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INFLUENCE OF A DISCRETE ADDITIVE OF ALUMINUM OXIDE ON STRUCTURE AND PROPERTIES OF ALUMINUM ALLOY

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On the basis of the literature review, there were identified the problem and the relevance of the development of the technology for introducing additives of nano-sized fillers into aluminum alloys in order to determine the mechanism for controlling the structurally dependent properties. As such an additive, alumina fibers of 10-20 nm in diameter were selected. The introduction of the additive into the liquid alloy is implemented by means of mechanical mixing. Technological features of the process allowed to solve the problem of overcoming the forces of surface tension and distribution of additives, which are quantitatively small and light in comparison with the main material. Experimental samples were obtained under laboratory conditions using the specially designed equipment. To perform the comparative analysis, samples of the base alloy of the composition AK6 and filled with a discrete additive of 1 % alloy of the same composition were obtained in identical modes. Investigations of the structure and properties of the base alloy and samples obtained by mixing in the base alloy of thin discrete alumina fibers in a volume of 1 % were performed using standard metallographic analysis techniques and a hardness measurement method. As a result of macro- and microscopic studies, a modifying effect was found from the addition of finely dispersed Al_2O_3 to an aluminum alloy, which manifested as grain refinement. The shape of the hardness distribution curves obtained as a result of the processing of statistical data is identical for the compared samples and has a pronounced shifted extremum, which indicates changes in the properties on the one hand and demonstrates a sufficient level of assimilation of the additives by the liquid alloy, on the other. Consequently, the expediency of using the suggested method of modification for obtaining materials of this group is obvious.

***Key words*:** modification, metal matrix materials, assessment of structure and properties, aluminum oxide

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Introduction. Aluminum is a key component of many alloys. Aluminum and alloys are highly demanded due to their specific and unique properties [1-3, 5, 7]. The developers of the products formulate specific requirements for the materials of the new generation to ensure a high level of uniformity in the structure of the castings, which is associated with ever-increasing demands for improved performance and reliability of materials. In such conditions, modification of alloys is a very significant and promising technological method. It is known that the modification of aluminum alloys increases the technological plasticity and uniformity of the distribution of mechanical properties in the whole body of the blank [2, 6]. An important advantage is the preservation of low density. However, there is a real technological problem of introducing modifying additives to overcome the forces of surface tension and the distribution of quantitatively small and relatively light additives in comparison to the base material.

The combination of heterogeneous components gives a certain effect and allows the guided adjustment of the structure and properties of the final product. The effectiveness of using various modifiers depends on the form, amount and technology of additives introduction. The most promising materials for modifying cast aluminum alloys are discrete fibers with nanodiameter range, mainly wire-type crystals [6, 9, 12, 13, 15, 16]. The effect of the modification is provided by introducing small amount of additives (0.05-0.15 % by weight of the liquid alloy) during casting directly into the liquid alloy. Because of the difference in the mechanical properties of the components of the composition, there is an obvious problem with the introduction of such additives.

Research methods. The base alloy is composed of aluminum AK6. A discontinuous alumina fiber was chosen as a modifying additive, according to the manufacturer's data, the used «Nafen» brand is pure Al_2O_3 with a diameter of 10-20 nm and thermal stability up to 1200 °C.

There are various methods for combining aluminum matrices with fillers to produce a composite material (CM): solid-phase or liquid-solid phase compacting of powder mixtures, including those prepared by mechanical alloying, foundry technologies for impregnating porous supporting structures made

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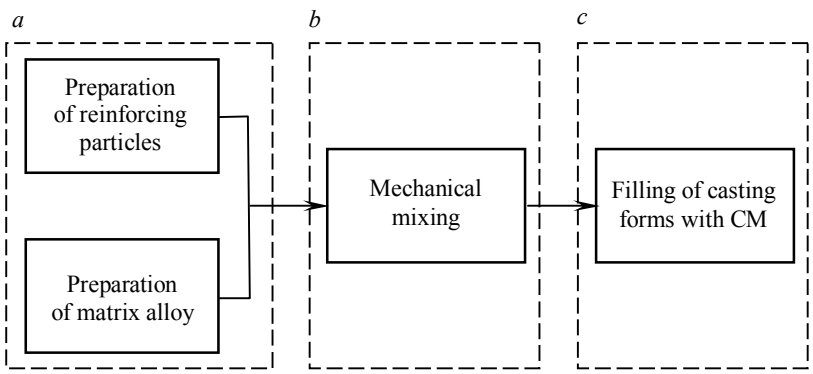


Fig.1. The scheme of production of the experimental sample:
a – preparation of primary components; *b* – establishment of bonding;
c – form shaping

of fibers, powders or short fibers, or mechanical mixing of discrete fillers in liquid alloys, and gas-thermal spraying of composite mixtures.

Production using liquid-phase methods is possible when the fillers are wetted with liquid alloys or when the external forced pressure is applied. From the listed methods of production of CM the most technological and cheapest is the foundry method of mechanical mixing. The process of obtaining samples for the research is shown in Fig.1.

The quality of the obtained samples (the filler distribution, the level of interfacial bonding, the presence of reaction products, etc.) depends on the wetting power of the matrix liquid alloy, mixing conditions, or following processing. Technologically significant parameters of the casting process are the design of the mixing plant; mixing and solidification modes; temperature of the liquid alloy and pre-heating of the particles, the speed of rotation of the device providing the introduction and distribution of the filler, the duration of mixing and maturing of the composite mixture before casting, and the rate of crystallization.

The conditions for obtaining the object of the research were individual, and the manufacturing technology was developed for the laboratory, so the size of one batch was about 300 g. The matrix alloy was melted and superheated to 800 °C, aluminum oxide wrapped in aluminum foil was put under the melt mirror, providing intensive mixing. The development and manufacturing of devices for the introduction of additives was carried out by the staff of the laboratory «Composite and nonmetallic materials» of the Materials Science department of MSTU n.a. N.E. Bauman.

The choice of the temperature of the melt is justified by technological parameters: the higher the temperature of the melt, the better the wettability, which in turn should ensure the complete assimilation of the additive. On the other hand, a significant obstacle to increasing the temperature of the melt is the growth of the oxide film on the surface of the melt. When melting in air, aluminum is intensively oxidized. As a result of oxidation of aluminum, aluminum oxides Al_2O_3, as well as Al_2O and AlO are formed. The probability of the formation of oxides becomes higher with increasing temperature. Under ordinary melting conditions, the thermodynamically stable phase is a solid alumina γ-Al_2O_3 that is insoluble in aluminum and does not form low-melting compounds with it. When γ-Al_2O_3 is heated to 1200°C, it is recrystallized in α-Al_2O_3. As oxidation on the surface of solid and liquid aluminum, a dense, strong oxide film with a thickness of up to 10 microns is formed, depending on the temperature and the duration of maturing. When such a thickness is reached, the oxidation practically stops, because the diffusion of oxygen through the film slows down sharply. The process of oxidation of liquid aluminum alloys is ambiguous and poorly understood. Nevertheless, theoretical calculations and analysis of the results of practical solutions made it possible to carry out a rational choice of the melt temperature.

The next important technological parameter is the duration of mixing and maturing (detention time). With insufficient maturation, it is not possible to obtain required homogeneity of the distribution of additives in the matrix liquid alloy. The choice of the mode was carried out empirically.

In order to obtain castings with a uniform distribution of properties over the cross section and to eliminate the effect of the temperature gradient on the crystallization conditions, the casting of the mixture was carried out in a graphite form. The graphite mold is convenient because the metal can be poured without preliminary preparation of the mold and the finished casting does not adhere to the mold even without the use of special coatings.

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The chemical composition of the experimental base sample and the sample with the added 1 % Al_2O_3 (modified) additive, determined by laser atomic emission spectroscopic analysis, is as follows:

Sample	Cu	Si	Cr	Ni	Fe	Mg	Mn	Ti	Zn	Al
Original	2.27	1.00	< 0.001	0.02	0.40	0.59	0.51	0.05	0.06	Base
Modified	2.28	1.01	< 0.001	0.02	0.40	0.58	0.52	0.05	0.06	Base

Comparative analysis of the structure. The research of macrostructure using the Neophot 21 microscope with an attachment for macroscopic studies demonstrated the presence of an explicit refinement, which confirmed the predicted modifying effect (Fig.2).

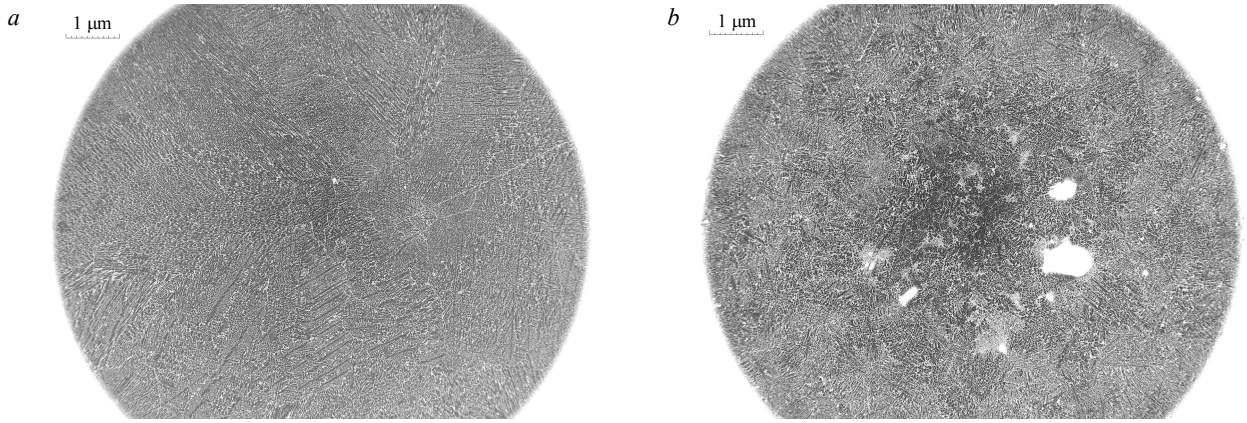


Fig.2. Macrostructure of cast aluminum alloy without additives (*a*) and with dispersed fibers additive (*b*). Zoom 20^x

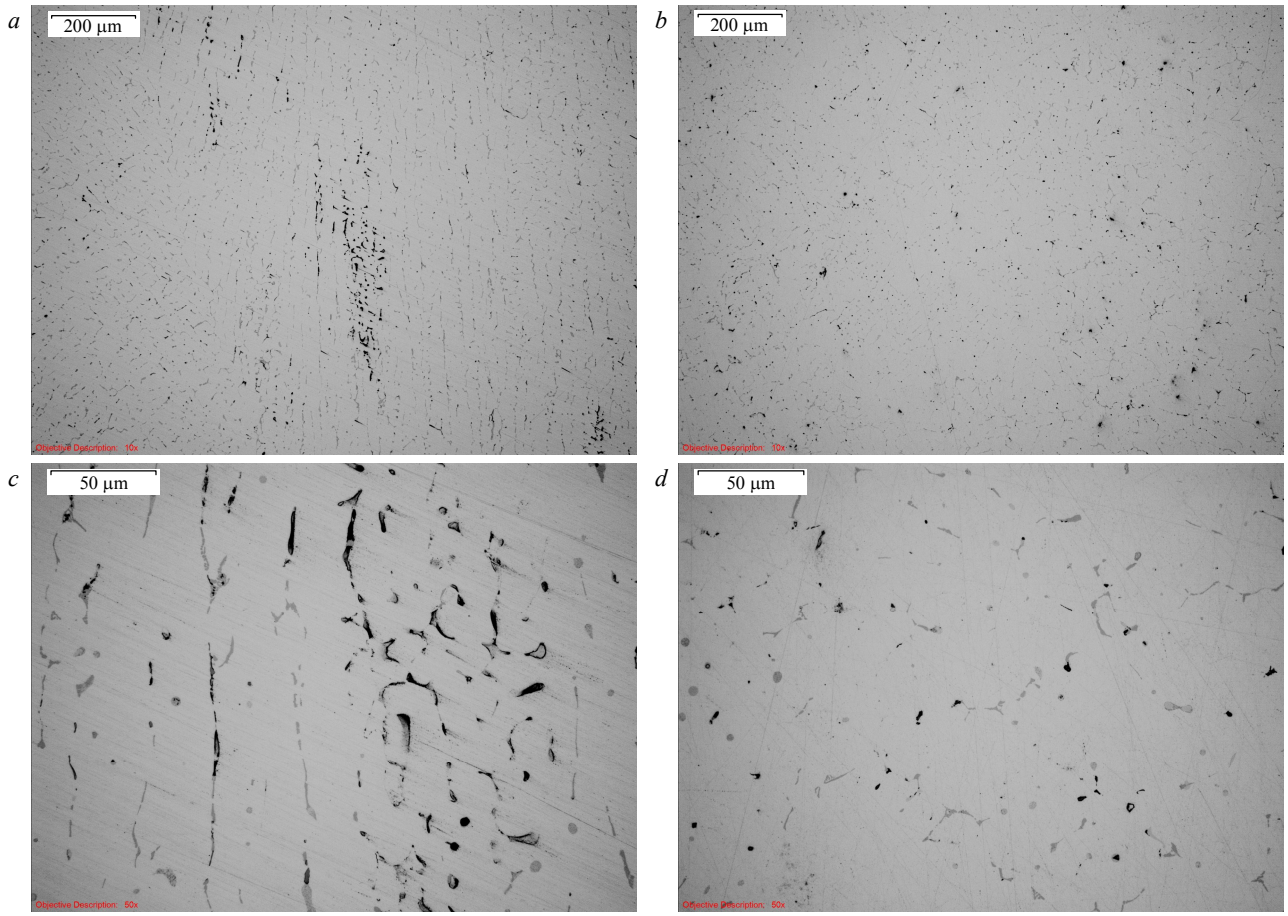


Fig.3. MMicrostructure of the studied aluminum alloy without fiber additives (*a*, *c*) and with them (*b*, *d*) before etching with zoom of 100^x and 500^x relatively

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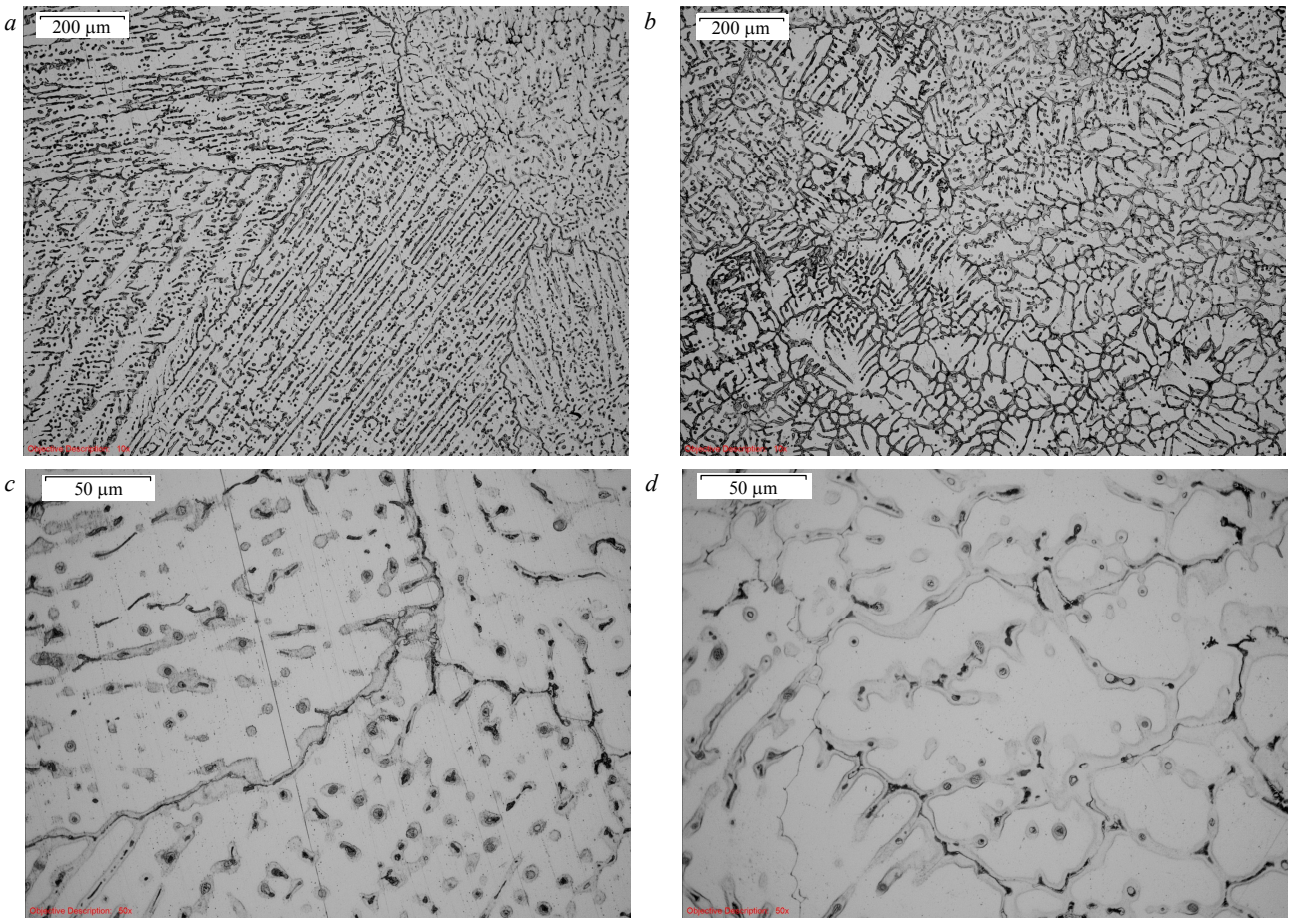


Fig.4. Microstructure of cast aluminum alloy without fiber additives (*a*, *c*) and with them (*b*, *d*) after etching with zoom of 100^x and 500^x respectively

It can be seen that the size of the structural components in the sample with additives is smaller than in the base one. In the modified sample there are large pores, apparently, these are air bubbles that did not have time to float to the surface, which indicates the need to correct the mixing time.

The microstructure analysis was performed on microscope Olympus GX51 with zoom of 100^x and 500^x. A comparative analysis of the microstructure before (Fig.3) and after etching (Fig.4) in 0.5 % aqueous HF solution at various zooming confirmed the conclusions drawn on the basis of qualitative macroscopic analysis of the refinement of structural components. So, for the quantitative index, the average grain size is adopted. The average grain area, estimated by the method of GOST 5639-82, is 1.1 and 0.015 mm^2 for the original and modified samples, respectively.

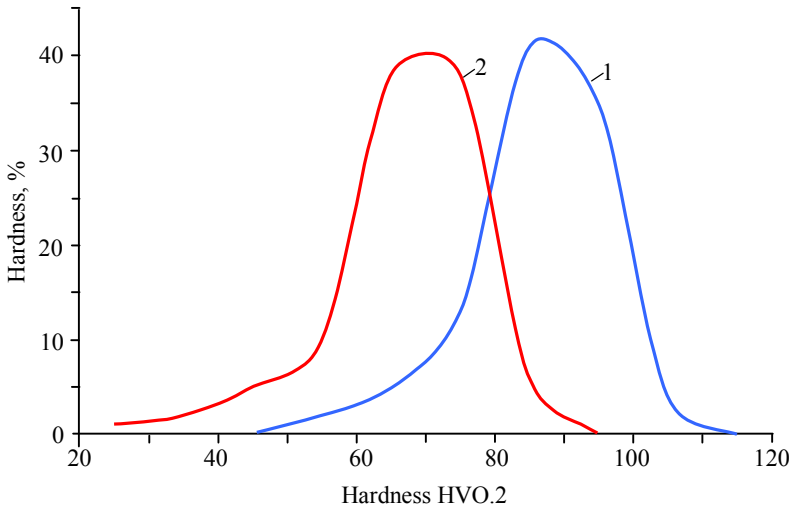


Fig.5. The microhardness probability distribution curve of the original (1) and modified (2) experimental samples

Hardness measurement. Based on the results of hardness measurements on the DURASCAN automatic microhardness tester with a load of 200 g, the probability distribution of the microhardness of the original and modified alloys was constructed (Fig. 5).

The accuracy of the repetition of the probability distribution of the microhardness at 100 points on an area of 1 cm^2 is demonstrated by the suffi-

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cient structural homogeneity of the experimental samples. The asymmetry of the curve is the difference between the mean value and the mode (the most common value) divided by the root-mean square value. The shape of the hardness distribution curves has an identical left-sided asymmetry, hence, it can be assumed that the pore volume introduced by the melting conditions is approximately the same. According to the results of the calculation and as can be seen from the graphs, the average hardness values for the original sample are 87 %, for the modified sample – 70 %. Consequently, the change in hardness is 20 %. The displacement of the extremum demonstrates the effect of the introduction of the additive.

Conclusion. As a result of the studies, samples of an aluminum alloy with the addition of a thin-discrete alumina with a diameter of 10-20 nm were obtained by modernizing the process of mechanical mixing. In the course of comparative analysis of the obtained experimental samples, the influence of 1 % of the additive on the structure and properties was established:

• refinement of the structure with an average grain area of 1.1 mm^2 for the base alloy and up to 0.015 mm^2 for the modified;

• change in hardness by 20 %.

Thus, the analysis of the results of the study showed the presence of a modifying effect in an aluminum alloy from the introduction of a finely dispersed alumina additive with the trade mark «Nafen». It is advisable to use the additive for refinement of the structure and increasing the structural homogeneity.

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REFERENCES

1. Kurganova Yu.A., Berezovskii V.V., Solyaev Yu.O., Lur'e S.A., Shavnev A.A. Investigation of mechanical properties of MKM based on an aluminum alloy reinforced with dispersed particles of silicon carbide. *Deformatsiya i razrushenie materialov*. 2014. N 12, p.12-16 (in Russian).

2. Kalashnikov I.E. Development of methods for reinforcing and modifying the structure of aluminum-matrix composite materials: Avtoref. dis… d-ra tekhn. nauk. IMET im. A.A.Baikova RAN. Moscow, 2011, p. 40 (in Russian).

3. Kurganova Yu.A., Kolmakov A.G. Structural metal matrix composites. Moscow: Izd-vo MGTU im. N.E.Baumana, 2015, p. 141 (in Russian).

4. Kurganova Yu.A., Lopatina Yu.A. Analysis of the distribution of the reinforcing phase in alumo-matrix CM. *Zagotovitel'nye proizvodstva v mashinostroenii*. 2015. N 4, p. 42-48 (in Russian).

5. Chernyshova T.A., Kurganova Yu.A., Kobeleva L.I., Bolotova L.K. Cast dispersion-hardened alumo-matrix composite materials: manufacturing, properties, application. UlGTU. Ul'yanovsk, 2012, p. 295 (in Russian).

6. Sokolov G.N., Troshkov A.S., Lysak V.I. et al. Modification of the weld metal structure by nanodispersed tungsten carbides. *Fizika i khimiya obrabotki materialov*. 2009. N 6, p. 41-47 (in Russian).

7. Serpova V.M., Shavnev A.A., Grishina O.I., Krasnov E.N., Solyaev Yu.O. Wetability and interfacial interaction in a metal composite material on an aluminum matrix reinforced with aluminum oxide. *Materialovedenie*. 2014. N 12, p. 29-35 (in Russian).

8. Fetisov G.P., Kurganova Yu.A., Gavrilov G.N. Composite materials in aviation and their forecasting. Tekhnologiya metallov. 2015. N 1, p. 22-25 (in Russian).

9. Zakaria M.R., Akil H.M., Kudus A.A., Saleh S.M. Enhancement of tensile and thermal properties of epoxy nanocomposites through chemical hybridization of carbon, nanotubes and alumina. *Compos*. A Appl. Sci. Manuf. 2014. N 66, p. 109-116.

10. Berezovskiia V.V., Solyaevb Yu.O., Lur'eb S.A., Babaitsevc A.V., Shavneva A.A, Kurganova Yu.A. Mechanical Properties of a Metallic Composite Material Based on an Aluminum Alloy Reinforced by Dispersed Silicon Carbide Particles. *Russian Metallurgy* (*Metally*). 2015. N 10, p.790-794.

11. Knowles A.J., Jiang X., Galano M. Audebert F.Microstructure and mechanical properties of 6061Al alloy based composites with SiC nanoparticles. *J. Alloys Compd*. 2014. N 615, p. 401-405.

12. Kollo L., Radbury B.C., Veinthal R., Jäggi C., Carreño-Morelli, Leparoux M. Nanosilicon carbide reinforced aluminium produced by high-energy milling and hot consolidation. *Mater. Sci. Eng*. 2011. A 528 (21), p. 6606-6615.

13. Meysam T.K., Fergusona J.B., Benjamin F.S., Kima C.S., Cho K., Rohatgi P.K. Strengthening mechanisms of graphene- and Al_2O_3 – reinforced aluminum nanocomposites synthesized by room temperature milling. *Mater. Des*. 2016. N 92, p. 79-87.

14. Saha R., Morris E., Chawla N. Hybrid and conventional particle reinforced metal matrix composites by squeeze infiltration casting. *J. Mater. Sci. Lett*. 2002. N 21, p. 337-339.

15. Jiang L., Yang H., Yee J.K., Mo X., Topping T., Lavernia E.J. Toughening of aluminum matrix nanocomposites via spatial arrays of boron carbide spherical nanoparticles. *Acta Mater*. 2016. N 103, p. 128-140.

16. *Tjong S.C.* Recent progress in the development and properties of novel metal matrix nanocomposites reinforced with carbon nanotubes and graphene nanosheets. *Mater. Sci. Eng*. 2013. R74, p. 281-350.

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