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ARCHIVES OF METALLURGY AND MATERIALS

Volume 58 2013 Issue 2

DOI: 10.2478/amm-2013-0034

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FORMATION OF BUILD UP LAYERS MICROSTRUCTURE BY ARC AUTOMATIC OVERLAY WELDING USING SECONDARY RAW MATERIAL POWDERS

TWORZENIE WARSTWOWEJ MIKROSTRUKTURY TECHNIKĄ NAPAWANIA W ŁUKU ELEKTRYCZNYM

Microstructure and properties of structural steel subjected to overlay welding with secondary materials powder is investigated. Crushed glass, grinding wheels (SiC), hard metals plates, high speed steel and cast iron chips as well as marble powders were used in automatic overlay welding of steel by low carbon wire. Powder spread over the steel surface and melted by continuously supplied wire arc enabled to obtain layers with graphite and carbides inclusions in the matrix; hardness of the matrix depends on the phases contained in it: martensite, troostite and residual austenite as well as secondary carbides. Depending on materials used for overlay welding the layers were obtained which abrasive wear resistance became equal to that of high alloyed hardened tool steel. Wear of these layers is much more less in comparison with low alloyed hardened tool steel.

Keywords: build-up layers, welding, microstructure, hardness, wear resistance, secondary raw material

Struktura i własności stali konstrukcyjnej poddanej napawaniu proszkiem surowców wtórnych została zbadana. Kruszywo szkła, tarcze szlifierskie (SiC), węgliki spiekane, złom stali szybkotnącej i wióry żeliwne, a także proszki marmurowe zostały wykorzystane do automatycznego napawania stali drutem niskowęglowym. Proszki rozłożone na powierzchni stali nierdzewnej i stopione w sposób ciągły z drutem dostarczanym w łuku umożliwiły uzyskanie warstw z wtrąceniami grafitu i węglików w matrycy; twardość matrycy zależy od faz w niej zawartych: martenzytu, troostytu i austenitu szczątkowego, jak również wtórnych węglików. W zależności od materiałów stosowanych do napawania warstw uzyskano odporność na ścieranie porównywalną do wysokostopowej hartowanej stali narzędziowej. Zużycie tych warstw jest znacznie mniejsze w porównaniu do niskostopowej hartowanej stali narzędziowej.

1. Introduction

Recently build-up hard layers are often used aiming to improve durability of parts working in intense wear conditions and restore dimensions of worn surfaces with significant cost savings [1÷3]. Hardness and wear resistance of build up layers depend on welding regimes, materials and heat treatment. It is shown [4÷7] that welding process parameters have tremendous influence on microstructure and wear of build-up layers. Many recent investigations reveal that advances in surface engineering can be achieved with composite coatings [4, 8÷12]. Analysis of microstructure and measurements of the hardness enabled to evaluate durability of composite coatings. Experiments of abrasive wear show [4] that one layer coating properties more strongly depend on welding current, in comparison with two layers coatings. Coatings having more and evenly distributed carbides, are more wear resistant. High wear resistance of the composite coating obtained by plasma welding of 1Cr18Ni9Ti steel using Fe-Ti-C powder [8] was obtained due to hard TiC inclusion into TiC/γ-Fe eutectic matrix. Wear resistance of the composite coating obtained 18 times higher in comparison with austenitic stainless steel without coating. In the plasma welding process change of B_4C amount in Fe+B_4C powder and current allows to obtain coatings with graphite inclusion [9]. Suitable overlay welding parameters allow obtain microstructure of the coating consisting of not melted B_4C particles, graphite and eutectic. The paper [10] presents study in which mixture of WC-Co (5% or 35%), iron and cobalt powder was used for plasma overlay welding. Iron and cobalt based coatings containing carbides were obtained. Microstructure of the coating was predetermined by powders mixture contents and welding regimes. More hard cobalt coatings were more wear resistant, but the hardness was not main factor decreasing wear of the coatings. Microstructure of the matrix and carbides effected wear resistance as well. Authors of [11] composite coating, consisting of hard WC carbides, included into mild matrix, obtained by overlay welding of carbon steel by powder wire in protective gas (97.5% Ar+2.5% CO_2) environment. Main components of powder wire are nickel and tungsten carbide particles. It was shown that change of welding regimes, resulted change of WC carbides size, form and distribution in nickel matrix.

It has also been reported by some researchers [13÷15] that types of electrodes and the flux compositions play an im-

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portant role in the formation of the characteristics of build-up layers also. Coating with TiC carbides inserted into iron base was obtained when middle carbon steel subjected to overlay welding by electrode, which cover main components were FeTi, TiO_2 and graphite [13]. In course of welding process due to metallurgical reactions into liquid phase, TiC carbides had been formed, which evenly distributed in martensitic-austenitic matrix and increased wear resistance of the coating. High hardness covers were made using electrodes with putty containing FeTi, FeV and graphite [14]. Overlay welding of low carbon steel using these electrodes, resulted layers of martensitic-carbidic microstructure. In the high electric arc temperature in course of metallurgical reaction, Ti-VC carbides evenly distributed in the matrix were formed. Hardness of welded layer increased with increase of FeTi, FeV and graphite amount in the putty. But the highest hardness (up to 64 HRC) was obtained increasing graphite amount up to 11%; exceeding this amount resulted decrease of the layers hardness. In the work [15], there was study the effect of different flux composition on the microstructure and mechanical properties of welds. The presence of acicular ferrite was detected for welds of fluxes with the highest content of titanium oxide. The variations in flux chemistry resulted in alloyed weldments with diverse weld metal mechanical properties as evident by Charpy impact, tensile, dynamic tear, and microhardness tests. Paper [16] deals with the possibility to use the slag generated during submerged arc welding. It is thrown away as a waste. The successful development of recycling technology that allows the use of slag as a fresh flux.

This very brief survey shows that the most of researchers apply expensive materials for the formation of build up layers. However, there is limited information about the applying inexpensive secondary materials for this purpose. Therefore, this investigation was focused on the study of the possibility to apply secondary materials for overlay welding of structural steel.

2. Materials and experimental procedure

Structural steel S235IRG2 (European standard EN 10025) was subjected to overlay welding, using materials powder and flux AMS1 (EN 750), in the device made of table turning machine tool and welder INTEGRA 350 Profesional. Materials powder mixtures were spread over the specimen surface and melted by electric arc between continuously supplied 1.2 mm diameter low carbon steel SFA/AWS A 5·17 (EN 756) wire and base metal (S235IRG2); MIG/MAG torch moved along the specimen. Specimen intended for overlay welding were cut from rolled sheet. Low carbon steel S235IRG2 (0.14÷0.22% C) 8 mm width and 60 mm length specimens surface was covered by materials powder or inserted into the flux and melted in low carbon (0.09% C) welding wire arc resulted layers of various chemical composition and microstructure. The electric current for all the tests was 180÷200 A at 22÷24 V. The weld speed was 14.4 m/h and the wire supply speed was 25.2 m/h.

The following secondary materials powders were used for overlay welding:

- glass,
- crushed grinding wheels (SiC powder),
- grinded marble; main components – calcit and dolomite,
- fine milling chips of high speed steel P6M5 (Russian standard GOST 19265-73) and chromium steel X12 (Russian standard GOST 5950-73) and turning chips of cast iron,
- grinded not suitable for use metal ceramic plates BK-8 and T15K6 (Russian standard GOST 3882-74).

In the course of overlay welding processes at high electric arc temperature, when materials powder was melted and decomposed, liquid metal was alloyed by elements from powder contents. Powders of Fe-70%Mn and Fe-60%Cr were used for alloying, as well as graphite powder, when high carbon layers were necessary to obtain.

Microstructure of the welded layers was carried out under an optical microscope. Surface hardness and microhardness of the build-up layers were determined by standard methods. Chemical composition of the layers was defined by spectral analysis. Resistance to abrasive wear of welded layers was determined on 8 mm width and 20 mm length tempered at 500÷650°C temperature specimens. The specimens were pressed to rotating abrasive wheel.

3. Results and discussion

Quality of machine parts surface greatly influence reliability and durability of machines and constructions [17]. Even small part surface defects can stop normal functioning of a system. Formation of coatings enables to improve surface quality, especially wear resistance. Big surfaces are strengthened by arc welding, because this process is not complicated and can be easily applied. Various materials – solids or powder [18] – are used for overlay welding. Usage of powder allows to increase process productivity and effectiveness, and to obtain optimal composition of welded layers.

For arc automatic overlay welding various composition fluxes are used, enabling to control microstructure and properties of welded layers. In this investigation an attempt is made to subject to overlay welding structural steel by low carbon wire; materials powder was spread over steel specimens surface. Table 1 shows material powders, which, spread over the surface subjected to overlay welding and melted in continuously supplied low carbon steel wire arc without standard flux, resulted layers with graphite inclusions (Fig. 1).

TABLE 1

Composition of materials powders and hardness of welded layers

Specimen No	Material content (%)					Hardness of the layer (HRC)
	Glass	Graphite	SiC	Marble	Fe-70%Mn	
1	52	10	38			37
2			60	30	10	62
3			70	30		61

At high electric arc temperature powder melted, liquid metal was protected from air environment and alloyed by elements from composition. Graphite inclusions were formed because in powders mixture there were enough carbon and silicon. A lot of carbides, which hardness is up to 7500 MPa, were formed in welded layers. Microhardness of bright phase located near graphite is about 2500 MPa. Microhardness of martensitic-troostitic phase (dark areas) is up to 4800 MPa.

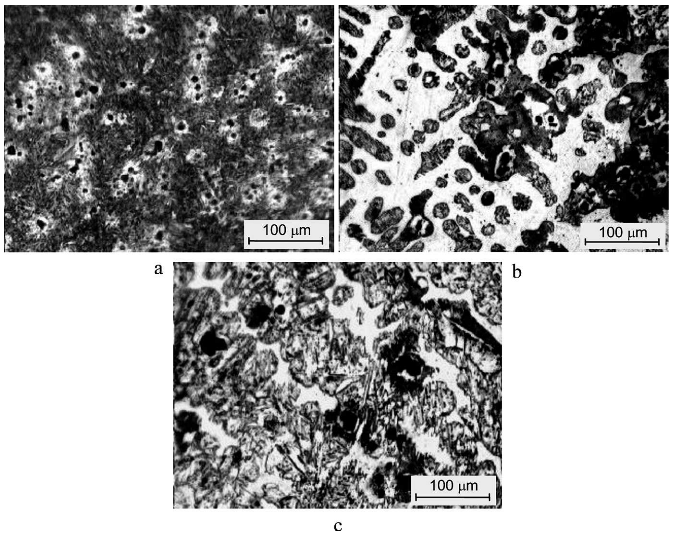


Fig. 1. Microstructures of welded layers: a – specimen 1; b – specimen 2; c – specimen 3

Use of P6M5 and X12 steels fine chips and hard metal BK–8 grinded plates for overlay welding, resulted layers hardening at 500÷650°C temperature tempering (Table 2, Fig. 2). It proves, that welded layers are alloyed by elements, which decrease temperature of martensitic transformation (Table 3), therefore austenite (residual austenite) was noticed after martensitic transformation in microstructures.

TABLE 2

Composition of materials powder mixtures and hardness of welded layers

Specimen No	Material content (%)							Hardness of the layers (HRC)
	P6M5	X12	BK-8	SiC	Fe-70%Mn	Graphite	AMS1	
4	60			20	20			49
5		60		20	20			38
6			31			6	63	42
7			31		11	6	52	44

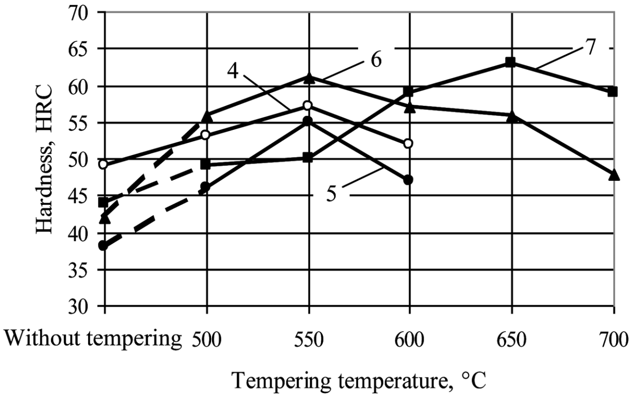


Fig. 2. Effect of the tempering temperature on hardness of welded layers

Metallographic investigation proves presence of residual austenite. After etching in 3% nitric acid alcohol solution martensitic and residual austenite areas stayed bright, because they are more resist to acid (Fig. 3). At tempering, residual austenite transforms to martensite, and layers hardness increases. Hardness increased due to disperse hardening as well, when there are carbides forming elements in the content. Carbides phase after etching stays bright.

TABLE 3

Chemical composition of welded layers

Specimen No	Element content (%)								
	C	Si	Mn	Cr	Mo	V	Co	W	Fe
4	1.16	3.69	4.72	0.76	0.88	0.36	0.04	1.10	Balance
5	1.26	3.65	4.49	2.31	0.16	0.07	0.08	0.07	Balance
6	0.95	1.25	2.32	0.06	0.04	0.02	0.95	10.5	Balance
7	1.02	1.67	6.04	0.08	0.08	0.04	1.27	10.6	Balance

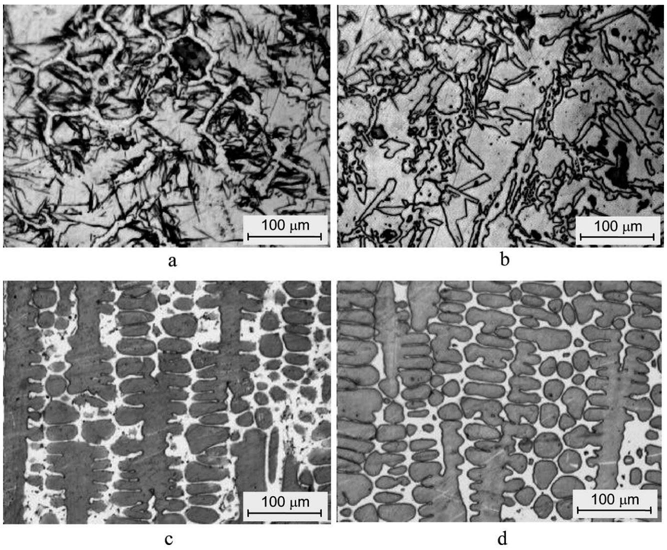


Fig. 3. Microstructures of welded layers: a – specimen 4; b – specimen 5; c – specimen 6; d – specimen 7

Wear resistance of the specimens was evaluated taking into account weight decrease after 20 min wear test (Fig. 4). Wear out of the welded layers was compared with that of standard hardened and tempered tool steels X12M (Russian standard GOST 5950–73) contains 2.0÷2.2% C and 11.5÷13.0% Cr and 100Cr6 (EN94-73) contains 0.95÷1.05% C and 1.3÷1.65% Cr. More resistant to wear layers welded with mixtures containing BK-8 powder (specimen 6 and 7). Tungsten carbide (92%) from hard metal BK-8 powder at high arc temperature was decomposed into tungsten and carbon; in the course of liquid metal cooling, hard carbides (8900 MPa) increasing wear resistance of the layers were formed again. Layers welded with X12 and P6M5 chips mixtures showed less wear resistance, but their wear was less comparing with that of hardened and tempered 100Cr6 steel (56 HRC).

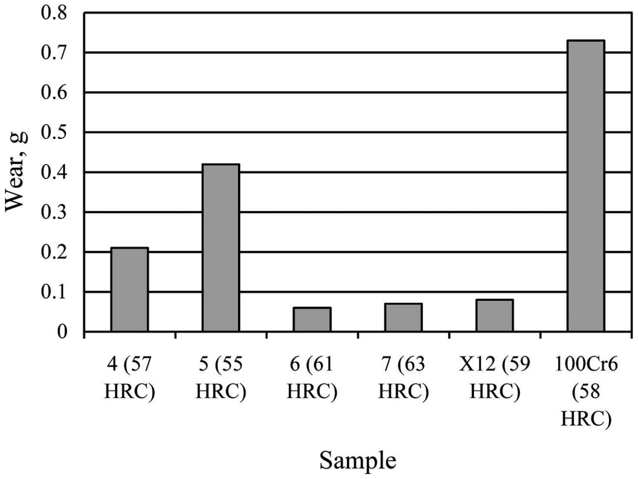
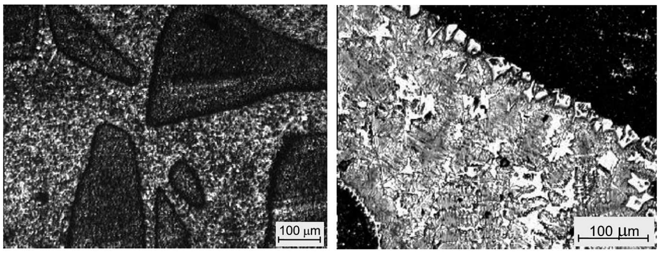


Fig. 4. Wear of welded layers

An attempt was made to overlay welded S235IRG2 steel which surface covered with BK−8 hard metal granules from 0.5 mm to 3 mm size. 54 HRC hardness layer was obtained, when on 8 mm width and 60 mm length specimen surface 8 g granules of BK−8 were spread over and melted by low carbon wire arc under flux AMS1 (microstructure of the layer shown on Fig. 5).

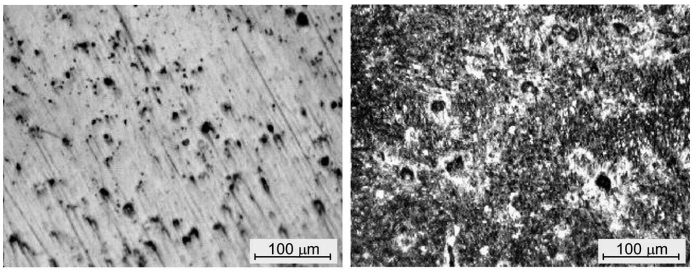


a b

Fig. 5. Microstructures of overlay welded layers

On the picture of lower magnification (Fig. 5, a) it may be seen that bigger BK−8 granules completely not melted (dark areas), only their surface melted. Metal between granules is alloyed by tungsten and cobalt, enriched by carbon due to melted surface of bigger granules and completely melted small BK−8 particles. Besides granules (Fig. 5, b), in zones with higher tungsten amount more hard carbides (microhardness 14500 MPa) were formed. Microhardness of carbides located aside of granules and inserted into eutectic matrix (carbides, martensite, troostite, and residual austenite) was 1055 MPa. Microhardness of eutectic matrix was 5000÷6000 MPa.

Layer of 62 HRC hardness was obtained, when on steel S235IRG2 surface (8 mm width and 60 mm length) was spread over 4 g T15K6 hard metal powder (particles size was up to 0,5 mm) and melted by low carbon steel wire arc under flux AMS1. When more that 4 g powder was used, layer badly fused together the base. Using T15K6 hard metal powder containing 16% TiC, 79% WC and 6% Co, in the course of overlay welding at high arc temperature the layer was subjected to alloying by titanium, tungsten, cobalt and enriched by carbon. Manganese and silicon from the flux AMS1 containing more than 50% SiO_2 and MnO migrated to the layer. In this layer due to high enough amount of carbon and silicon, graphite inclusion were formed, and they are well seen on microsection not subjected to etching (Fig. 6, a). Welded layer hardened up to 62 HRC in the course of cooling; the microstructure formed consisted of hard matrix (martensite) with small inclusions of carbides (white particles) and graphite enclosed by ferrite. In general, these results accord with previous studies [2, 19, 20] in which was emphasized that the microstructure was more important than hardness in determining wear.



a b

Fig. 6. Microstructures of welded layers: a – microsection not subjected to etching; b – microsection etched in 3% nitric acid spirit solution

4. Conclusion

Utilization of crushed into powder glass, grinding wheels, hard metal plates, steel and cast iron chips and marble for structural steel S235IRG2 overlay welding enables to obtain layers of various microstructures. Choosing powders mixture composition it is possible to obtain layers containing graphite and carbides.

Layers hardening at high temperature tempering up to 63 HRC can be obtained when flux AMS1 mixed with BK–8 hard metal, Fe-70%Mn and graphite powder is spread over structural steel S235IRG2 surface and melted into low carbon steel wire arc. No hardening is needed for that layer. If mixture with hard metal's BK–8 powder is used for overlaying welding, the layer is alloyed by tungsten and at sufficient carbon amount hard carbides are formed and they increased resistance to abrasive wear.

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Received: 20 September 2012.