Analysis of the microstructure of tic-based surfaced layer by combining arc surfacing with self-propagating high-temperature synthesis

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Abstract
The comparative analysis of microstructures of the built-up layers obtained by arc surfacing by powder electrodes is carried out. The electrodes as filler contained prepared powder of titanium carbide in one case, and in another case, powder mix of titanium and technical carbon (carbon black), where the self-propagating high-temperature synthesis of titanium carbide proceeded in case of thermal influence of electric arch. For the built-up layers, the complex of the structural parameters defining wear resistance under the conditions of friction on fixed abrasive is determined. Results of tests show that the wear resistance of layers applied at combination of arc surfacing with SPHTS is 1.27 times higher relating to the layers, which are built up by electrode with prepared powder of titanium carbide as filler.

Key words: ARC SURFACING, COMPOSITE COATINGS, POWDER ELECTRODE, IMAGEJ, ABRASIVE WEAR RESISTANCE, FIXED ABRASIVE

Wide use of composition materials carbide–metal matrix under the conditions of abrasive influence is caused by their high and stable wear resistance in the wide range of characteristics of abrasive and conditions of abrasive wear [1-3]. Among all the widely applied carbides of high-melting metals, titanium carbide has the highest temperature of melt, and also hardness [4]. It causes increased scientific interest to the search of optimum structure of composite coatings based on titanium carbide and ways of its maintaining, including arc surfacing.

Perspective method of an arc surfacing is its combination with the self- propagating high-temperature synthesis of high-melting components [5]. The impact of such combination on microstructure of the built-up layer requires additional study as there are almost no data on results of similar tests in the literature.

Known methods of stereometric metallography [6], which are conducted by the metallographic analysis with the subsequent measurements of structural parameters and their processing characterized by the considerable labor intensity caused by the necessity of measurement of a large number of data, often are in big error because of complexity of evaluation of the particles shape by means of simple geometrical figures. Recently, successful attempts of the analysis of structure and phase composition of carbon and low-alloy steels are made [7], including the use of software “ImageJ” for processing of metallographic analysis results [8-9]. However, the requirements to quality of metallographic section and techniques of their etching will increase significantly, as even insignificant violations introduce significant errors when preparing samples. The electron-microscopic methods of research in the mode of back-scattered electron diffraction (EBSD), in case of which the color saturation is proportional to density of appropriate phases (structural components), do not contain abovementioned drawbacks.

The purpose of work is comparative research of pictures of the microstructures obtained by electron-microscopic method, determination of impact of a complex of structural parameters of microstructures under investigation on abrasive wear resistance of built-up coatings based on titanium carbide, which were applied by traditional arc surfacing with powder electrodes, and also by arc surfacing combined with the self-propagating high-temperature synthesis. Surfacing was conducted by powder electrodes of two types. The first type contained filler in the form of powder of titanium carbide, and the second one was a powder compound of titanium and technical carbon. Thus, self-propagating high-temperature synthesis of titanium carbide proceeded in case of surfacing by electrodes of the second type with their powder filler at thermal effect of electric arc.

2. Materials and technique of researches

Surfacing material for applying of the arc coatings under investigation was conducted in the form of powder electrode by cutting of a single-clamp band with the lapped lock to 400 mm long measured pieces. Design of the specified band is presented in Figure 1. Advantages of this design are the simple production technique, and also opportunity to obtain a high filling coefficient. Moreover, the position of the lock in a middle part of section of powder band is conductive to more uniform core melting [10]. The rolling mill for band cast tungsten carbide production developed by Paton Electric Welding Institute was used for production of powder electrodes [11]. This rolling mill was equipped with the additional measuring device of conveyor type with the vibrator and special node of cutting as distinguished from prototype.

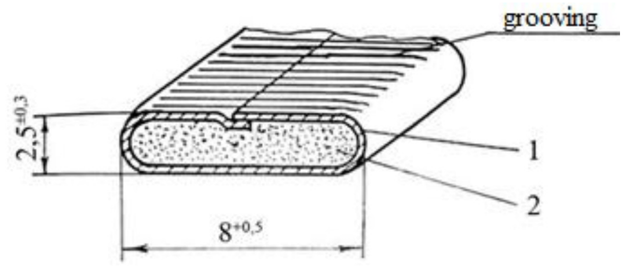


Figure 1. Design of powder band with the lapped lock: 1 – metal coating; 2 – powder filler

The coating is made of cold-rolled steel band of grade 08kp according to GOST 3559-75; it is 0.5 × 20 mm in size and produced by JSC “Zaporizhia Iron and Steel Works “Zaporozhstal”. The powder filler (furnace charge) is prepared by mechanical mixing of components, which grades are shown in Table 1.

Before weighing and mixing, components are carefully dried in the drying box such as SNOL during 60 min at a temperature of 90 ^{o}C. In order to en-

Table 1. Filler components

Powder component	Grade	GOST, TR	Size of particles, micron
Titanium	PTKh-6-1	TR 49-10-78-83	60 - 88
Technical carbon (carbon black)	K-354	GOST 7885-86	9 - 320
Titanium carbide	Ch	TR 6-09-492-75	20 - 40

sure a high-quality mixing of components of powder filler, the laboratory V-shaped mixer of powders of C2K/6 grade is used. Time of mixing is 60 min with rotation frequency of 50 min^{-1}.

The coefficient of filling of powder electrode is calculated by a formula:

$$K_f = \frac{G_{pow}}{G_{el}} \cdot 100\% \,, \qquad (1)$$

where G_{pow} – mass of powder filler;

G_{el} – total mass of powder electrode.

The coefficient of filling is controlled by series weighting of not less than three measured pieces of electrode by laboratory mechanical scales BA-4M.

Two types of powder electrodes are produced. The first type contains filler in the form of powder of titanium carbide, and the second one is powder mix of titanium and technical carbon taken in stoichiometric ratio (80% of Ti and 20% of C). The filling coefficient for both types of electrodes is 25%. The powder filler in the electrodes of the second type has provided the self-propagating high-temperature synthesis of titanium carbide when surfacing under thermal effect of an electric arc.

Surfacing of materials under investigation was conducted in manual mode with use of the rectifier welder VDU-506. Surfacing mode has the following indexes: the volt-ampere characteristic is falling, the current is 160-180 A, arc voltage is 30-32 V, polarity is negative (plus is applied to electrode). Surfacing has been carried out on steel plates of 10 mm thick; material of plates is steel 45 according to GOST 1050-88. Cooling of the built-up layer takes place in air.

For research of microstructure of the built-up coatings, sections were produced by mechanical grinding and subsequent polishing in accordance with standard technique [12].

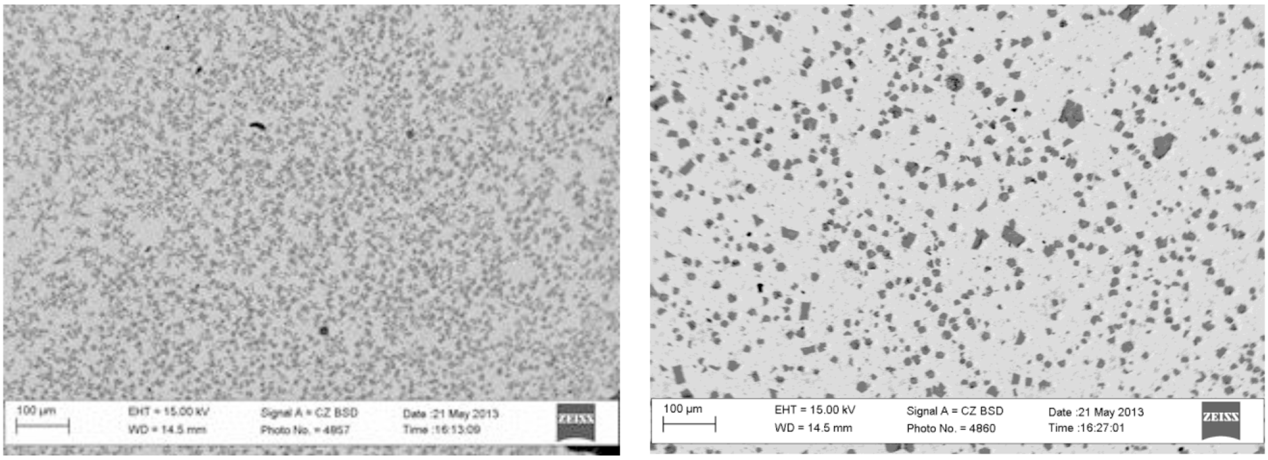
The qualitative and quantitative metalgraphic analysis is carried out by the scanning electronic microscope ZEISS EVO40XVP, which is equipped with detectors of secondary electrons, reflected electrons and x-ray spectrometer. The analysis of microstructures of the built-up layers obtained by electron-microscopic method is carried out by means of specialized software package for processing and analysis of images «ImageJ». Sequence of the analysis is the following. The large-scale tags of 100 microns in size were put in pictures of microstructures (Figure 2, a, b); the image was stored with extension 800×600 pixels at the gif format. Then, the image was changed in binary one (black-and-white) by means of teams: “File →Open →Image →Adjust →Threshold”. The ratio between distances was established in pixels and millimeters for appropriate scale in the menu “Analyze→Set scale”. After that, using tab “Find Edges” in the menu “Process”, the contours of particles were found (Figure 3); then, in the tab “Analyze Particles” of the menu “Analyze” the range of measurements was established.

For the specified structures, distribution of sizes and shape (rotundity degree C) of particles were determined by a formula:

$$C = 4\pi\left(\frac{S}{P^2}\right), \qquad (2)$$

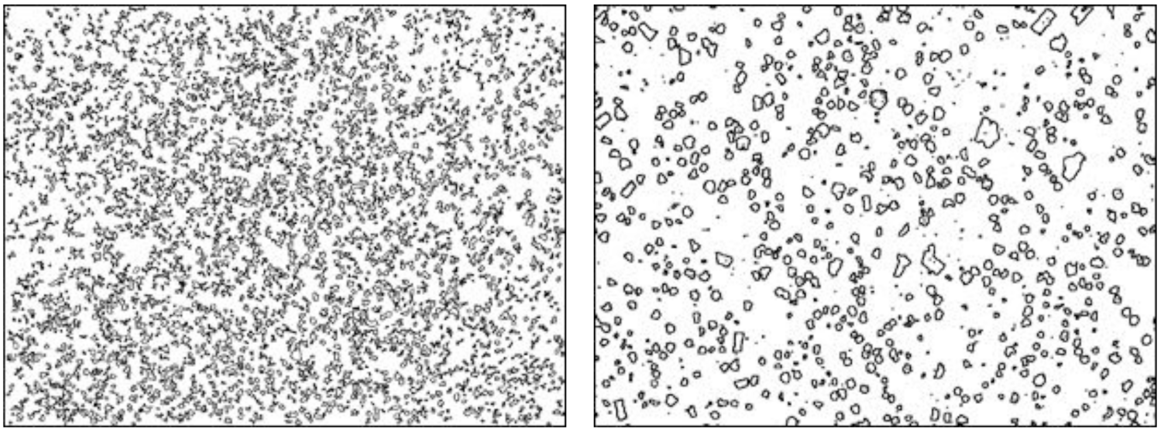
where S – area, P – particle perimeter.

Uniformity of particles distribution in matrix metal was evaluated by distribution of binding by random linear intercept method. The distance between intercepts was 50 microns, the spots of crossing of binding and intercepts were determined by imposing of pictures of structure on their images and subtraction by command: “Process → Image Calculator →Substract”. The pieces obtained by this method



a b

Figure 2. Fragments of built-up layers microstructure: a – surfacing of an electrode with the powder TiC as filler; b - surfacing of an electrode with the mix Ti + C as filler



a

b

Figure 3. The processed fragments of built-up layers microstructure: a – surfacing of an electrode with the powder TiC as filler; b - surfacing of an electrode with the mix Ti + C as filler

were measured by the command "Analyze Particles" as it was mentioned above.

Mathematical processing of the statistical data obtained during the analysis of built-up layers microstructures was conducted with use of software package «*OriginPro* 8» for data numerical analysis.

Wear resistance of coatings under investigation was determined under the conditions of friction on fixed abrasive in the MT-1 installation using the technique described in the paper [13]. The abrasive, which is used, poses grinding wheels made of green silicon carbide of grade 64C F46 K 7 V according to GOST P 52781-2007 with a grain size of 425-355 microns and diameter of 300 mm and 40 mm in thickness. The wear was determined as arithmetic-mean value of weight loss after three results of tests for each sample.

3. Results and their discussion

Nature of reinforcing particles distribution (including carbide, boride, etc.) on sizes, their shape (spherical, cut, acicular, etc.), and also character of mutual arrangement in the built-up layers when wear-resistant arc surfacing are the most important indicators defining their operational properties, first of all abrasive wear resistance and crack resistance [1, 3, 14]. With increase in the maintenance of carbide phase, wear resistance increases monotonously due to growth of protective action of carbide particles in relation to intercarbide layers of metal binding [1]. At the same time, components with complex geometry in structure (for example, the eutectic formations) complicate evaluation of phase structure and, as a result, of predicted properties.

Results of measurement of particles distribution in accordance with sizes (Figure 4) show that the average size of particles (28 microns) in the layer, which is built up at combination with SPHTS, is almost twice bigger than for surfacing with use of the prepared powder TiC as filler. Thus, in both cases, nature

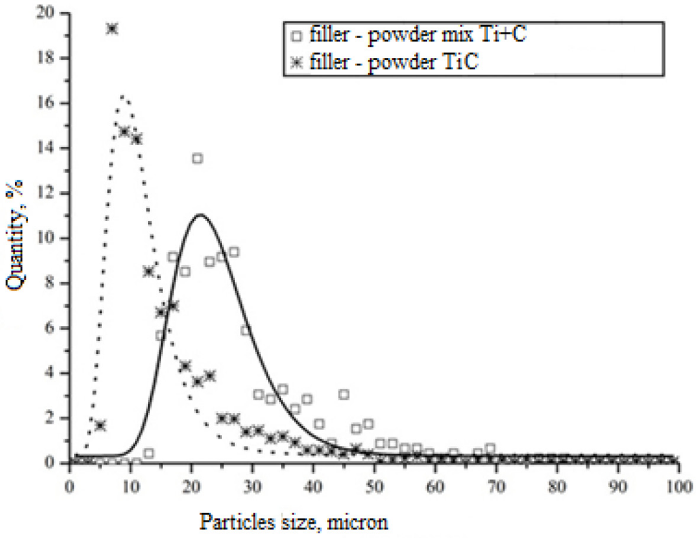


Figure 4. Nature of carbide particles distribution according to the size in the layer obtained when surfacing by electrode with mix Ti + C as filler (continuous lines) and when surfacing by electrode with powder TiC as filler (shaped lines)

of distribution is described with high probability by lognormal law of distribution:

$$K = K_0 + \frac{A}{wr\sqrt{2\pi}} e^{\left(\frac{-\ln\left(\frac{r}{r_c}\right)^2}{2w^2}\right)}, \qquad (3)$$

where K_o, A, w, r_c – parameters of the equation, which values are presented in Table 2.

As can be seen from Table 2, dispersion of particles at surfacing combination with SPHTS, as well as their sizes, is almost twice higher in comparison with surfacing by the powder TiC.

Thus, the layer obtained at surfacing combination with SPHTS is characterized by 2 times bigger particles of wear resistant reinforcing phase (which quantity is more than 50%); in turn, it predetermines the increased wear resistance under the conditions of abrasive wear. For example, according to data [15], two times increase of the size of carbide particles leads to increase in abrasive wear resistance by 30%.

Besides the size of particles, geometrical parameters of their shape have significant impact on wear resistance. The strengthening phase in an alloy in the form of arborescent inclusions worsens the uniformity of its distribution, and also reduces its maximum possible concentration in alloy; therefore, under the conditions of abrasive wear, the strengthening phase in the form of equiaxed particles, which are uniformly distributed throughout an alloy, is the most preferable [16]. Moreover, in case of increase of deviation degree of particles shape from the spherical one, the degree of their polyhedron and structure branching increases; this creates a significant amount of stress-risers and, as a result, causes significant reduction of crack resistance.

The analysis of rotundity of particles shape (Figure 5) shows main distinction depending on surfacing method: the maximum quantity of particles (~ 25%) at SPHTS surfacing is characterized by rotundity degree of ~ 0.7, and at surfacing by powder TiC; this indicator is approximately 3 times lower (for the majority of particles (~ 25%), degree of rotundity is ~ 0,2). It should be noted that nature of particles distribution according to the shape is described by the law of Gauss for SPHTS surfacing, and at surfacing by powder TiC is described by lognormal one. It testifies that in the first case, uniform distribution of more rounded particles takes place; this has positive impact

Table 2. Parameters of particles distribution

Surfacing method	Parameters				
	K_o	w	A	r_c	Dispersion, % $D = (e^{w^2} - 1)e^{2\ln(r_c)+w^2}$
Powder mix Ti+C	0,37	0,41	162,21	10,58	24,95
Powder TiC	0,32	0,27	167,85	23,18	47,29

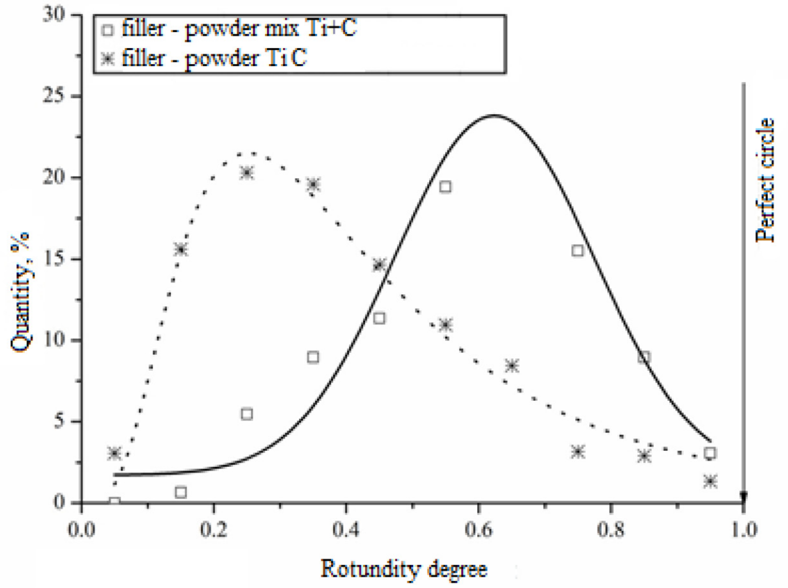


Figure 5. Nature of carbide particles distribution on rotundity in the layer obtained when surfacing by electrode with mix Ti + C as filler (continuous lines) and when surfacing by electrode with powder TiC as filler (shaped lines)

on firmness of the built-up layer under the conditions of shock loads owing to crack resistance increase.

Properties of the heterophase composite coatings consisting of firm carbide inclusions and rather plastic steel binding depend significantly on uniformity of its distribution that is on size of intergranular layers. At low values of this parameter, high probability of emergence of "dry" contacts of carbide-carbide takes place that leads to significant reduction of strength properties (shear and compressive strength) [17]. As can be seen from nature of distribution of binding according to size, there are significant distinctions structures under investigation (Figure 6): surfacing by SPHTS method with high reliability is described by lognormal law with average value of 18 microns as against the layer obtained by surfacing with powder TiC, where distribution of binding is submitted to exponential law, and thus, the majority of layers have the sizes of ≤ 1 microns. Thus, in the second case, there is much more substantial risk of cracks on the fragments forming skeletal conglomerates with the subsequent separation from a basis.

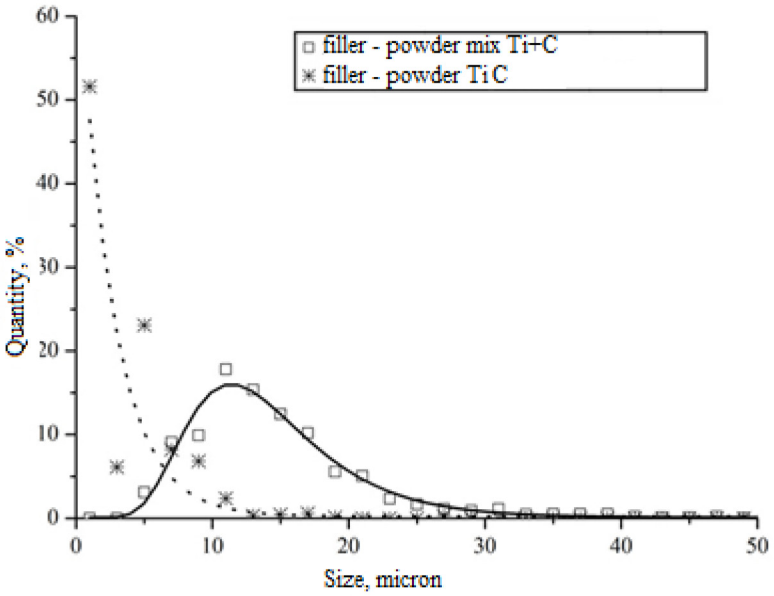


Figure 6. Nature of intergranular layers according to the sizes in layer obtained when surfacing by electrode with mix Ti + C as filler (continuous lines) and when surfacing by electrode with powder TiC as filler (shaped lines)

Results of tests on determination of abrasive wear resistance of coatings under investigation have shown that the layers, which are obtained by surfacing using electrode with mix Ti + C as filler have wear resistance by1.27 times higher in comparison with layers, which are built up by an electrode with prepared powder TiC as filler; it is in line with the revealed differences of their microstructural parameters.

4. Conclusions

1. The comparative analysis of microstructures of built-up layers obtained by traditional surfacing with use of prepared titanium carbide and surfacing at combination with SPHTS have shown significant impact of SPHTS on final structure of the built-up coatings.

2. The microstructure of the layers obtained at combination of surfacing with SPHTS is characterized by the average size of particles (28 microns), which is twice bigger than for surfacing with use of prepared powder of titanium carbide as filler.

3. Nature of particles distribution according to the size is described by the law of Gauss for combination of surfacing with SPHTS and at surfacing by powder TiC is described by lognormal law; this testifies that in the first case uniform distribution of particles takes place. Moreover, the analysis of rotundity of particles shape has shown that at combination of surfacing with SPHTS, titanium carbide particles are characterized by rotundity degree of ~ 0.7, and at surfacing by powder TiC, this indicator is 3 times lower, degree of rotundity is ~ 0.2; that is conductive to growth of wear and crack resistance.

4. The study of nature of distribution of binding according to the size have shown that surfacing combined with SPHTS provides distribution of binding in accordance with lognormal law with average value of 18 microns as against the layer obtained by surfacing by prepared powder of titanium carbide, where distribution of binding is submitted to exponential law, and thus, the majority of layers have the sizes of ≤ 1 microns.

5. The tests of determination of abrasive wear resistance of coatings under the conditions of friction on fixed abrasive have shown that layers, which are

obtained by surfacing combined with SPHTS, have wear resistance by1.27 times higher in comparison with layers, which are built up by an electrode with prepared powder of titanium carbide.

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