Journal of Chemical, Biological and Physical Sciences

An International Peer Review E-3 Journal of Sciences

Available online atwww.jcbsc.org

Section C: Physical Sciences

CODEN (USA): JCBPAT Research Article

Self-Fluxing Surfacing Ferrous Alloy

I.K. Beysembetov, B.K. Kenzhaliev, V.G. Mironov, G.T. Shilov, Z.B. Ilmaliev, K.R. Omurbekova

Kazakh British Technical University, «KBTU ETALLUM» LLP, Almaty, Tole bi str., 59

Received: 12 May 2015; **Revised:** 1 June 2015; **Accepted:** 9 June 2015

Abstract: The article contains data on the research and development of self-fluxing surfacing ferrous powder and production specifications for apilot batch of surfacing powder designed for the reconditioning of critical components of various equipment and parts of machinery and mechanisms of miscellaneous purpose in transport and power engineering industrial sectors. The new self-fluxing surfacing ferrous powder alloy for gas powder surfacing was produced with the use of mechanochemical method.

Keywords: Self-fluxing alloy, gas powder surfacing, durability, mechanochemical technology, attritor, granulation.

INTRODUCTION

In most cases (up to 90 %), railway equipment parts break down due to the wear of their work surfaces. For this reason, development of surfacing materials designed to form a solid and durable layer of metal on work surfaces is a critical and urgent issue [1]. Production of specialized self-fluxing surfacing powder materials will allow for their wide industrial use in application of protective and reinforcing coating resulting in the extension of equipment service life. Surfacing powder materials produced under various methodologies are used for reconditioning of parts with gas-flame spraying and surfacing, and there are some specific requirements to their properties: the production technology should be simple, and the materials should be highly effective when used for spraying on worn surfaces. Application of protective and reinforcing coating to worn parts of miscellaneous equipment and machinery allows for reduction of ferrous metals' expenditure. In particular, it helps to significantly increase service life of railway rolling stock, reduce idle time spent awaiting maintenance, and reduce the costs of routine maintenance, major overhauls and reconditioning repairs, with the extension of equipment service life. This way of equipment parts and components reconditioning yields considerable economic benefits. Many different surfacing materials have been developed and are used at the present time [1].Complex alloys containing expensive and difficult-to-obtain alloying elements find their application, but complex alloyed steel is not widely used, and the cost of reconditioning involving expensive alloys is ever increasing [2]. 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 alloys are cobalt-, nickel- and copper-based with various carbide-forming additions ensuring required physical and mechanical properties of surfaced (applied) coating. Powder surfacing alloys have melting temperature of 970-1100°C. The new self-fluxing surfacing ferrous powder material 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. Technologically, the alloy closest to the proposed engineering solution is the surfacing ferrous alloy PG-Z14 produced under technical specification №19-4206-139-86 and designed for parts reconditioning by thermal spraying and surfacing with coating hardness of 40,8 HV. The production of this alloy is a metallurgical process during which the fusion mixture is melted in an induction furnace, and after that the liquid metal is sprayed through a nozzle with the use of noble gas. However, this alloy has poor adhesive properties causing insufficient adhesion between the coating and the base. The metallurgical process of the alloy production can be characterized by high energy consumption and low yield of powder particles of required size (40-160µm).

RESEARCH METHODOLOGY

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. 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 as well as scanning and transmission electron microscopy. 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 200x, 500x and 1000x magnification. Energy-dispersive elemental microanalysis was used to perform surface spot analysis and mapping. Further research of the sample was performed with mapping which helped to identify oxide containing solid solutions of Fe, Cr, B, Ni and microinclusions[4-6].

Self-Fluxing Surfacing Ferrous Powder Production Technology: Fe, Ni, Cr, Si, Cu,B,C powders, the properties of which are listed in the **Table 1**, were used as the base components.Copper was added to increase fluidity of the liquid melt and to improve corrosion resistance of the alloy. Vanadium was added to improve cold resistance of the alloy. Vanadium and carbon form strengthening phases improving wear resistance of the alloy. Increased carbon content is necessary to produce carbides that evolve from the liquid solution during gas powder surfacing, become the centers of crystallization and aid to the structure granulation, which in turn improves the alloy's durability.

Table 1: Base components properties

№	Powder name	Particle size, µm	Microhardness, MPa	Formation method
1	Fe,	40-80	125±32	Liquid melt spraying, electrolysis
2	Ni	70-100	140±50	
3	Cr	20-40	161±20	Metallothermic reduction
4	Si	60-100	1245±40	Ingot granulation
5	Cu	60-100	96±18	Electrolysis
6	B	40-90	40±80	Ingot granulation
7	C	10-20	110±130	

Test charges of the base powders conforming to the set chemical composition of the proposed powder alloy were loaded into a laboratory high-powered generator – attritor (SGL-70 type) and subjected to mechanochemical treatment in an argon environment. The alloy was being produced with the following production conditions:

- mixer rotation rate - 330 rpm;
- ball weight / powder mix weight ratio- 30:1;
- volume of balls loaded into the attritor- 0,42 of the attritor drum capacity;
- Process duration – 16 hours.

The powder mix that had underwent mechanochemical treatment was subjected to magnetic separation to separate the particles of the produced homogeneous powder alloy from the particles of base metal powder which did not form chemical compounds with the fusion mixture components. The particles of homogeneous powder alloy with the size of 10-30µm were granulated with the addition of organic bond (phenolic varnish) in a laboratory planetary granulator allowing for the production of high density grain with the size of 40-160 µm. Figure 1 demonstrates the dependence of grain size on granulation time.

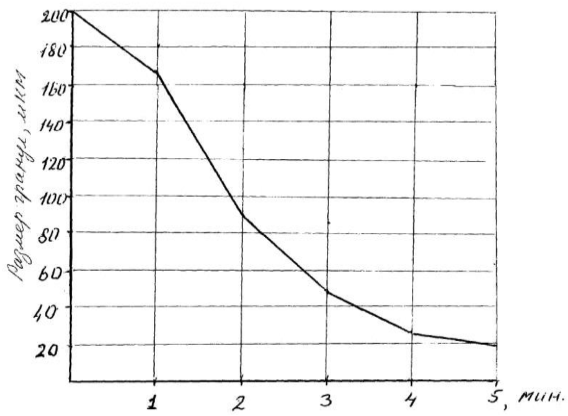


Fig. (1): The dependence of grain size on granulation time

Processing behavior of the produced granulated mix was tested on the samples with gas-flame surfacing method. The grain was loaded into the hopper of a propane-oxygen welding torch of the type patented as №1276 RK. The test demonstrated high flow of the grain blown with oxygen into the propane-oxygen flame zone; the presence of fluidizing agent in the surfacing powder mix does not impair the flow and wetting of the sample surface with the new surfacing alloy [7-8].

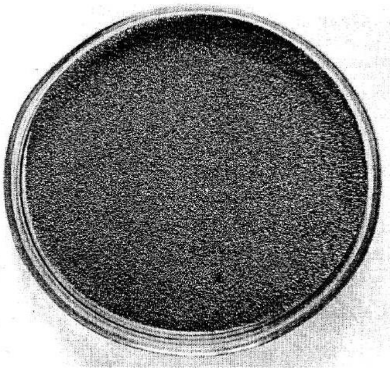
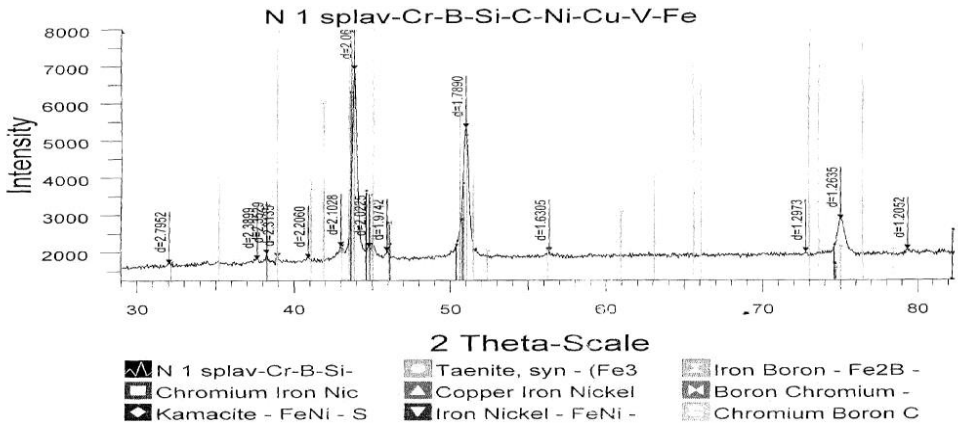


Fig. (2): The new surfacing alloy after the granulation with KBTU LLP planetary granulator, grain size 50-160 µm

SURFACING ALLOY STRUCTURE AND PHASE COMPOSITION ANALYSIS

X-ray phase analysis method was used to determine the phase composition of the new surfacing alloy. See **Fig. 3** for the X–ray spectrum of the examined sample.



Diffraction pattern of the Alloy Cr-B-Si-C-Ni-Cu-V-Fe sample

Fig. (3): Phase composition of the new surfacing alloy

See **Table 2** for the phase composition of the coating.

Table 2: X-ray phase analysis results

№	Name	Chemical formula	Percentage
1	Chromium iron nickel	FeCr0,29 Ni0,16	31,5
2	Iron nickel	FeNi	18,1
3	Chromium boron carbide	$Cr_7 BC_4$	15,3
4	Iron nickel	Fe Ni	13,3
5	Constituents	Fe_3 Ni	7,9
6	Boron chromium	BCr	6,3
7	Copper iron nickel	Cu0,33, Fe0,33, Ni0,33	5,7
8	Iron boron	Fe_2 B	1,9

X-ray structure analysis showed that the alloy's structure is mainly represented by iron nickel matrix (76,5%) with the inclusion of chromium and iron borides and chromium carbides: BCr, Cr_2 BCu, Fe_2B (23,5%). These are the strengthening phases of the surfacing alloy that improve hardness, and consecutively, performance properties of the alloy.

Metallographic analysis was performed on a sample surfaced with the new surfacing alloy: 19% NiB15; 18% Ni; 18% CrB17; 5% Cu; 4% Si; 1% C; 35% Fe. Scanning electron microscopy delivered images made with the use of secondary and back-scattered electrons. The images show non-uniformly distributed rectangular particles. Mapping and surface spot analysis were performed with a JXA-8230 electron probe microanalyzerand energy-dispersive element microanalysis. A general view of the microstructure achieved with the new surfacing alloy application is shown on **Fig. 4** made with scanning electron microscope and optical microscope. According to the analysis, the surfacing alloy is a low iron nickel alloy with a typical two-phase structure.

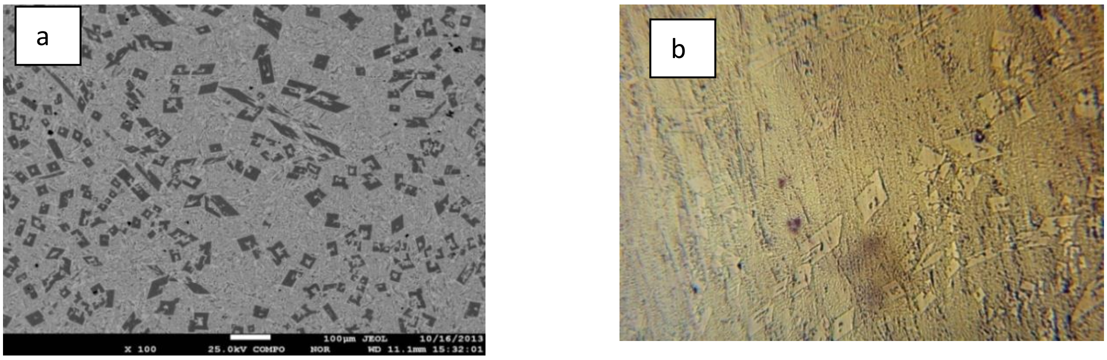


Fig. (4): Microstructure of the new surfacing alloy coating as shown by a scanning electron microscope (a) and an opticalmicroscope(b)

Further examination of the sample was performed using mapping which aided in the identification of element arcs for oxide containing solid solutions of Fe, Cr, B, Ni and inclusions. See **Fig. 5** for mapping results.

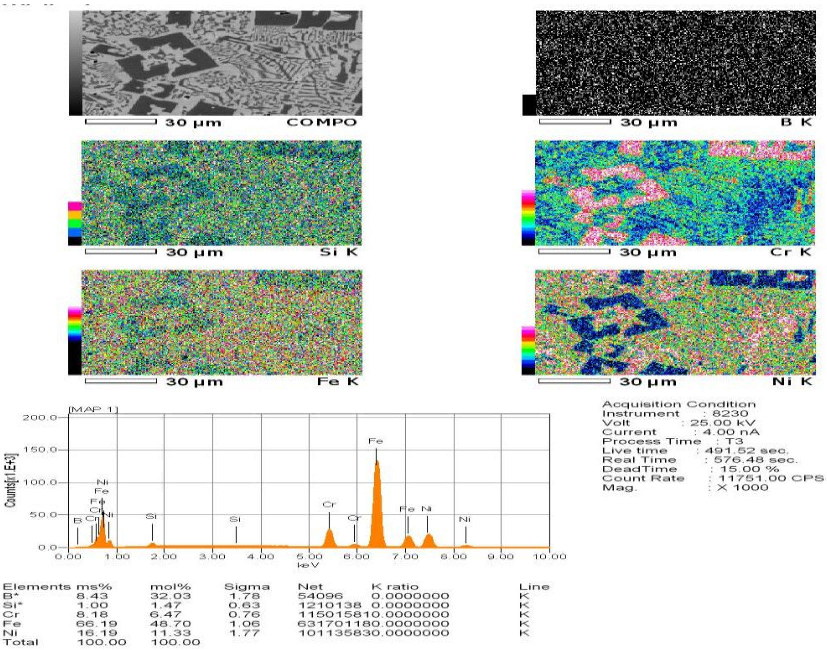


Fig. (5): The results of sample mapping

Based on the research, the concentration of the alloy's main chemical elements is shown by the peaks of X-ray patterns taken at the dark and light areas of the specimen. One can note high content of nickel, iron and chromium and low carbon content resulting in improved wear resistance and, consecutively, improved performance properties of coatings.

Coating microhardness values are uniform, there areno apparent hardness variations. The value range from 400 to 500 MPa, implying uniform distribution of carbides and borides, i.e. the structure is homogeneous through the whole area of the surfacing coating.

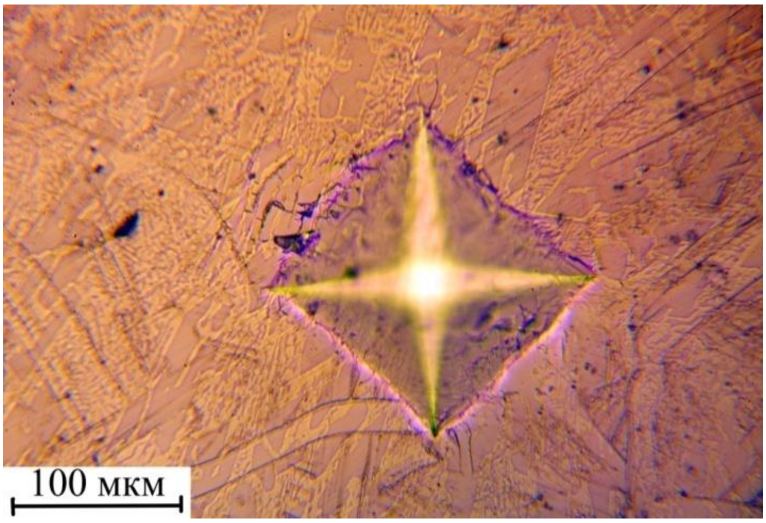


Fig. (6): Size of indentation on the specimen sample

The microhardness values for the surfacing of the examined coating sample are shown in **Table 3**.

Table 3: The examined sample's microhardness measurement results

Indentations	HV 10 kgf
1	527.47
2	482.71
3	519.13
4	544.76
5	487.67
6	538.90
7	492.71
8	500.42
9	513.68
10	414.55
11	410.66
12	524.67
	AverageHV=**496.44**

In general, it can be noted that the distribution of hardness, and therefore, carbides and borides in the coating, is uniform.

The conclusion is that the new surfacing alloy helps to achieve homogeneous structure through the whole area of coating, which is important for the recovery of physical and technical properties of parts, in particular, automatic coupling devices in the environment of impact and abrasive wear.

CONCLUSION

A pilot batch of self-fluxing surfacing ferrous alloy was produced and examined. The developed alloy allows for significant reduction of surfacing material production costs, in particular, by replacing metallurgical method of powder production with mechanochemical production which does not require complex equipment use. The new technology also helps to reduce the percentage of expensive chemical elements such as nickel and copper in the alloy through the increase of iron content. Self-fluxing surfacing ferrous powder pilot batch production technology was developed; the team also identified technical specifications for the surfacing powder material pilot batch production and developed the list of process equipment and powder materials required for the production of the new surfacing powder alloy.

The advantage of this material lies in the potential of quality application of thin coatings with thickness of 0,1 to 3 mm with even surface, without melting of base metal, high gas and flux protection of surfacing bath, preservation of the original composition of surfaced material and high (up to 80%) rate of powder usage. The new surfacing alloy possesses self-fluxing properties.

The testing of the developed PG-Z40 alloy was carried out at industrial enterprises involved in repair of automatic coupling devices of freight and passenger railway cars and specialized rolling stock: Almaty Railway Car Repair Plant JSC, Kaztemirtrans Kushmurun car repair depot JSC, Remplazma LLP (Petropavlovsk). The developed alloy was used for the recovery of various machinery and equipment parts in the Republic of Kazakhstan.

The replacement of currently used nickel-based surfacing powders with the new ferrous surfacing powder alloy will result in significant reduction of reconditioning costs for worn surfaces of parts and components of a wide range of recoverable parts.

REFERENCES

1. V.N. Lozinsky, Welding technologies at railway transportation enterprises/ The materials of the scientific and technical seminar “Advanced welding techniques in industry”, Kyiv, 2003. P. 24-26.
2. N.A. Kostinand V.V. Artemchuk, Strengthening and reconditioning of parts with the use of laminated coating, - Surface engineering and renovation of equipment, the materials of the 8th International scientific and technical conference (27–29th May, 2008, Yalta), Kyiv – 2008. P. 109-110.
3. B.K. Kenzhaliev, V.G. Mironov, G.T. Shilov and E.N. Sueymenov, Patent №27499 of the Republic of Kazakhstan. Production process for surfacing powder alloy for gas-thermal coating /, published in September, 2012.
4. M. Hocking, Metallic and ceramic coatings. Production, high temperature properties and applications. // Translation from English edited by G.A. Andrievsky. M.: Mir, 2006. 518 p.
5. L.I. Mirkin, X-ray diffraction control of engineering materials / – M.: Mashinostroyenie, 1979, 134 p.

6. S.S. Gorelik, X-ray diffraction and electron optical analysis, – M.: Metallurgia, 1970, 338 .
7. V.A. Popov, V.A. Zaycev and A.S. Prosviryakov,The study of mechanical alloying processes during the production of composite materials with nanoscaled strengthening particles. Nanostructuredmaterialsandfunctionalcoatings, №1, 2010, p. 48-52.
8. Procedural guidelines "Physical and chemical basics for granulation and mixing of oxide materials and produced powder quality control methods". Belarus State University. Physical chemistry department. Minsk, 2010.

*** Corresponding author: K.R. Omurbekova;**

Kazakh British Technical University, «KBTU METALLUM» LLP, Almaty,Tole bi str., 59