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THE STUDY OF THE EFFECT OF CHROMIUM BORON (CrB_2) HARDENING ADDITIVE ON THE DEVELOPED PG-Zh40 SURFACING POWDER*

V. G. Mironov[1], G. T. Shilov[1], Zh. B. Ilmaliyev[2], A. A. Bekisheva[1]

[1] *Kazakh British Technical University, «KBTU METALLUM» LLP (Almaty, Kazakhstan)*
[2] *JSC «Institute of Metallurgy and Ore Beneficiation» (Almaty, Kazakhstan)*

E-mail: ardabekovna@mail.ru

AUTHOR'S INFO

V. G. Mironov, Cand. Eng., Head of the Project "TOO KBTU SPLAV",
G. T. Shilov, Senior Researcher, Mechanical Engineer,
Zh. B. Ilmaliyev, Head of the Staff,
A. A. Bekisheva, Doctoral Candidate.

Key words:

self-fluxing alloy, gas powder surfacing, durability, mechanochemical technology, attritor, granulation.

ABSTRACT

Powders of Fe, Ni, Cr, Si, Cu, B, C and hardening additive CrB_2 ligature were used as initial reagents for creating self-fluxing surfacing powder. The synthesis of the composite material was carried out by mechanochemical method using an attritor. Optimization of the composition of new composite alloys with the addition of a chromium boron ligature was carried out and the conditions for the formation of the alloy were determined. The conditions of phase formation and the structure of a new composite filler with boride hardening under mechanical alloying were also studied. The following rational composition of powder alloy was obtained : Fe = 32–40 %; C = 1.1–1.4 %; Cr = 14–15 %; Si = 2–3 %; B = 2.0–2.9 %; Ni = 30–32 %, Cu = 2–3 % with a hardness of 30–44 HRC. The analysis of structure in blankets of surfacing alloy on the basis of iron is carried out it was carried out by means of the metallographic analysis.

Introduction

The world economy annually loses approximately 80 billion USD due to wear and corrosion, but adequate proactive wear protection can help to avoid these losses. This protection involves surfacing of new parts as well as reconditioning and return of worn ones to economic circulation. Surfacing with materials with high performance characteristics is an effective method of machinery parts surfaces hardening. This method is cost-effective, because surfacing is applied only to the surfaces functioning in an aggressive wear environments, and as a rule, the weight of deposited material is very low in comparison with the total weight of a part. Durability of hardened parts is determined by the characteristics of deposited material, and for this reason, the materials or alloys used for surfacing are selected on the basis of the part's operational environment and the surfacing method. Also, alloying elements used for powder deposition and affecting the structure and properties of surfacing materials are selected. Powder alloys based on Fe–Cr–Ni and Fe–Co–Ni are used as the base material. Based on their composition, features of the structure of the surfacing layer, which has a crystalline dendritic structure, are revealed. The influence of alloying elements on the formation of the microstructure of surfacing, which affects the processes of structure formation during crystallization, is established. The features of the phase composition during doping are revealed, its positive effect on the mechanical properties of the weld deposition is evaluated [1]. One of the most promising areas for the development of materials science is powder metallurgy. New possibilities for obtaining products from powder of different chemical composition are opened up by the creation and testing of synthesis technology, as well as the formation of coatings on surfaces of parts with enhanced performance properties [2].

The new self-fluxing surfacing ferrous powder material with hardening additive developed by our team will be used for the reconditioning of components of equipment and machinery operating in abrasion wear, corrosion, high temperature or aggressive environment exposure conditions.

Currently, there are many self-fluxing surfacing powder nickel- and copper-based alloys produced under various methodologies. These alloys have started to take the lead among the materials commercially produced by the world's leading companies such as NACA, JNCO, Battelle, Cabot, BBC, Vienna, KRUPP etc. Alloys with hardness specified in the range from 35 to 55 HRC (such as PSR-2, PSR-3, PSR-4 etc. (GOST 21.448-75)) were developed to create coating of different hardness. All these

* I. K. Beysembetov (Satbayev University, Kazakhstan) and B. K. Kenzhaliev (Institute of Metallurgy and Ore Beneficiation) were also the participants in this work.

alloys are cobalt-, nickel- and copper-based with various carbide-forming additions ensuring required physical and mechanical properties of the surfaced (applied) coating.

The goal of this research is to develop a new alloy technology, based on the previously developed self-fluxing surfacing powder alloy PG-Zh40, but with the addition of chromium boron hardening additive. The team also studied the formation of structure, phase composition and features of gas-flame coatings.

Research methodology

Fe, Ni, Cr, Si, Cu, B, C powders and CrB_2 hardener were used as initial reagents for the production of the self-fluxing surfacing powder. Copper was added to increase fluidity of the melt and to improve anti-corrosive properties of the alloy. The increase of carbon content is necessary for the formation of carbides. Carbides evolve from the liquid solution during gas-powder surfacing, become crystallization centers and contribute to structure refinement resulting in the improvement of the alloy's durability.

The composite material was developed under mechanochemical methodology with the use of attritor [3], and the produced powder was granulated with planetary granulator to create powder of required grain size. Grinding in the attritor improves the stability of multicomponent amorphous phases, which can be explained by changes in the cluster-atomic structure of the amorphous phase due to intense plastic deformation [4]. The structure of the surfacing alloy, its physical and mechanical performance properties were identified with standard techniques. In particular, the structural analysis in the surface layers of the surfacing ferrous alloy was carried out using metallographic analysis. X-ray crystallography was used to determine the phase composition of samples. Microhardness was measured with PMT-3 microhardness tester using static indentation method in accordance with GOST 9450-76. Surfacing layer adhesive strength was examined with CDM10/91 strength testing machine. Surfacing layer hardness was determined with TP-7R-1 material and alloy hardness measurement device using Vickers method. Technological properties of produced granulated powder mix were examined with the use of gas-flame surfacing on various steel samples.

Phase composition of the new surfacing alloy was determined with D8 Advance (BRUKER) diffraction meter. Microanalysis of specimen was performed with Neophot-2 metallographic microscope with ×200, ×500 and ×1000 magnification [5–7].

Experimental part

To try out the new alloy technology involving the addition of CrB_2, the team used self-fluxing surfacing powder alloy PG-Zh40 with 50–160 μm grading fraction and the following chemical composition: Fe = 38%; Cr = 15.0%; Si = 3.1%; B = 2.9%; Ni = 33%; Cu = 3%. Using CrB_2 can be a good way to obtain a composite material with high properties. The use of mechanically alloyed modifying ligatures, the manufacture of which is distinguished by simplicity, environmental safety and versatility, makes it possible to exclude from the technology for producing materials high-temperature, requiring special expensive furnace equipment, an environmentally hazardous process for the production of cast ligatures [8].

Addition alloy CrB_2 with the following chemical composition: Ti = 0.08%; Fe = 0.4 7%; Ni = 0.52%; B = 15%; Cr = 83.43% was used as a hardening additive. CrB_2 hardener was granulated for 5 minutes in a laboratory planetary granulator in alcohol environment with the use of grinding media (5–8 bearing balls with 1:3 powder mix/balls weight ratio). After the granulation average size of CrB_2 particles was 10–30 μm.

2 types of powder mix were prepared for the experiment.

The first type of powder mix was the new surfacing alloy PG-Zh40, and the second type was PG-Z40 with CrB_2 hardener. The powder mix was a mechanical mixture of the new PG-Zh40 alloy initial state components and CrB2 hardener subjected to mechanical alloying in an attritor. Mechanochemical activation of the powder mix was also carried out in attritor. Prior to the mechanochemical activation, 1% of zinc stearate was added to the powder mix to prevent mix material sticking to the balls and the inner surface of the drum. The mix was treated in attritor with the following production conditions:

Mixer rotation rate — 340 rpm;

Ball diameter — 5 mm;

Powder mix weight / ball weight ratio — 1/18;

Process duration — 2 hours.

Mechanical alloying produced composite powder materials with particle size 10–20 μm [9–12]. To produce glomed powder surfacing material, the initial powder material obtained in the attritor was mixed with an organic bond of 2–3% alcohol solution of phenolic varnish FL-98 with subsequent sintering in a LH15/12 batch furnace at the temperature of 700 °C.

After the sintering, the glomed material was granulated and sieved through a set of sieves to sort out 50–160 μm size particles. The testing of experimental boride-hardened powders for gas powder surfacing was prepared in accordance with GOST 21448-75 «Surfacing alloy powders».

Surfacing was performed by a oxypropane torch with No.5 tip manufactured under the specification No. 200 of Kaz. SSR 210-84, under the patent №1276 issued by the Republic of Kazakhstan. Compressed gases were used during surfacing: oxygen under GOST 5583-78 and propane under GOST 20448-80. The reference specimen was made of 45 steel under GOST 1050-88, and had dimensions of 30×45×11 (mm). Gas powder surfacing was carried out by the application of 1.2–1.5 mm thick surfacing layer under the following conditions:

Oxygen pressure at the torch inlet — 9.0 kg/cm^2;

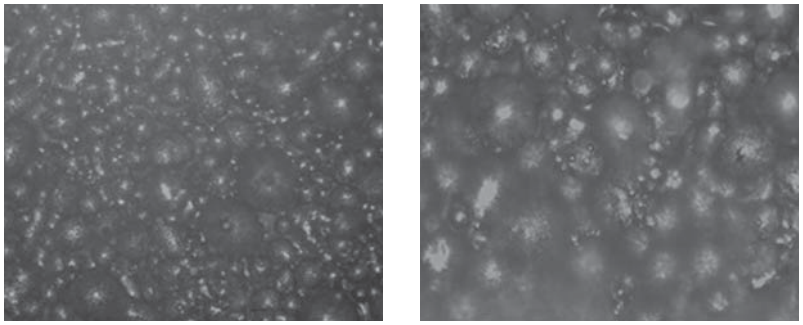

Fig. 1. Photomicrographs of the powder with ×200 and ×500 magnification

Propane pressure at the torch inlet — 1.2 kg/cm²;
Oxygen expenditure — 750 l/h;
Propane expenditure — 700 l/h;
New surfacing alloy expenditure — 50 g/min;
Surfacing layer thickness — 2–3 mm.

The surface of the surfacing layer was treated with an abrasive tool made of green silicon carbide. The coating is free of pinholes and slag inclusions.

Research results and discussion

Fig. 1 contains photomicrographs of the produced surfacing powder demonstrating that the particles are globe- and oval-shaped and their size ranges from 50 to 160 μm.

Chemical composition (**Fig. 2**), powder and composite coating structure was studied with a spectrometer. The used spectrometer had no function of boron, carbon and silicon identification, therefore the initial data on their content in the studied alloys was put in the graph. The content of other elements in the alloy corresponds to their content in the initial powder. The effect of CrB_2 additive on the changes in the chemical composition of the PG-Z40-based alloy is shown on the graph.

X-ray structure analysis (**Fig. 3**) showed that the alloy's structure is a composition including relatively strong and plastic iron nickel matrix and strengthening phases in the form of carbides and borides such as FeB; Cr_2B; Cr_2B_2; Cr_3C_2; Cr_5B_3; Cr_7C_3; $Cr_{23}C_6$; Fe_3C; Cr_7BC_4; Fe_3C, silicon nickelide Ni_2Si_5. The produced material is an iron nickel low alloy with a typical two-phase structure. The 12.1% increase of chromium content in the two-phase Fe–Cr structure of the PG-Zh40+10% CrB_2 alloy in comparison with the similar PG-Zh40 structure should also be noted.

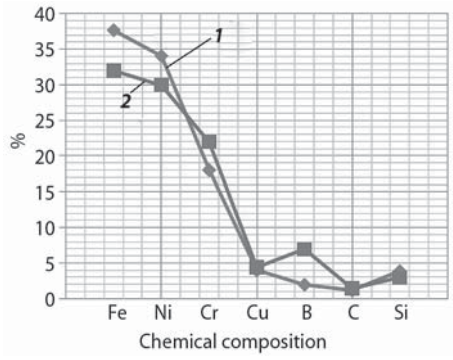

Fig. 2. Chemical composition of the surfacing powder
1 — powder alloy PG-Z40 — 100%; *2* — powder alloy PG-Z40 90% + 10% CrB_2

Microhardness on Vickers scale was measured separately for the two alloys and the diffusion zone with the results showing hardness value on the steel baseplate in the diffusion zone and on the surface of the studied glomed powder alloy. The obtained microhardness values for the surfaced coating in the fusion zone of the studied specimen are shown in the **Table 1**.

It has to be noted that microhardness increases in the direction towards the surfaced coating of the studied sample.

Coating microhardness values are uniform, there are no apparent hardness variations. The value range from 400 to 500 MPa, implying uniform distribution of carbides and borides, i.e. the structure is homogeneous throughout the entire area of the surfacing coating. (**Fig. 4**). The coating microhardness was measured on the polished specimen No. 1, No. 2 having 2 mm thickness in 4–7 measurements of the diagonal of impression.

The obtained microhardness values for the surfaced coating of the sample are shown in the **Table 2**.

According to microhardness measurement results, the average microhardness value of the sample surfaced with the boride-hardened alloy increases by 54.41 HV in com-

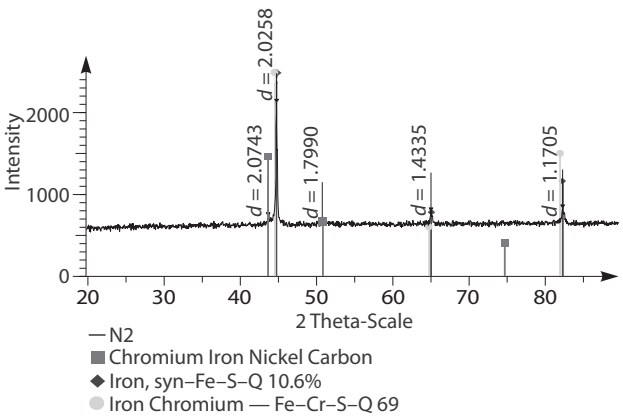

Fig. 3. The results of X-ray structure analysis for PG-Z40+10% CrB_2

Table 1. **Microhardness measurement results for the studied sample**

Impressions	Vickers hardness, HV 10 kgf		
	Steel baseplate	Diffusion zone	Sample material, 90% PG-Zh40 +10% CrB_2
1	382.72	381.40	456.72
2	362.75	426.57	470.63
3	375.41	428.62	530.29
4	359.34	443.42	485.18
Average	HV = 370.34	HV =420.00	HV =546.96

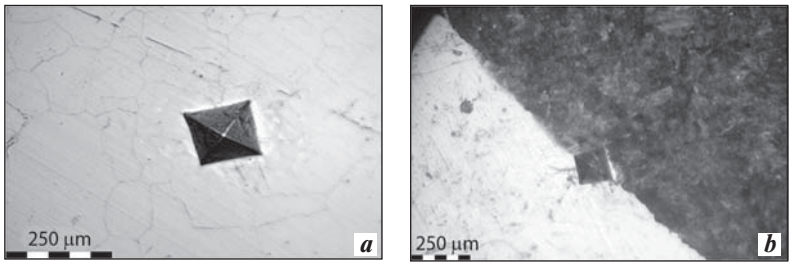

Fig. 4. The size of an impression on the polished specimen of the samples: *a* — PG-Zh40; *b* — PG-Zh40 +10% CrB_2

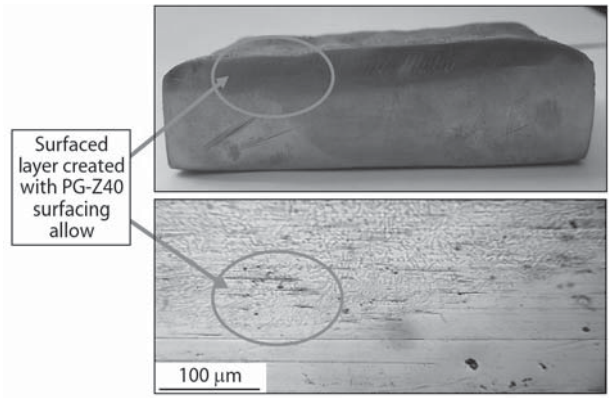

Fig. 5. Microstructure of the surfaced metal (PG-Zh40+10% CrB_2) with base metal, ×500

Table 2. **Microhardness measurement results for the polished specimen of the sample No. 1 surfaced with PG-Zh40 alloy**

Impressions	Vickers hardness, HV 10 kgf (the specimen No. 1)	Vickers hardness, HV 10 kgf (the specimen No. 2)
1	482.71	563.64
2	519.13	546.15
3	487.67	542.09
4	492.71	547.96
Average	HV = 495.55	HV = 549.96

parison with the initial alloy obtained with the surfacing with PG-Zh40 material.

The study of the fusion zone of the new boride-hardened alloy was carried out with the use of metallographic microscope with ×200 and ×500 magnification. The polished specimen was prepared using a sample surfaced with glomed powder alloy of the following composition: 90% PG-Zh40 + 10% CrB_2. **Fig. 5** shows the boundaries of the surfaced alloy's diffusion zone. The structural condition of limit of the section between a gas-flame covering and substrate is defined and existence of a diffusive zone as transitional area from covering material to a substrate is established. However owing to a number of factors (dependence of structural and phase transformations at a deposit from element structure and a preliminary state to a deposit; a variety of the modes of a deposit, etc.) the available information is still not enough for full understanding of regularities of structural and phase transformations and adequate forecasting of allocation of certain phases when fusing. Thereof the

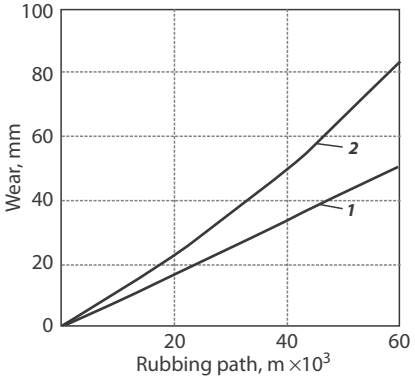

Fig. 6. The new alloy and steel wear rates: *1* — The new PG-Z40+10% CrB_2 alloy; *2* — 45 steel, 55 HRC hardness

problem of carrying out additional complex materials research researches is relevant.

Fig. 6 shows the results of wear assessment for the samples with surfaced coating hardened to 55 HRC compared to 20GL steel pads. We can assume that wear resistance and durability of components of friction units is increased after their reconditioning by PG-Zh40 +10% CrB_2 alloy surfacing.

Metallographic analysis was conducted for the sample No.1 surfaced with PG-Zh40 alloy and for the sample No.2 surfaced with PG-Zh40+10% CrB_2 alloy. Microanalysis was preformed with the use of Neophot-32 metallographic microscope with в ×200 and ×500 magnification.

Fig. 7 shows homogeneous polyhedral, equiaxial block structure with a coarse-grain to fine-grain structure transition zone and localized solid copper solution particles.

Chains of multiple proeutectoid constituent precipitations of two types (dark, and sometimes light), which seem to be iron and chromium carbides, can be observed along the grains' boundaries.

Fig. 7 also shows large crystals composed of ultrafine grain sub-crystals in the microstructure of the alloy. Polyhedral ferrite crystals — solid carbon solution in α-iron and perlite — eutectoid mix of ferrite with carbide of iron and chrome.

From the obtained data we can conclude that the developed boride-hardened surfacing powder PG-Zh40 + 10% CrB_2 has increased hardness and better properties compared to PG-Zh40 surfacing powder.

Conclusion

As the strengthening additive CrB2 ligature has been chosen, hardener added to the new PG-Zh40 surfacing alloy. It has been determined that in order to achieve 450–600 HV hardness of surfaced metal, the hardener has to be added in the amount up to 10% of total weight.

X-ray structure analysis showed that after compound mechanical the composite surfacing alloy PG-Zh40 with the addition of 10% of chromium boron appears as an

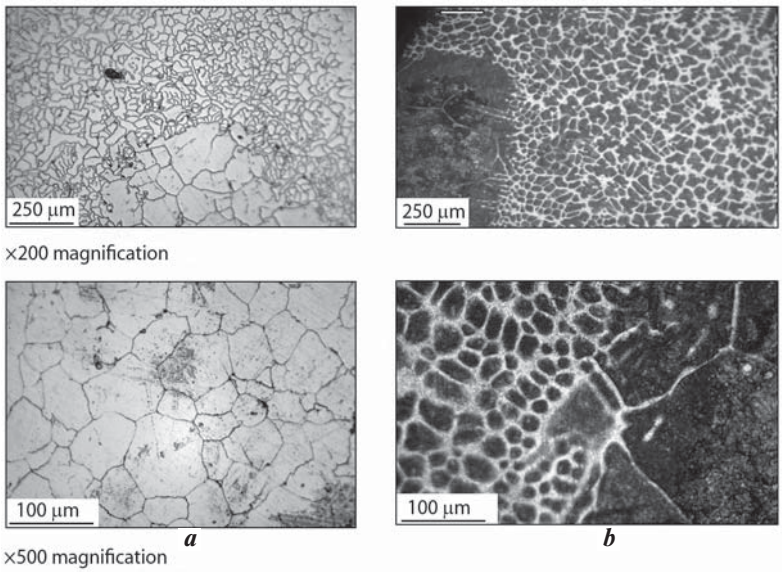

Fig. 7. Microstructure of the layer surfaced with PG-Zh40 alloy (*a*) and PG-Zh40+10% CrB_2 alloy (*b*)

iron nickel matrix with evenly distributed iron, chromium and nickel borides and carbides, and this observation is confirmed by the surfaced metal microhardness increase from 495.55 to 549.96 HV.

Increased hardness coatings can be created on the basis of the self-fluxing PG-Zh40 alloy by adding chromium borides to the alloy prior to gas powder surfacing. Chromium borides are genetically bound by the composition of the surfacing material. The obtained structure ensures maximal wear-resistance of the coating and is characterized by even distribution of hardening crystal throughout the entire section achieved by the coating layer surface melting at the temperature of 1000–1100 °C. Inadequate temperature during melting does not dissolve the added borides, and it results in non-homogeneity of the surface microstructure. Fuller studying of distribution requires carrying out electronic microscopy.

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