

# Wear resistant layers obtained by using materials powder for overlay welding structural steel

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**crossref** <http://dx.doi.org/10.5755/j01.mech.17.2.340>

## 1. Introduction

Hardfacing is one of the most useful and economical ways to improve the performance of components submitted to severe wear conditions. A study [1] was to compare the microstructure and abrasion resistance of hardfacing alloys reinforced with primary chromium carbides, complex carbides or tungsten carbides. The results showed that the wear resistance is determined by the size, shape, distribution and chemical composition of the carbides, as well as by the matrix microstructure. The best abrasion resistance was obtained in microstructures composed of eutectic matrix and primary  $M_7C_3$  or MC carbides, while the higher mass losses were measured in completely eutectic deposits.

In the investigation [2] the microstructure and erosion-corrosion behavior of a Fe-Cr-C overlay (Fe Cr C-matrix) produced by plasma transferred arc welding and its metal matrix composite (Fe Cr C-M M C) were assessed. The Fe Cr C-M M C was obtained by the addition of 65 wt.% tungsten carbide. The Fe Cr C-matrix showed a dendrite structure and high concentration of carbides in the interdendritix zone. The addition of the WC reinforcing phase promoted the formation of W-rich intermetallic phases increased the microhardness values of the matrix phase of the Fe Cr C-matrix overlay and dramatically improved its erosion-corrosion performance as expected.

The wear properties of harfacing welding depend upon several factors such as hardness, thickness of surfacing layers, the microhardness and toughness of matrix structure, volume fraction and distribution of the hardness phases, operating conditions, welding process, etc [3]. Based on lath martensite and carbides, the surfacing electrode with high hardness was developed owing to adding graphite, ferrotitanium, ferrovandium, etc. in the electrode coating. Although the content of carbon element in deposited metal is very high, the lath martensite is generated in welded metal because TiC-VC particles are formed by means of high temperature arc metallurgic reaction. The results show that the hardness of surfacing metal is above 60 HRC. Surfacing layers have fine crack and high wearability.

The influence of the composition and heat treatment of overlays on the abrasive wear resistance of iron base hardfacing alloy overlays is reported in [4]. Overlays were deposited using a shielded metal arc welding process on structural steel using two commercial hardfacing electrodes, i.e. Fe-6% Cr-0.7% C and Fe-32% Cr-4.5%C. It was found that the wear resistance of the high Cr-C coating is better than the low Cr-C hardfacing under identical conditions. The microstructure of overlays is more important than the hardness is deterring the low abrasive wear resis-

tance of iron based hardfacing alloys.

The abrasive wear of machine parts and tools used in mining, earth moving and transporting of mineral materials can be lowered by filler wire welding of hardfacing alloys. In paper [5] the microstructures of Fe-Cr-C and Fe-Cr-C-Nb/Ti hardfacing alloys and deposits and those of newly developed Fe-Cr-C-B and Fe-Ti-Cr-C-B ones are described. They show up to 85 vol.% of primarily solidified coarse hard phases, i.e., carbides of MC,  $M_7C_3$ ,  $M_3C$  type and borides  $MB_2$ ,  $M_3B_2$ ,  $M_2B$ ,  $M_3B$ ,  $M_{23}B_6$  type, which are embedded in a hard eutectic.

The abrasive wear resistance of the weld overlay coating containing primary carbides  $M_7C_3$  depend on the size of carbides and strength of the matrix [6]. Better abrasive wear resistance was achieved with larger primary carbides, which are better able to resist fracture than the smaller and narrower carbide rods.

Study [7] presents the research related with abrasive erosion wear of electrical arc welded hard layers. Under abrasive erosion condition the wear of electrical arc welded hard layers is lower if compared to Hardox 400 up to 31% at the abrasive particles impact angle of  $30^\circ$ , and only up to 4% at the perpendicular particles impact. Under the abrasive particles stream impacting the surface at oblique impact angle the most resistant to wear are the layers alloyed with 1.6-1.9% carbon and 4-8% chromium while under the normal impact the most resistant to wear are the low carbon layers with 0.15% C and high chromium layers alloyed with 15% Cr.

In the investigation [8, 9] is determined that the service life of machine elements depends from surface properties and wear conditions.

Work [10] examines the feasibility of applying wear resistant cladding material to grey cast iron, which was usually used as the material of machine tool structures to improve their wear performance. The extent to which cladding powders and post treatment that affects the wear resistance of the clad layer is also studied. A W-Ni clad layer formed with W (90 wt.%) and Ni (10 wt.%) powder, outperforms clad layers formed by similar powders with different cladding materials, in term of wear performance. Although the other clad layers, such as W-Cu, W-Co and W clad layer, had different shapes of precipitate, their wear performance was also better than of the base metal, obviously.

In general overlaying welding is performed by various arc welding techniques: using continuous or powder wire, under flux or protective gas. Most often the objective of overlaying welding is formation of wear resistant layer. The best results are obtained when hard carbide particles are inserted into the mild steel subjected to overlay-

ing welding matrix. The objective of this investigation is to analyze properties and microstructure of the layers produced using powder materials as well as effect of heat treatment and effect of chemical composition and microstructure on adhesive wear.

## 2. Materials and investigation procedures

Simple, widely used in practice automatic submerged arc welding was chosen for our experiments. A strip of structural steel Cr3 (GOST 380-88) subjected to surface grinding was used for the specimen preparation. Low carbon steel Cr3 (0.2% C) was overlay welded by materials powder melted by low carbon 1.2 mm diameter welding wire Cв08 (C < 0.1%) (GOST 2246-70) arc. Standard flux AMS1 containing more than 50% SiO<sub>2</sub> and MnO was used for overlay welding. Purpose of the flux is to protect molten metal from oxidation and ensure necessary metallurgical processes. Addition into the flux of materials powder resulted alloying of the molten metal by the elements from the powder. Aiming to alloy the welded layer powder containing alloying elements (Cr, Mo, W, Co), Fe-60%V, Fe-70% Mn, B<sub>4</sub>C, WC-8%Co, P6M5K5 was spread over the steel surface or mixed with the flux. WC-8%Co powder is used for hard metals production; it is obtained mixing WC with cobalt. WC-8%Co powder was obtained from grinded used hard metal plates. SiC powder was obtained from grinded wheels. Grinded glass and marble as well as cast iron and P6M5 steel chips were used for overlaying welding. Boron is desirable in welded layers element, because it improves steel hardenability, forms hard borides or carboborides. Layers of high primary hardness are obtained when welding material contains boron. To obtain the layers alloyed by boron, boron carbide was used. Carbon amount in the layers was increased by addition of graphite powder into the powder mixtures.

## 3. Results of the investigation and analysis

Cr3 steel specimens were subjected to overlaying welding by the same regimes:  $I = 180-200$  A,  $U = 22-24$  V,  $V_{wire} = 25.2$  m/h,  $V_{weld.} = 14.4$  m/h [11]. Composition and microstructure of the welded layers is effected by powder

used for welding composition; powder was melted together with flux, when it was inserted into the mixture or if it was spread over the surface. In course of the welding process in the arc zone continuously supplied low carbon steel wire results welded layers enriched with iron: aiming to obtain alloyed layer containing high enough contents of carbon, more powder should be used. Addition of the powder into the flux worsens metallurgical processes, going on in the welding zone, metal of the welded layers is not high quality, because the amount of flux forming liquid slag decreases, and liquid metal is badly deoxidized and protected from air effect.

Utilization of metals powder for arc overlaying welding enables to improve process effectiveness and to obtain optimal alloyed welded layers [12, 13]. Besides, the amount of expensive welding wire is decreased.

Hard and wear resistant layers were obtained when base structural Cr3 steel was subjected to overlaying welding by low carbon wire Cв 08 and alloying elements and graphite powders. Composition of the powder mixtures and dependence of the welded layers hardness on tempering temperature are shown in Table 1.

Hardness of the first layer is 48 HRC; tempering at 650°C temperature resulted hardness increase to 62 HRC. Chemical composition of this layer is similar to high speed steel P6M5K5 (GOST 19265-73) composition (Table 2). The second layer is obtained utilizing drill milling chips (P6M5 steel). Composition of the layer is similar to that of P6M5 steel composition. Both layers contain increased manganese and silicon amount; these elements came from AMS1 flux, containing more than 50% SiO<sub>2</sub> and MnO. Increased carbon amount in the layers is obtained when graphite powder was inserted into the mixture (specimen 1) or into the AMS1 flux (specimen 2).

Microstructure of the welded layers subjected to etching by 3% nitric and spirit solution is shown in Fig. 1. Microstructures are similar: bright areas represent dendrites, which were not subjected by the solution. It means that overlayed layers at cooling were subjected to hardening and their microstructure consisted of martensite and residual austenite, which in course of tempering transformed to martensite and increased the layer hardness.

Table 1

Hardness dependence of the layers obtained by submerged arc welding of metal powder spread over Cr3 steel surface and melted by Cв 08 wire arc on tempering temperature

Specimen Nr.	Composition of powder mixture, mass, %								Flux	Tempering temperature, °C				
	C	Cr	W	Mo	Fe-60%V	Co	P6M5K5	P6M5 chips		No temp.	550	600	650	700
1	7	17	20	14	16	18	8		AMS1	48	52	55	62	57
2		9	9	18	6			60	AMS1+9% graphite	50	60	62	56	54

Table 2

Chemical composition of the welded layers

Specimen Nr.	Elements contents, mass, %								
	C	Mn	Si	Cr	W	Mo	V	Co	Fe
1	1.19	1.79	0.96	4.37	7.55	3.54	1.69	4.68	Remainder
2	1.06	2.33	1.02	3.41	6.85	6.80	1.15	0.008	

WC-8%Co powder spread over the Cr3 steel surface (powder layer thickness 4 mm) and melted in CВ08 wire arc under flux AMS1 containing graphite resulted hard (Table 3), and many carbides containing layers (Fig. 2). The change of graphite powder amount inserted

into the AMS1 flux enabled to obtain the layers containing to 80% carbides which microhardness was 8000 – 11500 MPa. Carbides are connected by martensite and residual austenite matrix, which microhardness after high temperature tempering was up to 6000 MPa.

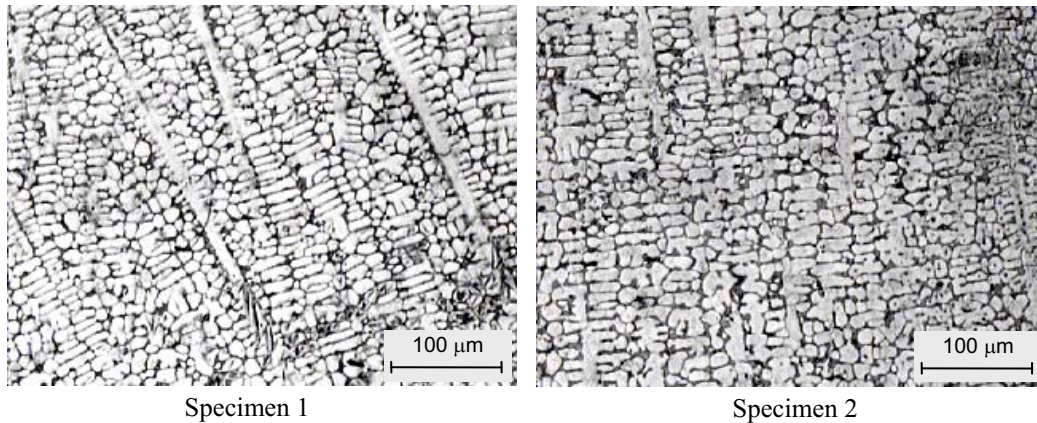


Fig. 1 Microstructures of the layers obtained by melting powder spread over Cr3 steel surface with CВ 08 wire arc under flux AMS1

Table 3

Hardness of the layers produced by melting WC-8%Co powder spread over Cr3 steel with CВ 08 wire arc under flux AMS1 and mixed with graphite powder dependence on tempering temperature

Specimen Nr.	Flux	Tempering temperature, °C			
		No temp.	500	550	600
3	87% AMS1+13% graphite	58	63	64	58
4	95% AMS1+5% graphite	60	65	66	59

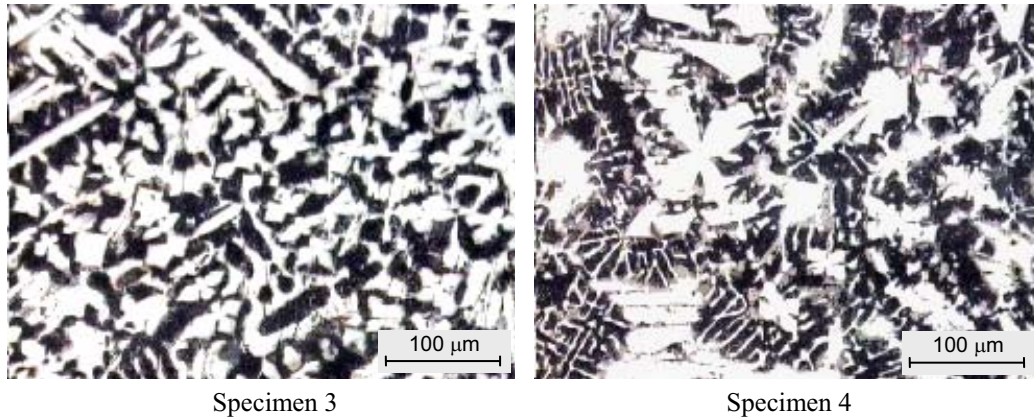


Fig. 2 Microstructures of the layers obtained by melting WC-8%Co powder spread over the Cr3 steel surface with CВ 08 wire arc under the AMS1 flux mixed with graphite powder

Wear resistance of the welded layers was analyzed by the device, in which 6 mm wide specimens were subjected to wear by 41 mm diameter and 14 mm wide rotating hard metal disk, pressed to specimen by 320 N load. The wear out of any specimen was evaluated after 20 min wear (6.69 m sliding distance) taking into account weight decrease (Fig. 3). Highest wear resistance was obtained for the layer welded utilizing WC-8%Co powder (specimen 4). Wear resistance of this layer is similar to high speed steel P6M5 (GOST 19265-73) and it is about twice more wear resistant in comparison with tool less alloyed steel XBG (GOST 5950-73).

Utilization of secondary materials for part production and restoration from the energy consumption point of view is urgent problem. The use of metal cutting chips for

surface overlay welding enables to save energy, because their preparation requires a little energy: most often it is needed to remove remainders of lubricant – coolant, or, in some cases, the chips should be grinded. Most valuable are the chips of alloyed steels because in course, of overlaying welding the layer is alloyed by elements from the chips. The Cr3 steel was overlay welded using P6M5 chips spread over the surface and melted by CВ 08 wire arc under AMS1 flux mixed with graphite or boron carbide powder. For comparison one specimen was overlay welded using cast iron chips melted under flux. Dependence of the welded layers hardness on tempering temperature is shown in Table 4. The P6M5 steel chips in course of welding layers were alloyed by chromium (0.6-1.01%), molybdenum (0.8-1.1%), vanadium (0.3-0.5%), tungsten (up to 1.84%).

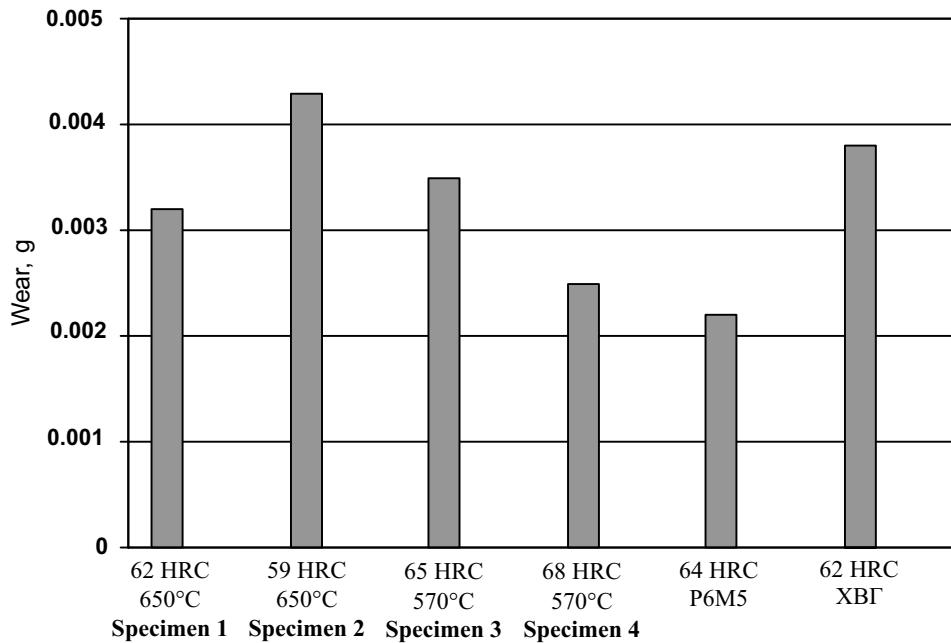


Fig. 3 Comparison of weight decrease of tempered welded layers with that of standard tool steels subjected to wear test for 20 min

From the AMS1 flux into welded layers migrated manganese (1.84-2.1%) and silicon (0.9-1.2%). Carbon amount in the layers was increased by graphite from the flux and boron carbide, which at high temperature decomposed into boron and carbon. Carbon contents in the layer was 0.65-0.92%. Boron as an element improving steel hardenability increased the layers primary hardness up to 65 HRC. More carbon containing layers after the welding hardened only

partially (48 HRC); at tempering, when residual austenite transformed to martensite, the hardness increased (550°C, 68 HRC). Hardenability of the layers was affected by increased manganese amount. Due to increased manganese amount, the layers welded utilizing cast iron chips, in course of cooling under flux hardened to 58 HRC (Table 4).

Hardness of the layers obtained by melting P6M5 steel or cast iron chips spread over the Cr3 surface with C<sub>B</sub> 08 wire arc under flux depending on tempering temperature

Table 4

Specimen Nr.	Chips	Flux	Tempering temperature, °C			850°C, H <sub>2</sub> O
			No temp.	550	600	
5	P6M5	90% AMS1+10% graphite	48	62	53	61
6	P6M5	85% AMS1+15% B <sub>4</sub> C	65	55	54	66
7	Cast iron	100% AMS1	58	44	36	64

Wear tests show that more resistant to wear is the layer welded under flux mixed with boron carbide powder (Fig.4). Wear resistance of this layer corresponds to that of standard chromium, tungsten and manganese (XBT, GOST 5950-73) alloyed tool steel, and this proves, that it is useful to subject structural steel to overlay welding utilizing P6M5 chips. Wear resistant depends not only on the hardness, but it is affected by microstructures as well. In the welded layer of the specimen 5 there was great amount of residual austenite and small number of hardness (48 HRC), in spite of this, the specimen wear was the same as it was when the specimen was hardened to 62 HRC after tempering at 550° temperature.

An attempt was made to subject structural steel to overlay welding without standard flux. Specimen was overlay welded using smashed glass, grinding wheels (SiC) and Fe-70% Mn powder. Silicon and manganese in the powder performed the same functions as Si and Mn in flux AMS1. Fig. 5 shows the dependence of welded layer hardness on tempering temperature. The highest hardness (67 HRC) is

obtained in welding by C<sub>B</sub> 08 wire arc spread over Cr3 steel surface mixture containing 40 % WC-8%Co powder (specimen 12). Investigation of the microstructure shows (Fig. 6) that in this layer there are carbides (white areas), fine dispersivity ledeburites (grey areas) and martensites-troostites (dark areas). Microhardness of the carbides – 7100 MPa, ledeburites – 6400 MPa, martensites – troostites – 4800 MPa. The layer of 62 HRC hardness (specimen 11), which was not getting milder at heating up to 600°C, was obtained using for Cr3 steel overlay welding powder mixture containing Fe-70%Mn and chromium powder in addition to WC-8%Co powder. Carbon amount in the layer was increased by decomposed in high welding zone temperature tungsten and silicon carbides. The layer was alloyed by tungsten, chromium, manganese, cobalt and silicon. Carbon together with alloying elements formed carbides phase (microhardness to 8000 MPa), which ensured heat durability of the layer. There is troostite in the layer as well (dark areas, Fig. 6), which is milder. The mildest layer was obtained (41 HRC) by melting powder mixture spread over

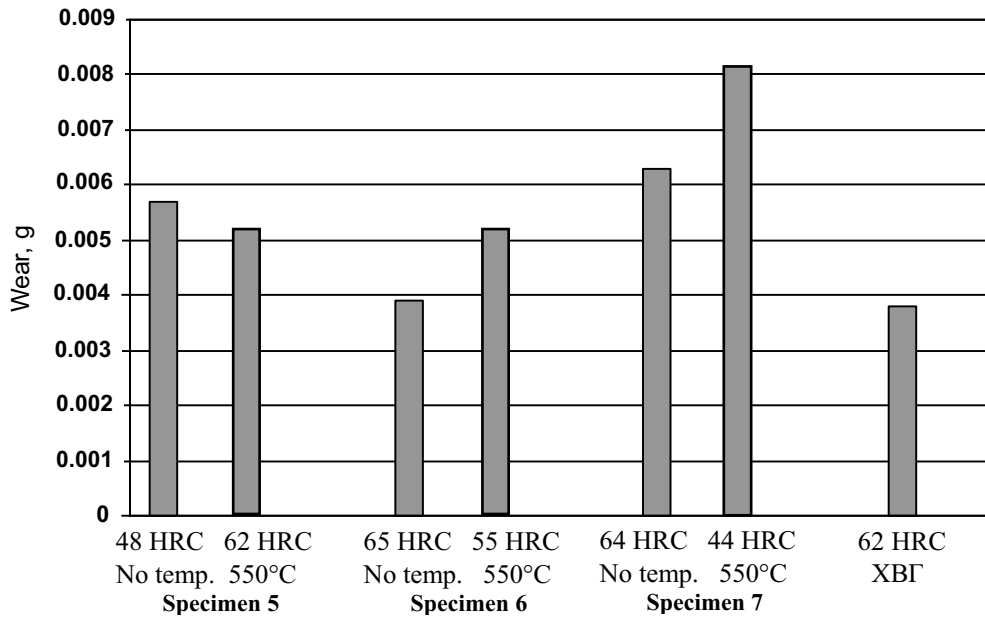


Fig. 4 Weight decrease of not tempered and tempered at 550° temperature layers in comparison with standard XBF steel subjected to 20 min wear test

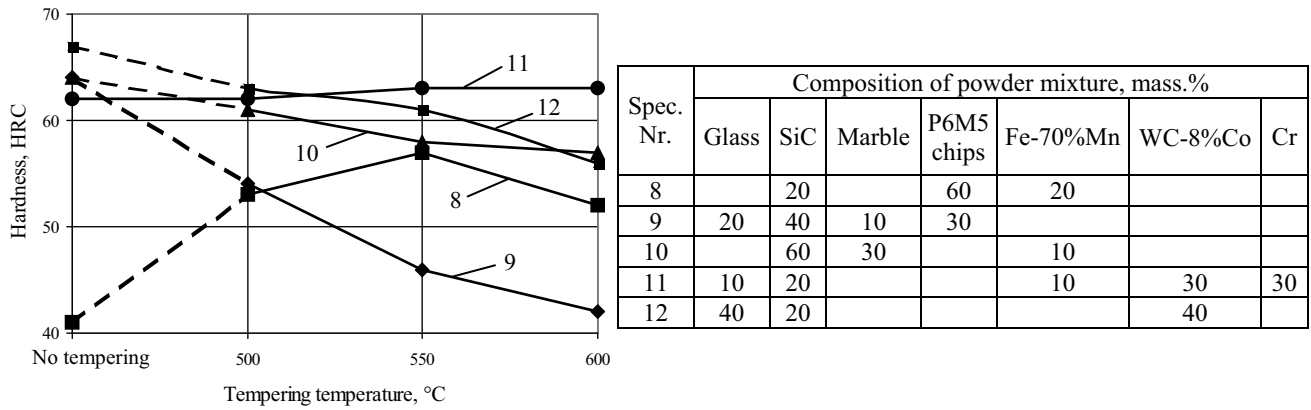


Fig. 5 Hardness of the layers obtained by melting in Cв 08 wire arc powder spread over the Cr3 steel surface dependence on tempering temperature

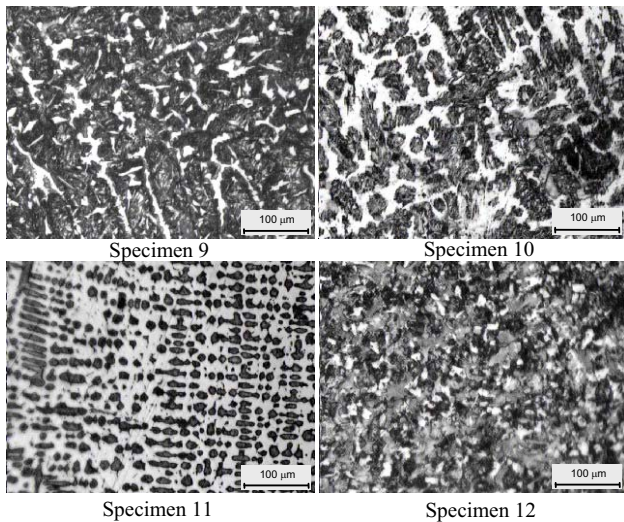


Fig. 6 Microstructure of the layers obtained by melting in Cв 08 wire arc powder spread over the Cr3 steel surface without flux

the Cr3 steel surface containing 60% P6M5 steel chips. Tempering at 550°C temperature resulted hardening of the layer to 57 HRC. Milder layer is easy to machine and later to harden by tempering; no hardening operation is needed.

#### 4. Conclusions

1. In the process of submerged arc welding, melting of materials powder spread over base metal surface or inserted into flux enabled to obtain alloyed, well melted with base metal welded layers.

2. Melting of WC-8%Co powder spread over the Cr3 steel surface in Cв 08 wire arc under flux AMS1 mixed with graphite powder, allowed to obtain rich in carbides, hard, wear resistant layers. Wear resistance is similar to that of standard high speed steel P6M5.

3. Melting of P6M5 steel chips spread over the Cr3 steel surface in Cв 08 wire arc under flux AMS1 mixed with graphite or boron powder, resulted hard layers. Primary hardness of the layer welded under flux mixed with boron carbide powder – 65 HRC, and secondary hardness of the layer welded under flux mixed with graphite powder – 62 HRC. It is possible to obtain the layers, wear resistance of which approaches that of chromium, tungsten and manganese alloyed tool steel.

4. Not using standard flux hard the layers up to 67 HRC are obtained, when grinded secondary materials (glass, grinding wheels waste, hard metal plates) are spread over the Cr3 steel surface and melted in Cв 08 wire arc.

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DILIMUI ATSPARŪS SLUOKSNIAI GAUTI  
KONSTRUKCINIO PLIENO APVIRINIMUI  
NAUDOJANT MEDŽIAGŲ MILTELIUS

R e z i u m ė

Darbe ištirta konstrukcinio plieno sluoksnių, apvirintų naudojant nesurištus medžiagų miltelius, struktūra ir savybės, o taip pat kietumo ir struktūros įtaka dilimui. Medžiagų milteliai užberti ant plieno Cr 3 arba sumaišyti su flisu AMS1, buvo išlydyti mažaanglės Cв 08 vielos lan-

ku. Apvirinimui buvo naudojami legiruojančiųjų elementų (Cr, Mo, W, Co), Fe-60%V, Fe-70%Mn, B<sub>4</sub>C, WC-8%Co milteliai bei antrinių žaliavų milteliai (stiklo, abrazyvinių šlifavimo diskų, kietlydinio plokštelių). Priklausomai nuo naudotų miltelių mišinių sudėties ir terminio apdorojimo, gauti legiruoti, kieti (iki 68 HRC) sluoksniai, kurių atsparumas dilimui panašus kaip ir standartinių įrankinių plienų.

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WEAR RESISTANT LAYERS OBTAINED BY USING  
MATERIALS POWDER FOR OVERLAY WELDING  
STRUCTURAL STEEL

S u m m a r y

Microstructure and properties of structural steel layers subjected to overlay welding utilizing materials powder as well as elect of hardness and microstructure on adhesive wear are investigated. Materials powder spread over the Cr3 steel surface or mixed with the AMS1 flux was melted in low carbon wire Cв 08 arc. The powder of alloying elements Cr, Mo, W, Co and Fe-60%V, Fe-70% Mn, B<sub>4</sub>C, WC-8%Co and of secondary raw materials (glass, grinding wheels, hard metal plates) was used for overlay welding. Depending on the used powder composition and heat treatment, alloyed, hard (to 68 HRC) layers, which wear resistance is similar to standard tool steel, are obtained.

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ИЗНОСОСТОЙКИЕ СЛОИ ПОЛУЧЕННЫЕ  
ИСПОЛЬЗОВАНИЕМ ПОРОШКОВ МАТЕРИАЛОВ  
ДЛЯ НАПЛАВКИ КОНСТРУКЦИОННОЙ СТАЛИ

Р е з ю м е

В работе исследована структура и свойства, а также влияние твердости и структуры на износостойкость слоев конструкционной стали наплавленной с использованием несвязанных порошков материалов. Порошки материалов, насыпанные на сталь Ст 3 или смешанные с флюсом AMS1, были наплавлены дугой малоуглеродистой проволоки Cв 08. Для наплавки были использованы порошки легирующих элементов (Cr, Mo, W, Co), Fe-60%V, Fe-70%Mn, B<sub>4</sub>C, WC-8%Co и порошки вторичных материалов (стекла, абразивных шлифовальных кругов, твердосплавных пластинок). В зависимости от состава смесей порошков и термической обработки получены легированные, твердые (до 68 HRC) слои, износостойкость которых такие же, как и стандартных инструментальных сталей.

Received October 15, 2010

Accepted April 05, 2011