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Simulation Modeling of an Inhomogeneous Medium, in Particular: Round, Triangular, Square Shapes

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Abstract. The article analyzes and develops an algorithm for the operation of the powder backfill process using vibration oscillations. The results of the study make it possible to predict the main properties of particles of any shape. The developed computer simulation model also provides for the superposition of horizontal and vertical oscillations. It should be noted that the difference between them is that the main one for the implementation of horizontal oscillations is the X-coordinate, and for vertical ones – the Y-coordinate. It is also important that the model algorithm provides for simultaneous application of vibration oscillations, which makes it possible to study the influence of the history of the backfill process. It should also be noted that in this scientific study, a number of experiments were conducted, the change in porosity during the imposition of oscillations was studied, and graphs of the obtained experimental dependences were constructed. Porosity from the main parameters of the bunker, in particular: width and height, is also studied. The obtained results made it possible to record the optimal porosity of the backfill with a reliable deviation error (±1%).

1 Introduction

One of the main directions of development today is the improvement of known and the development of new materials based on modern modelling [1, 2]. A special feature when creating such materials is that you can control their properties within a fairly wide range [3, 4]. In turn, structurally inhomogeneous materials that can have different shapes and sizes are characterized by changes in composition and properties in a given direction [5, 6]. Improving technologies for obtaining such materials with heterogeneous operational properties has always been and will always be one of the important areas of research [7, 8]. Because when obtaining such materials with guaranteed properties, it is advisable to control the parameters of their structure during the manufacturing process, which include: the density of pressing, the quality of contacts, the size of particles (grains), the shape, the content of components, etc. [9, 10, 11].

Analysis of the structures and the results of their computer modelling show [12, 13] that the blanks obtained using traditional powder metallurgy technology have significant disadvantages [14, 15]. The authors of the work [16, 17] implemented the concept of the configuration space of geometric objects, the generalized variables of which are metric and placement parameters. This is especially true for the process of filling powders, which is accompanied by the formation of additional voids - the "arched effect". The appearance of the" arched effect " leads to heterogeneity of properties within materials, and does not make it possible to obtain structural characteristics at the qualitative level [18, 19, 20]. Thus, forecasting the structural characteristics of materials using computer modelling methods, as well as those obtained as a result of a combination of technological operations with known characteristics, is an urgent task today [21, 22].

2 Main Part

The analysis of the structure of various materials, the study of sintering, extrusion and diffusion processes, as well as modelling the structure of porous systems are covered in [23, 24, 25]. The peculiarity of these works is that the process of filling molds with regular-shaped particles is considered, that is, sets of identical elements that are naturally placed in space and distributed statistically [26, 27, 28]. A universal method for the production of nanomaterials based on the use of solid-phase matrices with ordered porosity is presented by the authors [29, 30]. In turn, large-scale particles in the correct order and structure may contain smaller defects [31, 32, 33, 34], as a result of which there is a large local heterogeneity of real materials, which you need to know and be able to control [35, 36, 37, 38]. Such problems arise, for example, in powder metallurgy, when modeling optimal packages of cylindrical objects with an elliptical base [39]. Therefore, to improve the quality of the final product, it is necessary to apply vibration oscillations, which will reduce labour costs by reducing the number of technological operations, as well as study structurally heterogeneous materials and predict the porosity distribution in any configuration of the workpiece, regardless of the size and geometric parameters of the bunker [40, 41]. Therefore, computer modeling is the most promising way to verify data from experimental studies [42, 43, 44, 45, 46].
Purpose of work: create a computer simulation model of powder filling using vibrational oscillations and analyze the resulting structures.

Materials. For better filling of the mold with powder, increasing the physical and mechanical properties of the resulting products, as well as obtaining powdered porous materials with high-quality structural properties, it is possible using "vibration oscillations", which are necessary for additional compaction of the workpiece. The compaction effect consists in breaking the initial bonds between the particles and moving them relative to each other (Fig. 1).

In Fig. 1 the window of the simulation program developed by us for studying the effect of vibration oscillations on structural changes in polydisperse backfill is presented.

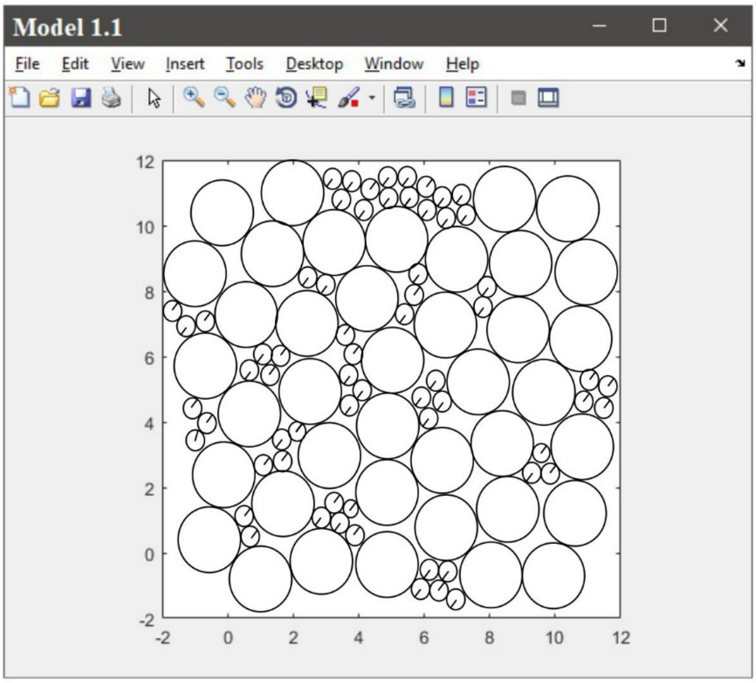

Fig. 1. Study of particles using oscillations.

The mold particle filling algorithm implements vertical and horizontal oscillations. They can be independently enabled or disabled at any time of the program's operation. The values that characterize vibration oscillations in the algorithm are: amplitude and frequency of oscillations. The structural characteristics of backfills are determined by: the magnitude of the oscillation amplitude A, the oscillation frequency W, the particle size and their percentage ratio in the charge. A variable parameter is also the period of applying oscillations. Particle sizes are set in millimeters or micrometers and do not depend on the monitor resolution. Vibration oscillation parameters can be changed using the vibration control panel. The model algorithm (Fig. 2) provides that the procedures for applying horizontal and vertical vibration oscillations are similar. The difference between them is that the main one for implementing horizontal oscillations is the X-coordinate, and for vertical ones – the Y-coordinate. The model assumes the possibility of simultaneous implementation of horizontal and vertical oscillations. The ratio of horizontal and vertical oscillations that are superimposed on the process simultaneously makes it possible to study the influence of the history of the backfill process.

The diagram of the algorithm for working using oscillations is shown in (Fig. 2).

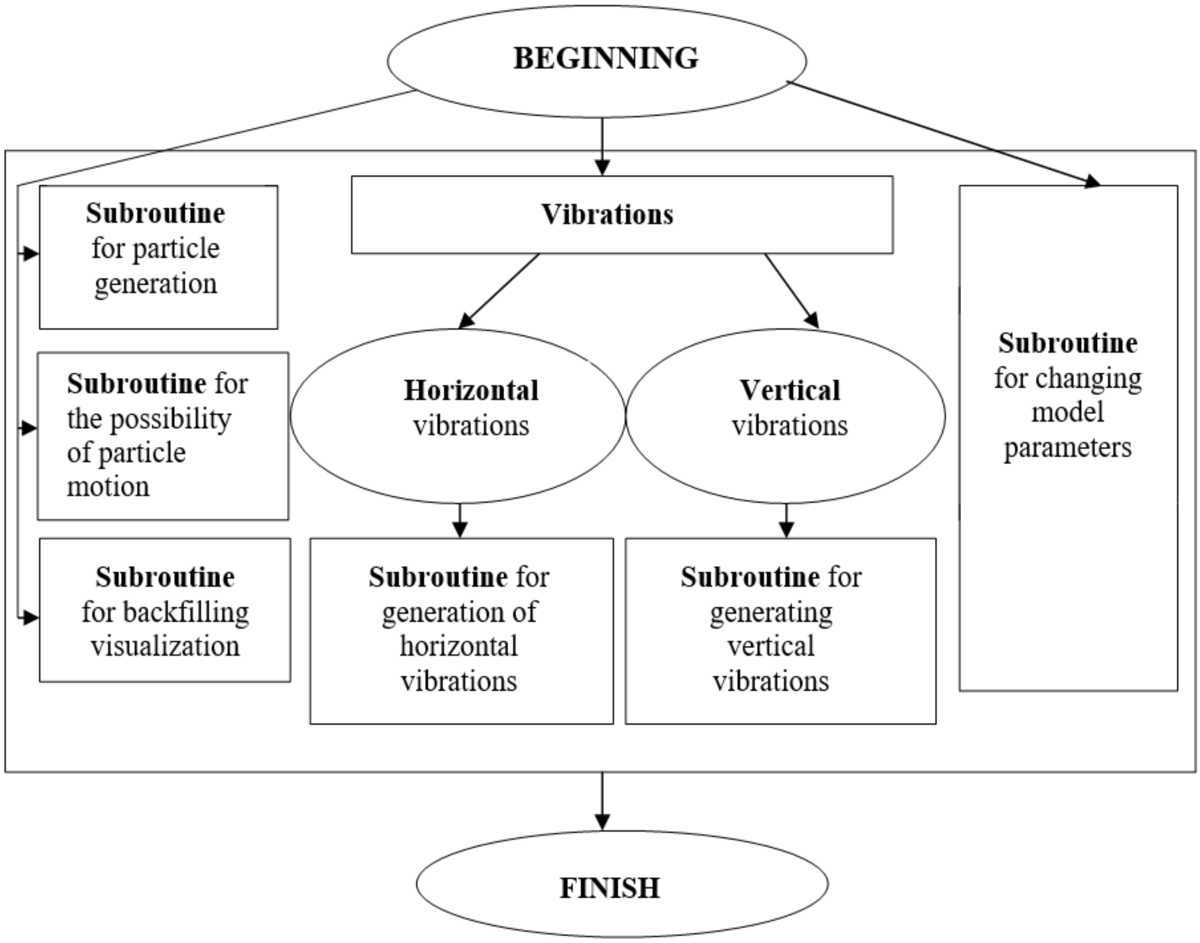

Fig. 2. Scheme of the work algorithm.

Tests. Based on the developed computer simulation model for studying the effect of vibration oscillations on structural changes in polydisperse backfill is presented. For an example of the model's operation, powder backfilling is given when using vibration oscillations. Also, researched Results of experimental porosity after applying vibrational oscillations. The obtained results show an insignificant effect of particle diameters on porosity. Also, researched influence of technological parameters on changes in porosity. It was found that, a width and height, has a very weak effect on the porosity of the backfill. Therefore, it was decided to fix the parameters of the 800×800 mm bunker during further research.

For an example of the model's operation, powder backfilling is given when using vibration oscillations. Backfill was carried out in a square bunker measuring 600 by 600 mm. The value of the angle α, was 10°, which characterizes the coefficient of internal friction of the particles. Vibration oscillations were applied for 5-10 minutes. The oscillation frequency was constant and was 2 oscillations per second. The initial parameters and results are shown in Table 1.

From the obtained results, a graph of the obtained dependencies was constructed, which is shown in (Fig. 3).

Also, for an example of the operation of the model, the filling of powders with the use of vibration oscillations is given. Filling was carried out in a square bunker measuring 800 by 800 mm. The value of the angle α was 10°. The size of the particles (diameter, D) varied from 5 mm to 25 mm. Vibration oscillations were applied for 5 minutes. The oscillation frequency was constant and equal to 2 oscillations per second. The initial parameters and obtained results are shown in Table 2.

Table 1. Results of experimental porosity after applying vibrational oscillations

D [mm]	**Porosity after vibration oscillations [%]**
5	12
8	13.7
10	16
13	18
15	19
18	22
20	24
22	25.5
25	28

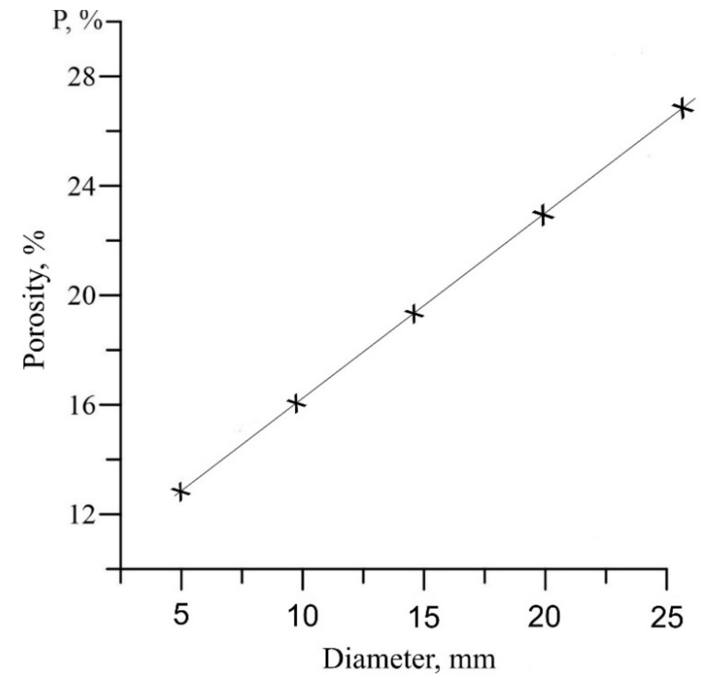

Fig. 3. The influence of vibrational oscillations on changes in porosity.

Table 2. Porosity results when superimposing vibrational oscillations

D [mm]	Initial porosity [%]	Porosity after vibrational oscillations [%]
5	12.2	12
8	14	13.7
10	16	15.7
12	18.9	18
15	20	19
18	22	21.2
20	24	23.5
22.5	26.5	25
25	30	28

From the obtained results, a graph of the obtained dependencies was constructed, which is shown in (Fig. 4).

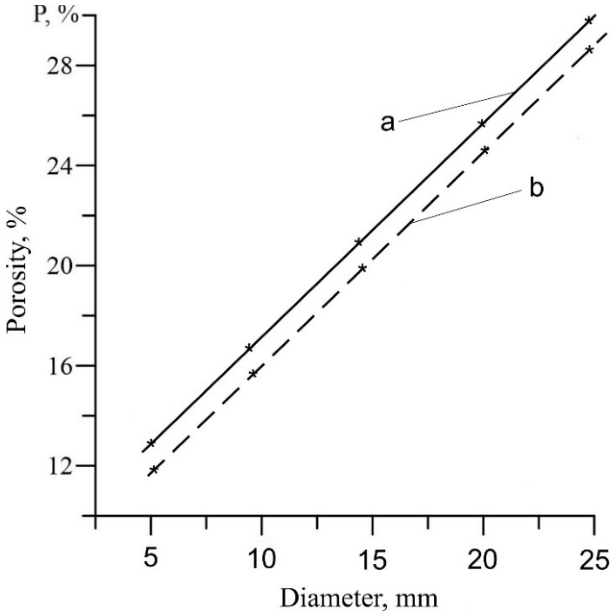

Fig. 4. Influence of technological parameters on changes in porosity, where:
a – porosity according to traditional technology; b – porosity using vibrational oscillations.

It should also be noted that the porosity was investigated from the main parameters of the bunker, in particular: width and height. For the experiment, the following parameters were set: the particle size was 10 mm, 20 mm and 30 mm. The experimental porosity ranged from 5 % to 30 %. The width of the bunker was 200 mm, 400 mm, 600 mm, 800 mm and 1000 mm. And the height of the bunker was constant and was equal to 800 mm. Experimental results of porosity from bunker parameters are presented in Table 3.

Table 3. Experimental results of porosity from bunker parameters

Porosity [%]	Width of bunker [mm]	Height of bunker [mm]
5	200	800
10	400	800
15	600	800
20	800	800
25	1000	800
30	1000	800

Fig. 5 presents the experimental results of porosity from the main parameters of the bunker (width and height) and modelling of elements of different sizes.

It should be noted that further growth of bunker parameters, in particular width and height, has a very weak effect on the porosity of the backfill. Therefore, it was decided to fix the parameters of the 800×800 mm bunker during further research.

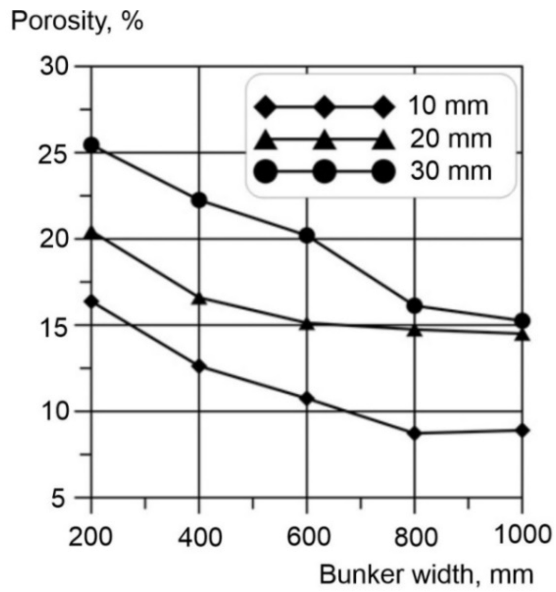

Fig. 5. Experimental results of porosity from bunker parameters.

3 Conclusion

Based on the developed simulation model and its implementation algorithm, it is possible to study changes in the structure of an inhomogeneous medium in a wide range of technological parameters. The use of the model makes it possible to reduce labour costs by reducing the number of technological operations, as well as to study structurally heterogeneous materials and predict the porosity distribution for any configuration of elements (round, triangular, square), regardless of the size and geometric parameters of the bunker. It should also be noted that the developed computer simulation model allows solving the following main tasks:

1) to study the main properties of forming products with different structures based on the analysis of the compaction process of structurally inhomogeneous materials (monodisperse and polydisperse inhomogeneous media);

2) to investigate the process of changing the structure of an inhomogeneous medium during the transition from a static to a vibrational state using modelling methods;

3) to model a mathematical model of the behaviour of elements, in particular: round, triangular, square shapes when using vibrational oscillations;

4) to calculate the main coefficients of the simulation model, their variances, covariances and confidence intervals at the qualitative level;

5) predict the basic properties of a structurally inhomogeneous medium with a reliable deviation error (±1 %).

References

[1] Deb. Apurba Kanti, P. Chatterjee, Study of deformation microstructure of nickel samples at very short milling times: effects of addition of α-Al2O3 particles, Journal of Theoretical and Applied Physics, 13 (2019) 63–73.

[2] A.V. Kondratiev, V.E. Gaidachuk, Mathematical analysis of technological parameters for producing superfine prepregs by flattening carbon fibers, Mechanics of Composite Materials, 57, 1 (2021) 91–100.

[3] N. Vijay Ponraj, A. Azhagurajan, S. Vettivel, Microstructure, consolidation and mechanical behaviour of Mg/n-TiC composite, Alexandria Engineering Journal, 55 (2016) 2077–2086.

[4] V. Pasternak, O. Zabolotnyi, N. Ilchuk, D. Cagáňová, Y. Hulchuk, Improvement of processes for obtaining titanium alloys for manufacturing parts with design elements, Lecture Notes in Mechanical Engineering, (2022) 323–333.

[5] W. Kang, T. Peng, Yi. Huang, Z. Yanjun, Li. Wenfang, J. Tian, Characterization of microstructures and tensile properties of recycled Al-Si-Cu-Fe-Mn alloys with individual and combined addition of titanium and cerium, Hindawi. Scanning, 34 (2018) 1–14.

[6] V. Pasternak, L. Samchuk, N. Huliieva, I. Andrushchak, A. Ruban, Investigation of the properties of powder materials using computer modeling, Materials Science Forum, 1038 (2021) 33–39.

[7] K. Leong, S. See, J. Lim, L. Tham, Effect of process variables interaction on simultaneous adsorption of phenol and 4-chlorophenol: statistical modeling and optimization using RSM, Journal of Theoretical and Applied Physics, 7 (2017) 2009–2020.

[8] Y.Danchenko, V.Andronov, E. Barabash, T. Obigenko, E. Rybka, R. Meleshchenko, A. Romin, Research of the intramolecular interactions and structure in epoxyamine composites with dispersed oxides. Eastern-European Journal of Enterprise Technologies, 6 12–90 (2017) 4-12.

[9] N. Fathy, M. Ramadan, K. Hafez, A. Alghamdi, A. Halim, Microstructure and induced defects of 6061 Al alloy after short times cyclic semi-solid heat treatment, MATEC Web of Conferences, 67 (2016) 1–6.

[10] H. Sulym, Ia. Pasternak, V. Pasternak, Boundary element modeling of pyroelectric solids with shell inclusions, Mechanics and Mechanical Engineering, 22 (2018) 727–737.

[11] O. Zabolotnyi, V. Pasternak, I. Andrushchak, N. Ilchuk, K. Svirzhevskyi, Numerical simulation of the microstructure of structural-inhomogeneous materials, Lecture Notes in Mechanical Engineering, (2020) 562–571.

[12] L. Qijun, Zh. Lin, W. Dongbin, R. Shubin, Qu. Xuanhui, Porous Nb-Ti based alloy produced from plasma spheroidized powder, Results in Physics, 7 (2017) 1289–1298.

[13] Zhao. Biao, Yu. Tianyu, Ding. Wenfeng, Li. Xianying, Effects of pore structure and distribution on strength of porous Cu-Sn-Ti alumina composites, Chinese Journal of Aeronautics, 30 (2017) 2004–2015.

[14] Z. Lin, L. Tian-Shu, D. Tao-Tao, L. Tao-Tao, Q. Feng, Y. Hong-Yu, Design of a new Al-Cu alloy manipulated by in-situ nanocrystals withsuperior high temperature tensile properties and its constitutive equation, Materials and Design, 181 (2019) 1–12.

[15] A. Ruban, V. Pasternak, N. Huliieva, Prediction of the structural properties of powder materials by 3D modeling methods, Materials Science Forum, 1068 (2022) 231–238.

[16] Y. Danchenko, V. Andronov, A. Kariev, V. Lebedev., E. Rybka, R. Meleshchenko, D. Yavorska. Research into surface properties of disperse fillers based on plant raw materials, Eastern-European Journal of Enterprise Technologies, 5 12–8 (2017) 20–26.

[17] K. Korytchehko, A. Ozerov, D. Vinnikov, Y. Skob, D. Dubinin, R. Meleshchenko, Numerical simulation of influence of the non-equilibrium excitation of molecules on direct detonation initiation by spark discharge. Problems of Atomic Science and Technology, 116 4 (2018) 194–199.

[18] N. Yumak, K. Aslantas, A review on heat treatment efficiency in metastable β titanium alloys: the role of treatment process and parameters, Journal of materials research and technology, 9 (2020) 15360–15380.

[19] G. Haar, T. Becker, D. Blaine, Influence of heat treatments on the microstructure and tensile behaviour of selective laser melting-produced Ti-6Al-4V parts, South African Journal of Industrial Engineering 27 (2016) 174-183.

[20] V. Venkatesh, R. Noraas, A. Pilchak, S. Tamirisa, K. Calvert, A. Salem, T. Broderick, M. Glavicic, I. Dempster, V. Saraf, Data driven tools and methods for microtexture classification and dwell fatigue life prediction in dual phase titanium alloys, Web of Conferences, 321 (2020) 1–8.

[21] B. Pospelov, E. Rybka, V. Togobytska, R. Meleshchenko, Yu. Danchenko, Construction of the method for semi-adaptive threshold scaling transformation when computing recurrent plots. Eastern-European Journal of Enterprise Technologies, 4/10 (100) (2019) 22–29.

[22] D. Sokolov, V. Sobyna, S. Vambol, V. Vambol, Substantiation of the choice of the cutter material and method of its hardening, working under the action of friction and cyclic loading. Archives of Materials Science and Engineering, 94 2 (2018) 49–54.

[23] S. Smirnov, L. Zamaraev, Comparative study of Shot creep of single-phase titanium alloys in air and neutral gas environment on the test temperature in range from 673 to 1323 K, Frattura ed Integrità Strutturale, 49 (2019) 201–211.

[24] I. Ryshchenko, L. Lyashok, A. Vasilchenko, A. Ruban, L. Skatkov, Electrochemical synthesis of crystalline niobium oxide, Materials Science Forum, 1038 (2021) 51–60.

[25] M. Wei-min, Zhu. Wen-zhi, Tensile properties and microstructure of rheo-diecast 7075 alloy prepared by serpentine channel process, Research and Development, 16 (2019) 161–167.

[26] G. Magnani, S. Galvagno, G. Sico, S. Portofino, C. Freda, E. Burresi, Sintering and mechanical properties of β-SiC powder obtained from waste tires, Journal of Advanced Ceramics, 5 (2016) 40–46.

[27] O. Blyznyuk, A. Vasilchenko, A. Ruban, Y. Bezuhla, Improvement of fire resistance of polymeric materials at their filling with aluminosilicates, Materials Science Forum, 1006 (2020) 55–61.

[28] Z. Lin, L. Tian-Shu, D. Tao-Tao, L. Tao-Tao, Q. Feng, Y. Hong-Yu, Design of a new Al-Cu alloy manipulated by in-situ nanocrystals withsuperior high temperature tensile properties and its constitutive equation, Materials and Design, 181 (2019) 1–12.

[29] S. Vambol, V. Vambol, Y. Suchikova, N. Deyneko, Analysis of the ways to provide ecological safety for the products of nanotechnologies throughout their life cycle. Eastern-European Journal of Enterprise Technologies, 1 10–85 (2017) 27–36.

[30] O. Sierikova, V. Koloskov, K. Degtyarev, O. Strelnikova, The deformable and strength characteristics of nanocomposites improving Materials Science Forum, 1038 MSF (2021) 144–153.

[31] A. Samar Reda, A. Hamid, A. Menam, I. Salah Elden, E. Haytham Abdelrafea, S. Hassan Abdel, Laser Powder Cladding of Ti-6Al-4V α/β Alloy, Materials, 10 (2017) 2–16.

[32] Sh. Balachandran, A. Tripathi, Ar. Banerjee, M. Chinara, R. Teja, S. Suresha, D. Choudhuri, R. Banerjee, D. Banerjee, Transformations, recrystallization, microtexture and plasticity in titanium alloys, Web of Conferences, 321 (2020) 1–13.

[33] V. Pasternak, L. Samchuk, A. Ruban, O. Chernenko, N. Morkovska, Investigation of the main stages in modeling spherical particles of inhomogeneous materials, Materials Science Forum, 1068 (2022) 207–214.

[34] Xin. Xu, I. Bantounas, D. Dye, Deformation behaviour of beta phase with similar chemical composition in beta and alpha + beta titanium alloys, Web of Conferences, 321 (2020) 1–5.

[35] V. Venkatesh, R. Noraas, A. Pilchak, S. Tamirisa, K. Calvert, A. Salem, T. Broderick, M. Glavicic, I. Dempster, V. Saraf, Data driven tools and methods for microtexture classification and dwell fatigue life prediction in dual phase titanium alloys, Web of Conferences, 321 (2020) 1–8.

[36] O. Kaglyak, B. Romanov, K. Romanova, A. Ruban, V. Shvedun, Repeatability of sheet material formation results and interchangeability of processing modes at multi-pass laser formation, Materials Science Forum, 1038 (2021) 15–24.

[37] V. Pasternak, A. Ruban, M. Surianinov, Yu. Otrosh, A. Romin, Software modeling environment for solving problems of structurally inhomogeneous materials, Materials Science Forum, 1068 (2022) 215–222.

[38] O.Z. Dveirin, O.V. Andreev, A.V. Kondrat'ev, V.Ye. Haidachuk, Stressed state in the vicinity of a hole in mechanical joint of composite parts, International Applied Mechanics, 57, 2 (2021) 234–247.

[39] V. Komyak, V. Komyak, A. Danilin, A study of ellipse packing in the highdimensionality problems. Eastern-European Journal of Enterprise Technologies, 1 4–85 (2017) 17–23.

[40] A. Kovalov, Yu. Otrosh, S. Vedula, O. Danilin, T. Kovalevska, Parameters of fire-retardant coatings of steel constructions under the influence of climatic factors. Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu, 3 (2019) 46–53.

[41] Y. Danchenko, V. Andronov, M. Teslenko, V. Permiakov, E. Rybka, R. Meleshchenko, A. Kosse, Study of the free surface energy of epoxy composites using an automated measurement system. Eastern-European Journal of Enterprise Technologies, 1 12–91 (2018) 9–17.

[42] V. Semko, M. Leshchenko, O. Cherednikova, Standardization of required level probability of no-failure operation of the building envelopes by the criterion of total thermal resistance. International Journal of Engineering and Technology(UAE). 7(3) (2018) 382–387

[43] A. Kovalov, Yu. Otrosh, M. Surianinov, T. Kovalevska, Experimental and computer researches of ferroconcrete floor slabs at high-temperature influences. Materials Science Forum, 968 MSF (2019) 361–367.

[44] P. Semko, S. Skliarenko, V. Semko, Concrete filled tubular elements joints investigation. International Journal of Engineering and Technology(UAE). 7(3) (2018) 494–500

[45] O. Vambol, A. Kondratiev, S. Purhina, M. Shevtsova, Determining the parameters for a 3D-printing process using the fused deposition modeling in order to manufacture an article with the required structural parameters, Eastern-European Journal of Enterprise Technologies, 2, 1(110) (2021) 70–80.

[46] Yu. Otrosh, M. Surianinov, O. Holodnov, O. Starova, Experimental and computer researches of ferroconcrete beams at high-temperature influences. Materials Science Forum, 968 (2019) 355–360.