AP19675471 «Developing the technology of synthesizing composite ceramic materials of the AlxFeySi system using the additive method», - p.m. PhD, Associate Professor V.A. Andreyashchenko

Relevance:

The use of aluminum alloys has an undeniable advantage over many other alloys, primarily due to their low weight, good performance properties, high electrical conductivity, anti-corrosion properties and sufficient mechanical characteristics. However, to achieve a high level of these characteristics, alloying with expensive, usually rare earth elements, is required. This approach leads to a sharp increase in the cost of finished parts. Ceramics of the MeSi type (silicides) have high hardness and wear resistance. To solve the problem of improving the quality of aluminum-based parts, it was decided to develop a composite ceramic material AlxFeySi. The uniqueness of the material lies in the ability to form the Al8Fe2Si phase, which has a highly symmetrical crystal lattice, providing the ability of the resulting composite ceramic materials to perceive plastic deformation.

The project purpose:

To develop a technology for synthesizing composite ceramic materials of the AlxFeySi system using an additive method to improve the quality of the material structure and parts based on them.

Expected and achieved results:

Results expected in 2023. The full list of alloying elements and their percentage content will be determined based on the principles of economical alloying, phase and thermodynamic analysis of the synthesized composite will be performed. Preparation of batch materials for synthesizing the composite material will be performed: crushing and grinding of alloying components, classification by size, fractional analysis. The composition of the flux that excludes the interaction of the batch materials with the surrounding atmosphere will be selected and prepared. The synthesis modes will be selected empirically and mathematical dependences characterizing the process of obtaining a composite material will be obtained. There will be participation in an international conference with publication of a report.

Results achieved in 2023. Alloying elements that expand the range of existence of the Al8Fe2Si phase were identified, a full list of alloying elements and their percentage content was determined based on the principles of economical alloying. Phase and thermodynamic analysis of the synthesized composite was performed. The completion form is thermodynamic and phase analysis in ThermoCalc software. The main alloying elements of the Al-Fe-Si system are copper, nickel, magnesium, chromium, manganese and boron. The introduction of alloying elements in an amount of up to 1% is considered, guided by the principles of economical alloying. It is revealed that the specified alloying elements contribute to changing the temperature boundaries of the highly symmetric Al8Fe2Si phase formation, the addition of copper leads to decreasing the lower boundary of formation, nickel, on the contrary, increases both the lower and upper boundaries, while for all the elements considered, the phase is observed with the iron content of no more than 35%. Manganese expands the boundaries of the existence of the Al8Fe2Si phase.

There were prepared charge materials for synthesizing a composite material: crushing and grinding of alloying components, classification by size, fractional analysis.

The differential thermal analysis of the charge materials was performed, and thermograms were obtained. The study was conducted on 10 compositions with each experiment duplicated at least 3 times. Comparison of thermograms with phase diagrams showed that the endothermic effects observed in the thermogram coincided with the temperatures of the liquid phase separation onset.

Mechanical alloying and compaction of the charge taking into account the required ratio of components, dosing, and packaging were performed.

A flux composition was selected that excluded the interaction of charge materials with the surrounding atmosphere. Its preparation was carried out. The granulometric analysis of the flux was performed.

Welding and technological properties of fluxes for arc welding and surfacing are determined by the following indicators: high arc stability; high-quality weld formation with a smooth transition to the base metal; low tendency to form pores and cracks; good detachability of slag crust. Based on the data on gas permeability, flux composition and their purpose, two welding fluxes: AN348 and AN60 were selected for the study. Thermogravimetric analysis was carried out with verification of the results by X-ray phase studies of three groups of samples: a charge, a charge with a flux, a flux. Within the groups of samples, the fractional composition of the flux, the amount of flux, and the type of flux varied. Based on the experimental data, the flux composition was selected that excluded the interaction of charge materials with the surrounding atmosphere. Flux AN-348A showed a greater efficiency. Therefore, flux AN-348A was adopted for further experiments on surfacing.

The synthesis modes were selected empirically and mathematical relationships were obtained that characterized the process of obtaining the composite material. The main technological conditions that ensure the efficiency of synthesis of metal-ceramic material by the additive method were revealed. The following was determined as the main technological factors: the method of laying the charge; the current value; the ratio of the charge thickness, the electrode thickness, the amount of flux; the granulometric and chemical composition of the flux; the fractional composition of the charge. The effect of the following technological factors was studied: various options for laying the charge were studied: between the base and the electrode, on the electrode, pre-compacted charge and uncompacted, different ratios of the amount of charge and its placement. The effect of thickness of the charge, electrode and the amount of flux on the synthesizing metal-ceramic materials was studied; the effect of the mode (current value) on the process of material synthesis; the effect of the granulometric and chemical composition of the flux were revealed; the effect of the fractional composition of the charge and flux; the effect of the gap between the electrode and the base on the formation of the arc was studied. A technology of synthesizing the components of a composite material using an additive method was developed. For the first time, a metal-ceramic material of the Al-Fe-Si system was obtained by surfacing with a consumable electrode. For the first time, a metal-ceramic material of the Al-Fe-Si system was obtained by surfacing in a powder layer.

Results expected in 2024:

- the composite material will be synthesized, rational parameters for the process will be developed, and a pilot batch will be obtained. A heat treatment mode for the resulting composite will be developed. A pilot batch of the composite ceramic material will be manufactured and rational parameters of synthesizing and heat treatment process will be experimentally identified. The ability of the resulting composite ceramic material to withstand plastic deformation, including that at elevated temperatures, will be studied. The resulting ceramic material will be plastically treated, the features of the shape change, and the energy-force parameters of the deformation process will be studied. The ultimate plasticity of the resulting composite will be determined, and indicators will be determined that make it possible to predict the moment of destruction during various deformation processes. There will be participation in two international conferences with publication of papers, an article and/or review will be published in peer-reviewed scientific journals indexed in the Science Citation Index Expanded of the Web of Science database and/or having a CiteScore percentile in the Scopus database of at least 35 (thirty-five).

Results achieved in 2024.

The composite material was synthesized, and rational parameters of the process implementation were developed. A mode of heat treatment of the obtained composite is being developed. Rational parameters of the synthesis process were experimentally identified. The Al-Fe-Si alloy was synthesized by the additive method, by surfacing with a horizontal consumable electrode. The synthesis was performed using a package of aluminum plates installed horizontally, iron was the electrode, and silicon was added in the form of powder between the aluminum plates. The package was melted by a welding arc burning from a steel electrode. The surfacing current

was selected taking into account the thickness of the package, the melting process occurred under a layer of welding flux to protect against oxidation and evaporation of the alloy components. The required composition is ensured by selecting the amount of aluminum, silicon and iron. Varying the ratios of the number of aluminum plates, electrodes, and powdered materials allows changing the mechanical and operational properties of the composite without using expensive initial alloy components in the form of ligatures or special ferroalloys. Silicon is added by applying pre-crushed silicon to aluminum plates using the wet method followed by drying at room temperature within at least 12 hours. The aluminum plates with applied silicon can be joined into a package either layer by layer or in pairs. The material obtained using this synthesis method is compact, with a uniform microstructure and improved mechanical properties.

To develop the heat treatment mode, three main modes were tested: heating, holding, cooling in air; heating, holding, cooling in water; heating, holding, cooling together with the furnace; annealing in a dilatometer environment to ensure a controlled mode of heating and cooling rates, which is unattainable when using conventional thermal furnaces (heating, holding, cooling under controlled conditions).

List of publications in 2024:

- Andreyashchenko V.A. Studying the technology of synthesizing a metal-ceramic material of the AlxFeySi system. University Proceedings. No. 1 (94), 2024, 50-56;

Toleuova A.R., Andreyashchenko V.A. Computer modeling of the process of aluminum matrix formation using the Thermo-Calc program. Bulletin of VKTU. No. 1, 2024, p. 244-251, DOI 10.51885/1561-4212_2024_1_244.

Figure 1 - Work of the research team at developing composite ceramic materials of the AlxFeySi system using additive manufacturing method

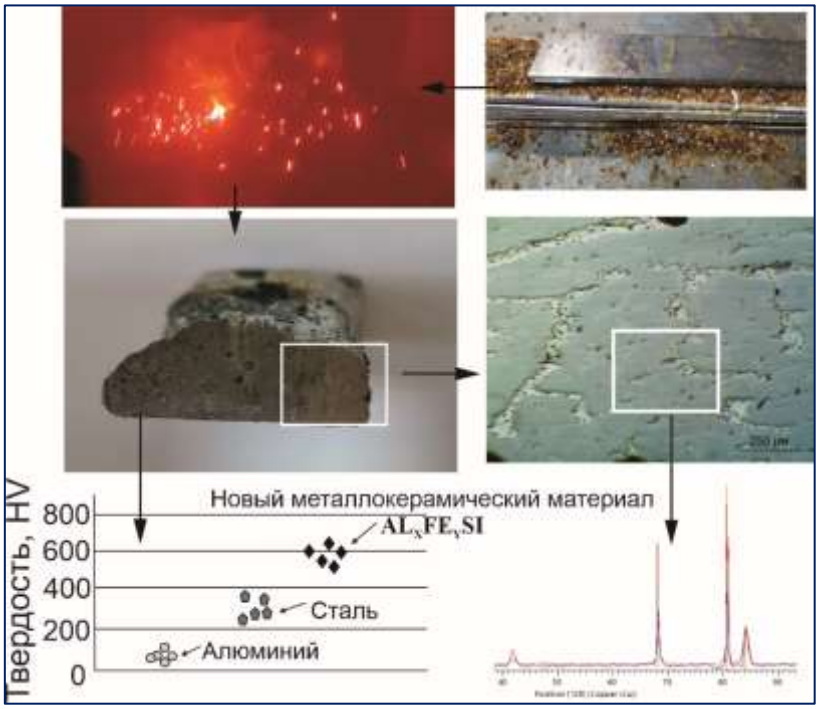

Figure 2 – The basic idea of the new metal-ceramic material

Figure 3 – Participation in the International Scientific Conference APCON-2024, Slovak Republic

Research team

No	Full name, education, academic degree, title	Hirsch index. ResearcherID, ORCID, Scopus Author ID identifiers (if any)
1	Andreyashchenko Violetta Alexandrovna, PhD, associate professor (associate professor) in the specialty of metallurgy, Head of the ELP "KORMS"	Hirsch index (Scopus) – 7; Hirsch index (WoS) - 6; ResearcherID: H-4328-2013; ORCID: https://orcid.org/0000-0001-6933-8163; Scopus Author ID 55308057400 .
2	Bartenev Igor Analolyevich, Cand. Tech. Sci. Associate Professor of the TEMESD	Hirsch index (Scopus) – 1; ORCID: 0000-0001-8982-7319 ; Scopus Author ID: 57207457067.
3	Ibatov Marat Kenessovich, Dr. Eng., Professor of the IT&LSD	Hirsch index (Scopus) – 3; Hirsch index (WoS) – 2; ResearcherID: N-9320-2017; ORCID: https://orcid.org/0000-0001-5062-7790. Scopus Author ID: 57189211438.
4	Alina A.A., Master, sn.teacher of the NTMD	Hirsch index (Scopus) – 1, Hirsch index (WoS) – 1. ResearcherID:DRQ-4173-2022, ORCID: https://orcid.org/0000-0003-3577-4914, Scopus Author ID: 57218196165.
5	Malashkevichute-Briyan Ye.I., master, sn.teacher of the NTMD	Hirsch index (Scopus) – 1; Scopus Author ID: 5876248970

List of publications

1. Andreyashchenko V.A. Effect of fluxes in the production of metal-ceramic materials of the Al-Fe-Si system. BULLETIN OF KGIU No. 2 (41) 2023, p. 25-30.

2. Andreyashchenko V.A., Toleuova A.R. Modern methods of synthesizing metal-ceramic materials of the Al-Fe-Si system. Proceedings of the International scientific and practical conference "Innovations and complex processing of mineral raw materials - relevant components of economic diversification", dedicated to the 30th anniversary of the National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan, Almaty, 2023, pp. 107-109.

3. Toleuova A.R., Andreyashchenko V.A. Computer modeling of phase processes in an aluminum matrix//Proceedings of the International Scientific and Practical Conference "Innovations and Complex Processing of Mineral Raw Materials - Actual Components of Economic Diversification" dedicated to the 30th anniversary of the National Center for Complex Processing of Mineral Raw Materials of the Republic of Kazakhstan, Almaty, 2023, pp. 82-83

4. Andreyashchenko V.A. Studying the technology of synthesizing a metal-ceramic material of the AlxFeySi system. University Proceedings. No. 1 (94), 2024, 50-56; DOI: 10.52209/1609-1825_2024_1_50

5. Toleuova A.R., Andreyashchenko V.A. Computer modeling of the process of aluminum matrix formation using the Thermo-Calc program. Bulletin of VKTU No. 1, 2024, p. 244-251, DOI 10.51885/1561-4212_2024_1_244.

Information for potential consumers

The project results are applicable for manufacturing machine components operating in severe conditions and subject to intensive wear. Using the new alloy as a structural material allows for significant reducing the weight of finished products (more than 2 times) compared to steel products, while the hardness of the new composite material is higher.

Scope

The application area of the project results is the automotive and mechanical engineering industries. The target consumers of the results obtained will be mechanical engineering and automotive enterprises manufacturing machine components operating in severe conditions and subject to intensive wear.

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