymer concrete and fibre concrete as efficient materials for manufacture of gear cases and pumps. E3S Web of Conferences, 168 (12), 00018 DOI: 10.1051/e3sconf/202016800018

[23] Baskanbayeva, D., Krupnik, L., Yelemessov, K., Bortebayev, S., Igbayeva, A. (2020) Justification of rational parameters for manufacturing pump housings made of fibroconcrete. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, № 5, 68 - 74 DOI: 10.33271/nvngu/20205/

Paper submitted: 27.05.2024.

Paper accepted: 17.09.2024.