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SUBMERGED ARC OVERLAYING WELDING OF STRUCTURAL STEEL BY WC-Co POWDER

NAPAWANIE ŁUKIEM KRYTYM STALI KONSTRUKCYJNYCH PROSZKIEM WC-8%Co

Arc welding under a flux, using various materials, technologies and regimes, enables to obtain thick, wear resistant coatings. Simple, easily realized is arc welding of spread over powder layer. In this research WC-8%Co powder was spread on low carbon structural steel surface and melted by arc under the flux, containing graphite powder.

The test performed show that using for overlaying welding under flux WC-8%Co powder, it is possible to obtain layers with large amount of carbides phase (about 90%); formation of carbides was influenced by both amount of WC-8%Co powder spread over the structural steel surface, and amount of graphite powder, mixed with flux. Electric arc between welding wire and base metal resulted, due to high temperature, melting of WC carbide in powder and formation of Fe_3W_3C carbide during cooling, because the iron into welding bath came from both melted welding wire and structural steel surface. The microstructure was obtained in which carbides are bonded by the matrix, having alloyed steel composition. The matrix is composed of martensite, troostite and retained austenite. Amount of those phases depends on the amount of alloying elements (W, Co, Mn and Si), and amount of carbon, as well as heat treatment.

The overlaying welded layers obtained had been more wear resistant than standard tool steel X12M (Russian Standard GOST 5950-73) of similar hardness.

Keywords: layer, arc welding, powders, microstructure, tempering, hardness, wear resistance

Spawanie łukowe pod topnikiem różnych materiałów na skalę przemysłową pozwala otrzymać grube, odporne na ścieranie powłoki. Stosunkowo łatwo zrealizować jest spawanie łukowe nakładane pod warstwą proszku. W tej pracy, proszek WC-8%Co był nakładany na powierzchnię nisko węglowej stali konstrukcyjnej i topiony łukowo pod topnikiem, zawierającym sproszkowany grafit.

Przeprowadzone próby wykazały, że używając napawania pod topnikiem proszkiem WC-8%Co, można otrzymać powłoki z dużą zawartością fazy węglików (około 90%); na tworzenie węglików wpływa zarówno ilość WC-8%Co nakładanego na powierzchnię stali konstrukcyjnej jak i na ilość proszku grafitowego zmieszanego z topikiem. Łuk elektryczny jaki powstaje pomiędzy drutem spawalniczym i metalem podłoża dzięki wysokiej temperaturze topi węglik WC w proszku i tworzy się podczas chłodzenie węglik Fe_3W_3C, ponieważ żelazo w kąpieli spawalniczej pochodzi zarówno z topionego drutu spawalniczego jak i powierzchni stali konstrukcyjnej. Otrzymano mikrostrukturę w której węgliki są związane przez osnowę, posiadającą skład stali stopowej. Osnowa jest złożona z martenzytu, trustytu i szczątkowego austenitu. Ilość tych faz zależy również od obróbki cieplnej.

Otrzymane napawane powłoki są bardziej wytrzymałe na ścieranie niż stal narzędziowa X12M (rosyjski standard GOST 5950-73) o podobnej twardości.

1. Introduction

Surface condition of structural components has been a persistent in modern engineering application. Some components stop functioning due to only the minor damage on the surface. Using cladding techniques, it is possible to improve surface properties. Submerged arc cladding has been used in modern industries, especially for the heavy section steels and for a large structure surface needing to be modified. Comparing with other welding process submerged arc cladding offer higher deposition rate, higher layering capacity and better bead characteristic with less-sophisticated automatic equipments [1].

Several cladding technologies exist. They are in varying states of development. Commercial availability of some might be limited in certain cases. The paper [2] deals with multiple wire submerged arc welding and cladding with metal powder addition. It was found

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that the use of metal powder will increase the deposition rate, and the welding arc efficiency and reduce the shielding flux consumption. The process is primarily meant for the cladding of worn surface or the production of surface with certain characteristics (corrosion or wear resistance). By using the metal powder addition it is possible to alloy a weld or a cladding with optional chemical elements. In the study [3] the hardfacing alloys were deposited twice on a low carbon steel substrate by a submerged arc welding method. Hardfacing alloys reinforced with complex carbides where hard, fine WC and TiC carbides were formed in a composite pattern were fabricated in order to develop new advanced materials applicable to high performance rolls. Microstructural analysis of the hardfacing alloys revealed that cuboidal carbides and rod-type carbides were homogeneously distributed in the bainitic matrix. Hardness and wear resistance increased with increasing volume fraction of complex carbides. Application of diffusion bonding in production of WC-base hardmetal-steel bimetal tools has been also discussed by J. Kubarsepp et al [4]. It was established that the shear strength of the cermet-steel joints was close to that of WC-base hardmetal-steel joints.

For overlaying welding metals it is used different ways and materials. Powders carbide it is widely used during thermal spaying for obtaining coverings of different structure and purpose. Exists works in which it is investigated coverings, are overlaying welded by the powder electrodes filled with powders carbide or overlaying welded by electrodes with a covering. In the work [5] were examined the following compositions: titanium carbide-pig iron, chrome carbide-pig iron and titanium carbide-chrome carbide-pig iron. The metallographic examination determined that the structure of the composition titanium carbide-chrome carbide-pig iron consisted of two structural composition such as inclusion of titanium carbide (microhardness 21-24 GPa) and eutectic mixture of titanium carbide-iron carbide (microhardness 19-21 GPa). The coatings investigated by J. N. Sarajev et al [6] were overlayed by special electrodes with a covering made of compound, consisting of titanium carbide and a binder (nichrom, high speed steel, carbon steel). It was found out that microstructure, phase composition and hardness of the welded pad depends on the electrode and basic metal both chemical composition. Coatings with austenitic and martensitic matrix structure were obtained. In this structure titanium carbides are uniformly distributed, titanium carbides pass to the coating from electrode covering or they are derived as a result of titanium and carbon reaction in melted layer. The paper [7] presents study in which Fe-based hardfacing coating reinforced by TiC particles was obtained by manual shielded metal arc welding (SWAW) in which H08A bare electrode was coated with fluxes, to which different measures of ferrotitanium, rutile, graphite, calcium carbonate and calcium fluoride had been added. The results indicate that TiC particles are producted by direct metallurgical reaction between ferrotitanium and graphite during welding. TiC particles are uniformly dispersed in the matrix of lath martensite and retained austenite with particle sizes in the range 3-5 μm. Fe-based hardfacing coating reinforced by TiC particles is found to possess better wear resistance and lower coefficient of friction than of AISI 1045 steel substrate.

The basic purpose of work there was to obtain of a wear resistance layers by overlaying welding under a flux with use powder WC-8%Co.

2. Experimental procedures

Specimens of a low carbon structural steel S235IRG2 FN (European Standard EN 10025) were overlaying welded in the device, assembled from the lathe and semi-automatic welder [8]. Powder spread over the surface, subjected to overlaying welding, was melted under the flux AMS1 (EN 750) in the arc between continuously supplied 1.2 mm diameter low carbon steel wire SFA/AWS A5·17 (EN 756) and structural steel plate. The chemical composition of a parent metal aimed at 0.14-0.22%C, 0.12-0.30%Si, 0.40-0.65%Mn. The average chemical composition of welding wire aimed at 0.09%C, <0.1%Si, 0.5%Mn. Specimens (20×100×4 mm) were fit in a holder with variable high of walls. The powder was simply poured on the specimens between these walls. The high of walls defined a thickness of the powder. The welded layer was obtained by one-pass and two-pass welding.

Layers of both various hardness and structure were obtained changing the amount of WC-8% Co powder (Russian Standard GOST 3852), spread over the surface, subjected to overlaying welding (Table 1). Carbon amount in the layers was changed adding graphite powder into a flux AMS1 having more than 50% of MnO and SiO_2. At high arc temperature the WC carbide (92%) and cobalt (8%) in the powder composition are melted as well as low carbon steel welding wire and graphite powder. Manganese and silicon diffused from the melted flux into metal bath. In course of liquid metal cooling, the carbide phase and solid solution (austenite) are formed and partially transformed into martensite or troostite. At room temperature the structure of overlayed layers consists of carbides, martensite - troostite and retained austenite. The retained austenite in process of tempering is transformed to martensite what resulted hardness increase of the layers. The hardness (HRC) of the specimens was investigated without tempering and after tempering at 550°C and 570°C temperatures. To characterize the structure and composition of the layers, X-ray diffraction and optical microscopy were used.

TABLE 1

Amount of spread out WC-8\%Co powder over the surface subjected to overlaying welding and amount of graphite in the flux

Specimen No	Thickness of WC-8% powder layer, mm	Flux AMS1+graphite, %	Specimen No	Thickness of WC-8% powder layer, mm	Flux AMS1+graphite, %
1	3	0	7	3	9
2	4		8	4	
3	5		9	5	
4	3	5	10	3	13
5	4		11	4	
6	5		12	5	

Abrasive wear — resistance of the layers was investigated according to the methodology presented in [9]. Test specimens (8×8×20 mm size) were pressed to rotating abrasive disk. The wear-out was evaluated by the decrease of the specimen mass.

3. Results and analysis

Hardness of one-pass welding layers depending on the amount of spread out powder and the tempering temperature and microhardness of the phases are shown in the Table 2. This shows that the hardness of layers obtained by one-pass welding varied from 47 HRC to 60 HRC due to different amount of carbon, tungsten and cobalt in their composition. The hardness was influenced by the amount of carbides and retained austenite. Tempering of the layers at 550°C temperature resulted both transition of the retained austenite to martensite and dispersion hardening, what allowed to obtain maximum hardness (until 65 HRC).

TABLE 2

Hardness (HRC) of overlayed layers and microhardness (MPa) of phases.

Specimen No	Amount of retained austenite, %	Tempering temperature, °C			Microhardness of phases after tempering at 570°C temperature	
		No tempering	550	570	Carbides	Martensite, troostite
1	31.0	57	62	60		5776
2	81.8	47	62	63	11381	6092
3	69.2	53	65	62	11545	5251
4	60.0	57	62	62	7926	5251
5	79.9	53	65	63	10103	5254
6	60.0	57	62	61	10788	5504
7	67.1	59	62	62	9482	5251
8	66.7	56	65	63	10650	4395
9	60.0	60	62	63	12384	5015
10	63.6	55	60	60	9482	6068
11	64.7	60	63	62	11166	4395
12	73.8	59	63	62	12384	4395

Wear resistance of the overlaying layers depends on amount of the carbides, structure of the matrix and the hardness. X-ray structural investigation shows that more retained austenite is in the martensite — troostite matrix of the second and fifth layers (about 80%), and about 65% in that of eight and eleventh layers (Table 2). It was detected from the registered X-ray patterns (Fig. 1) by measuring intensities of martensite and retained austenite lines.

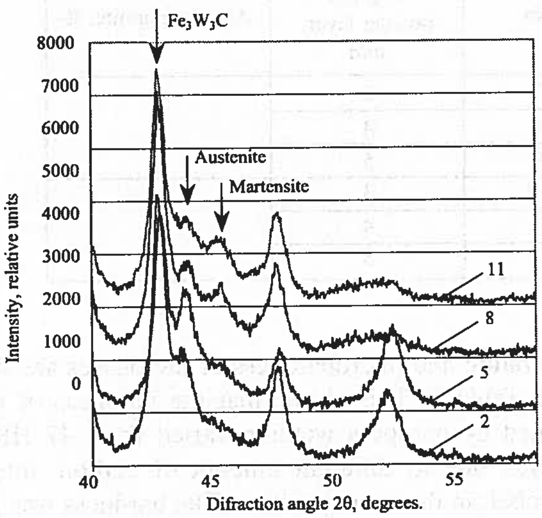

Fig. 1. X-ray patterns of overlayed layers

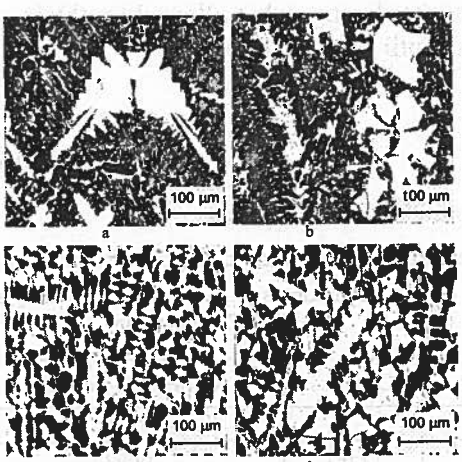

Fig. 2. Microstructure of tempered at 570°C temperature layers, obtained by melting under flux AMS1 of WC-8%Co powder (layer thickness 4 mm) spread over the structural steel surface. The amount of graphite powder in the flux was (%): a — 0; b — 5; c — 9; d — 13 (transverse microsection)

In course of overlaying welding when WC-8%Co powder melted, the tungsten, carbon and cobalt distributed in the liquid metal, main component of which was iron. Cooling of this alloy resulted formation of iron - tungsten carbide Fe_3W_3C instead of WC carbide. In the X-ray patterns (Fig.1) maximum intensity peak of carbide is between 40° and 45°. Different intensity of the peaks, in X-ray patterns registered for the layers chosen for wear tests, shows that the amount of carbide phase was different, but this difference was comparatively small, at the same time, when in the microstructure of less tungsten and carbon containing layers, amount of primary carbides is smaller (Fig. 2).

Wear tests of overlayed and not tempered specimens show that largest wear — out was in the second and fifth layers (Fig. 3). They were softest and had biggest percentage of retained austenite. There were less primary carbides in their microstructure (Fig. 2, a and b), the carbides are big-sized and not uniformly distributed. When more WC-8%Co powder was spread over the surface subjected to overlay welding, the higher alloyed and more wear resistant layers had been obtained (Fig. 4). Highest wear resistance was obtained for the ninth specimen layer.

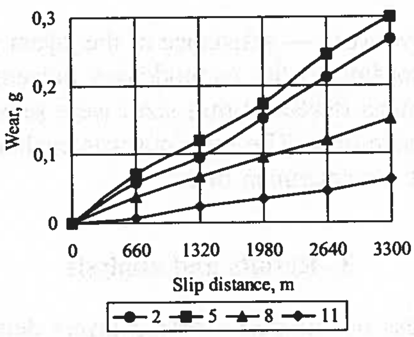

Fig. 3. Relationship between wear - out and slip distance for the layers obtained by melting under flux AMS1 of WC-8%Co powder spread over the overlayed surface (layer thickness 4 mm). The amount of graphite powder in the flux was (%): 2 — 0; 5 — 5; 8 — 9; 11 — 13

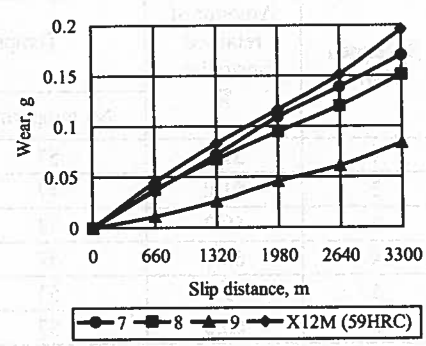

Fig. 4. Dependence of the layers welded under flux AMS1, containing 9% graphite powder, wear on slip distance. Thickness of WC-8%Co powder layer, spread over the overlayed surface, was as follows (mm): 7 — 3; 8 — 4; 9 — 5

Hardness of intended for wear tests specimens after tempering at 550°C temperature increased to 62-65 HRC (Table 2), because retained austenite transformed

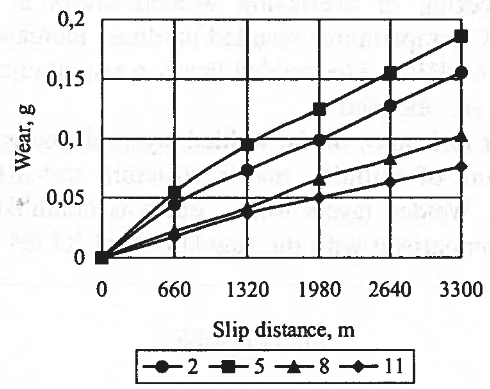

Fig. 5. Dependence of wear on slip distance for the layers obtained by melting 4 mm thickness of WC-8%Co powder layer under the flux AMS1, containing the following percentage of graphite powder: 2 — 0; 5 — 5; 8 — 9; 11 — 13. The layers tempered at 550°C

to martensite. Wear of the eleventh layer was similar to that not tempered, less wear was noticed for eight layer (Fig. 5). The second and fifth layers at tempering hardened most of all, therefore their wear was smallest in comparison with not tempered layers. Overlay welded layers showed higher wear resistance than chromium steel X12M (GOST 5950-73) (Fig. 4). Steel X12 M was subjected to hardening and tempering to the hardness 59 HRC. Microstructure - martensite and carbides.

Overlay welded layers can be of different hardness. The hardness depends on layer chemical composition, cooling speed and following heat treatment. Alloyed layers after the welding during the cooling under flux can be hardened. At high enough alloying level, high primary hardness is obtained, therefore the repeated hardening is not necessary, only the tempering can be applied. When in welded layers is great amount of alloying elements (W, Co, Cr, Mo, V, etc.) and carbon, the cooling from high welding temperature does not result maximal hardness: high temperature tempering only results full hardening. Such covers can be used for metal cutting tools production, because in course of cutting process such cover can be heated to the temperatures, allowable for high speed steels.

Layers produced by one — pas welding are narrow, therefore, aiming to cover larger surface area, multiple — pass welding is required. Structural steel was overlayed by two - pass welding, spreading over it˜s surface WC-8%Co powder. Powder layer of 4 mm thickness was melted by the electric arc between 1.2 mm diameter wire and base metal under flux AMS1 without additives or mixed with graphite powder. Chemical composition of welded layers is presented in Table 3 and hardness — in Table 4.

TABLE 3

Chemical composition of two – pass welded layers

Specimen No	Chemical composition, mas.%								
	C	Si	Mn	Cr	Mo	V	Co	W	Fe
13	1.0	0.8	1.45	0.06	0.05	0.025	2,5	21.0	Remainder
14	1.2	0.82	1.60	0.08	0.06	0.03	2.25	16.5	Remainder

TABLE 4

Hardness (HRC) of two – pass welded layers depending on tempering Temperature

Specimen No	Flux without additives or mixed with graphite powder	Number of passes	Tempering temperature, °C		
			No tempering	550	600
13	Without additives	1	52	63	62
		2	51	62	61
14	9 % graphite	1	51	63	62
		2	61	63	62

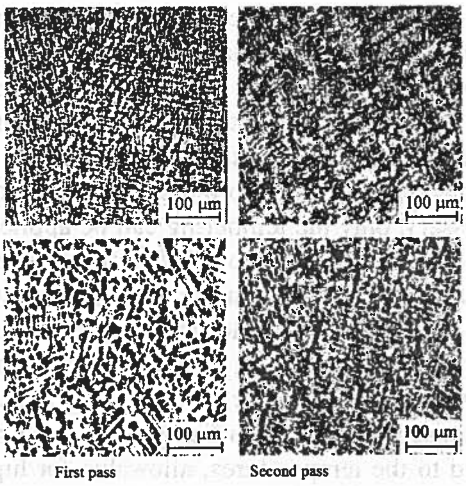

Fig. 6. Microstructure of layers tempered at 550°C temperature, which were obtained by two - pass welding of 4 mm thickness WC-8%Co powder layer, spread over the structural steel surface, under the flux, containing following of graphite powder (%): a — 0; b — 9

Hardness measurements show (Table 4) that hardness of the layer welded under flux mixed with graphite powder (14 specimen) is different for different passes. Tempering at 550°C temperature resulted hardness increase up to 63 HRC in 13 and 14 layers, and it was uniform across the layer.

4. Conclusions

1. Hard, containing large amount of carbides and resistant to abrasive wear layers can be obtained in an arc welding of WC-8%Co powder layer spread over the structural steel surface under the flux AMS1 mixed with graphite powder.
2. Tempering of overlaying welded layers at 550 - 570°C temperatures resulted hardness increase up to 60 - 65 HRC. The welded layers resistant enough to heat are obtained.
3. Wear resistance of the welded layers depends on the amount of carbides, matrix structure and it˘s hardness. Welded layers wear - out was obtained lower in comparison with the standard steel X12M.

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