ANNOTATION

dissertation work on the topic:

«RESEARCH AND DEVELOPMENT OF A NEW IRON-BASED SELF-FLUXING POWDER SURFACING MATERIAL FOR THE RESTORATION OF PARTS SUBJECTED TO HIGH FORCE AND SHOCK LOADS»,

submitted for the degree of Doctor of Philosophy (PhD)
in the specialty 6D071000 – «Materials Science and Technology of New Materials»

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The purpose of the dissertation. Physico-chemical substantiation of obtaining self-fluxing powder surfacing material based on iron by mechanical activation.

Research Objectives.

To achieve the purpose of the study, the following **tasks** were solved:

1. Theoretical substantiation of the possibility and prospects of the process of mechanical activation of an iron-based powder composition for obtaining a surfacing alloy.
2. Thermodynamic calculation of physico-chemical transformations in an alloy of Fe-Ni-Cr-Cu-Si-B-C.
3. Selection of optimal technological parameters of the mechanical activation process for obtaining a self-fluxing powder surfacing alloy based on iron for gas-flame surfacing.
4. Study of structural and phase transformations in a surfacing alloy occurring during mechanical activation.
5. Investigation of the physico-chemical features and mechanical properties of the coating obtained by the method of gas-flame surfacing.
6. Development of technology for obtaining a wear-resistant coating from a self-fluxing surfacing alloy based on iron for gas-flame surfacing, showing the possibility of using the method of mechanical activation.

Research Methods.

The following types of instruments and analyzers were used in the research:

- thermodynamic modeling of phase transformations was carried out using computer calculation of characteristic polythermal sections of the alloy phase diagram using the Thermo-Calc software package (TCW5 version), based on numerical modeling of phase equilibrium by CALPHAD method and using the TTFe - Thermotech Fe-based Alloys Database;
- a planetary mill MPP-2-1K was used for mechanical activation of the powder mixture; conglomeration was carried out in a high-temperature chamber furnace model LH15/12 (Nabertherm); gas-flame surfacing was carried out with a propane-oxygen burner in one pass;

- sample preparation was carried out using a Secotom-50 rifling machine, a tabletop grinding and polishing machine Tegramin-25/-30;

- X-ray phase analysis was carried out on a diffractometer D8 ADVANCE "Bruker Elemental GmbH" on copper radiation at an accelerating voltage of 36 kV, a current of 25 mA using the DIFFRAC plus SEARCH phase search program;

- the study of the structure, particle distribution and mapping of the elemental and phase composition of samples after mechanical activation and deposited coating was carried out on an electron probe microanalyzer JXA-8230 from JEOL (Japan) at an accelerating voltage of 25 kV and an electron beam current of up to 100 nA;

- thermal analysis of the surfacing powder was carried out using a synchronous thermal analyzer TG-DTA/DSC with a quadrupole mass spectrometer: STA 449 F3 Jupiter ® "NETZSCH" (Germany);

- metallographic analysis of coating samples obtained by gas-flame surfacing was performed using an optical microscope NEOPHOT – 32;

- measurements of mechanical properties were carried out using a PMT-3 hardness tester, a 2070 SMT-1 machine to determine wear**.**

Main provisions (proven scientific hypotheses and other conclusions that are new knowledge) submitted for defense:

The following provisions are submitted for the defense of the dissertation work:

- Results of thermodynamic calculations of phase transformations in the alloy 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C.

- Data on physico-chemical transformations in the alloy 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C under various modes of mechanical activation.

- Results of experimental and theoretical consideration of the influence of charge processing conditions in a planetary mill on the formation of structure and physico-chemical properties.

- Physico-chemical properties of a wear-resistant coating obtained by flame spraying of an iron-based surfacing alloy.

- Technological scheme of manufacturing a self-fluxing surfacing alloy by mechanical activation for gas-flame surfacing.

Description of the main results of the research.

1 Polythermal sections are calculated on the phase diagram of the 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C system to determine the critical temperature of the phase transformation in the alloy and the chemical composition of the phases formed in this case (α, β, β2, γ, γ2, L). The crystallization curve of the alloy is constructed.The results of thermodynamic modeling show that the microstructure of the deposited alloy becomes more complicated, and the phase composition changes as they fuse. The polythermal section showed that all components completely dissolve in the liquid phase at ~1400 °C. The temperature-dependent nature of melt crystallization showed that the nonequilibrium crystallization of the melt passed into the equilibrium phase at 950 °C, which indicates the fine-grained structure of the coating.

2 The optimal time is 20 minutes and the energy dose is at least 150-170 kJ/g, of the mechanical activation process, in which the particle size of the powder mixture is ~ 10-160 microns and the elements in the volume of the powder composition are evenly distributed. To enlarge the particle size to 60-140 microns, it is proposed to use the conglomeration method using 5% liquid glass as a binder.

3 General regularities of the formation of the phase composition and structure of the 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C alloy during mechanical activation are established. When studying phase transformations in a powder composition, it was determined that after 1 min of mechanical activation, numerous new phases are formed and by 20 min the alloy turns out to be multiphase, including intermediate phases, intermetallides, carbides, borides. Thermogravimetric analysis of the surfacing powder showed that the temperature of the burner bath ensures complete melting of the composition, which is ~1400 ° C.

4 General regularities of morphological changes of 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C alloy during mechanical activation are established. The study of the granulometric composition, depending on the duration of mechanical activation in the time interval of 1-20 minutes, allowed us to establish the optimal process time – 20 minutes, at which the particle size is ~ 10-160 microns. The results of the study of the distribution of elements in the volume of the powder mixture, depending on the duration of mechanical activation, confirmed the selected optimal process time, because within 20 minutes, all the elements are distributed over the volume of the powder mixture completely evenly.

5 The general regularities of the formation of the structure and mechanical properties of the coating obtained by gas-flame surfacing are established. Metallographic and microscopic analyses were used to determine the ferrite-martensitic fine-grained structure of the coating with inclusions of ledeburite. map mapping has established that the distribution of elements over the volume of the coating and the boundaries of the surfacing with the substrate is uniform. The results of studies of the mechanical properties of the coating have established the value of the tensile strength of 50.66 MPa and the hardness of 546.96 HV.

6 A technological scheme for obtaining a wear-resistant coating from a self-fluxing surfacing powder material 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C has been developed, showing the possibility of using the mechanical activation method in obtaining surfacing materials for gas-flame surfacing.

The justification of the novelty and importance of the results obtained.

1) A new self-fluxing powder surfacing material based on iron has been created.

2) The possibilities and prospects of mechanical activation of an iron-based powder composition for obtaining a surfacing material are theoretically substantiated.

3) The technological parameters of the mechanical activation process have been optimized to obtain a new self-fluxing powder surfacing material for gas-flame surfacing.

4) The methods of research and analysis of the obtained products are selected.

5) The structural and phase transformations in the powder composition occurring during mechanical activation have been studied.

6) The structural features and mechanical properties of the coating obtained by the method of gas-flame surfacing are investigated.

7) A technological scheme for obtaining a wear-resistant coating from a self-fluxing surfacing powder material has been developed, showing the possibility of using the mechanical activation method in obtaining surfacing materials for gas-flame surfacing.

The totality of the results of the theoretical and experimental studies carried out will contribute to the development of new promising surfacing alloys based on iron, which have a high level of operational characteristics and are intended for use in the repair production of the machine-building industry. The resulting surfacing alloy 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C has passed experimental testing and is confirmed by the act of conducting experimental tests of the results of research work. It is shown that the use of a new wear-resistant surfacing powder alloy ensures the mileage of a freight car for two or more scheduled repairs. This indicates the suitability of the developed surfacing powder material based on iron for the repair of railway transport parts, in particular automatic coupling devices, by the method of gas-flame surfacing.

The research carried out in the field of the tasks set ensures the production of a new self-fluxing surfacing powder material 40%Fe-30%Ni-16%Cr-5%Cu-5%Si-3%B-1%C for gas thermal spraying. The developed technological process, which allows the use of mechanical activation, has an economic advantage over existing technologies based on the traditional metallurgical method. The developed new powder composition and the method of mechanical activation used allows to obtain in the future a wear-resistant coating with a hardness of 546.96 HV, which has a high applicability potential.

The results of the study have novelty, practical value, significantly complement the existing ideas about the mechanism of mechanical activation of multicomponent powders and can be used to solve similar problems. The conducted review of scientific and technical literature allows us to conclude that the work corresponds to the modern scientific and technical level. The main research results have been published in peer-reviewed scientific journals recommended by the CCSON, as well as an article in a journal with a non-zero impact factor (included in the Scopus database).

Compliance with the directions of scientific development or state programs.

The dissertation work was carried out in the laboratory "Advanced Materials and Technologies" of JSC "Kazakh-British Technical University", within the framework of the program "Targeted development of university science focused on innovative results" for 2012-2014 on the topic "Development of a new alloy for the rehabilitation of critical components and parts of railway rolling stock", funded by the Ministry of Education and Science Republic of Kazakhstan.

Description of the contribution of the doctoral student to the preparation of each publication

The author's personal contribution consists in setting the goals and objectives of the work, conducting experimental research, processing and analyzing the results obtained, formulating conclusions, writing articles and abstracts.

The materials of the dissertation work have been published in 11 scientific publications, including rating international (3) and Kazakh scientific journals (3) recommended by the Committee for Quality Assurance in the Field of Science and Higher Education, as well as in the materials of international conferences (5):

Articles with a high impact factor in the Thomson Reuters database or in publications included in the international scientific database Scopus:

1. F.R. Kapsalamova, B.K. Kenzhaliyev, Vl.G. Mironov, S.A. Krasikov. Structural and Phase Transformations in Wear Resistant Fe-Ni-Cr-Cu-Si-B-C Coatings // Journal of the Balkan Tribological Association. – 2019. – Vol. 25, No 1. – P. 95-103.

2. F.R. Kapsalamova, S.A. Krasikov, V.V. Zhuravlev. Phase Transformations in a Fe–Ni–Cr–Cu–Si–B–C Composition during Mechanochemical Alloying // Russian Metallurgy (Metally). - Vol. 2021, No. 8. - P. 930–936.

3. F.R. Kapsalamova, S.A. Krasikov. Thermodynamic Estimation of the Phase Transformations of the Fe–Ni–Cr–Cu–Si–C System // Russian Metallurgy (Metally). - Vol. 2021, No. 8. - P. 1004–1009

Articles in publications recommended by the KKSON of Education and Science of the Ministry of Education and Science of the Republic of Kazakhstan:

1. Ф.Р. Капсаламова, Б.К. Кенжалиев, В.Г. Миронов, Г.Т. Шилов. Распределение элементов в объеме порошка системы Fe-Ni-Cr-Cu-Si-B-C в зависимости от времени механохимического легирования // Комплексное использование минерального сырья. – 2016. - № 2 (297). - С. 64-68.

2. Kapsalamova F. Studying the Properties of a Fe-Ni-Cr-Cu-Si-B Powder System after Mechanochemic alloying // Herald of the Kazakh-British Technical University. – 2017. - № 2-3 (41-42). - P. 57-63.

3. Ф. Капсаламова.Оптимизация технологических режимов аттритора для получения нового наплавочного материала // Промышленность Казахстана. – 2017. - № 2 (101). - С. 43-45.

Publications in proceedings of international conferences:

1. Kapsalamova F., Kenzhaliev B., Mironov V. Wear-Resistant Coating from Composite Powder Fe-Ni-Cr-Cu-Si-B-C obtained by Gas-Flame Surfacing / Proceeding of the II International Scientific Conference Material Science

“Nonequilibrium Phase Transformations”. - 12-15 September, 2016. - Varna, Bulgaria. - P. 41-42.

2. Kapsalamova F.R., Kenzhaliyev B.K., Mironov V.G., ShilovG.T.Application of the Mechanochemical Alloying in obtaining the Powder Alloy for Gas-Flame Spraying / XX Mendeleev Congress on general and applied chemistry. Volume 2b Chemistry and technology of Materials and Nanomaterials. - 26-30 September, 2016. – Ekaterinburg. – P. 278.

3. Ф.Р. Капсаламова, Б.К. Кенжалиев, В.Г. Миронов. Фазовые превращения в порошковом сплаве Fe-Ni-Cr-Cu-Si-B-C, полученного методом механохимического легирования /Сборник трудов IV Международной научной конференции Современные проблемы физики конденсированного состояния, нанотехнологий и наноматериалов (Сарсембиновские чтения). - 10-12 октября, 2016. – Алматы. - С. 54-55.

4. F. Kapsalamova, B. Kenzhaliev, V. Mironov. Features of Structuring Iron based Coating Obtained using Gas Flame Surfacing Method / Proceeding of the 48th International October Conference on Mining and Metallurgy. - September 28 to October 01, 2016. - Bor, Serbia. - P. 85-87.

5. Капсаламова Ф.Р., Кенжалиев Б.К., Миронов В.Г., Шилов Г.Т. Получение нового порошкового сплава методом механохимического легирования для газопламенной наплавки / Тезисы докладов III Международной молодежной научной конференции Физика. Технологии. Инновации. ФТИ-2016. - 16–20 мая, 2016. – Екатеринбург: УрФУ. – С. 391-392.