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# Enhancing coating properties by application of pulsed arc surfacing method when modifying the molten metal by composite powder materials

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**Abstract.** The aim of the work is to study the structure, physical, mechanical and operational properties of the deposited coatings by pulsed welding methods with modification of molten metal composite powder materials with submicrocrystalline structure. Samples of weld joints of steel 09G2S. Welding was performed with composite electrodes of the power source Feb-315 "Magma" remote "pulse" for the implementation of the pulsed arc process. The influence of modification by dispersed particles and electric arc impact on the structure, physical, mechanical and operational properties of coatings is studied. It was found that the modification of refractory compounds with submicrocrystalline structure allows to increase the dispersion of the structure and the hardness of the coatings.

## 1. Introduction

Surfacing is an economical and widely used in industry method of restoring parts of machines and mechanisms, enhancing wear resistance of their working surface [1]. The most common wear-resistant surfacing materials include composite compositions containing chromium, tungsten, boron, molybdenum, etc. First of all, these are compounds of the following types: Fe-C-Cr; Fe-C-Mn; Fe-C-W; Fe-C-Cr-Mn; Fe-C-Cr-B; Fe-C-Cr-Ni; Fe-C-Mo; Fe-C-Cr-Mo; Fe-C-Cr-W; Fe-C-Cr-W-V; Fe-C-Cr-W-B and others. To increase the resistance to abrasion wear, modifying additives with a high content of the carbide phase are widely used. The wear resistance of these surfacing materials strongly depends on the type and the amount of the carbide phase. Most often, the strengthening phases in such surfacing compositions contain carbides, borides and nitrides Fe, Cr, W, V, Ti, Mn, Mo, etc., as well as carboborides and carbonitrides of these elements. The process of surfacing exerts a specific influence on the properties of coatings owing to differences in values of heat inputs and properties of electrode materials. A decrease of weld metal properties occurs because of defects that may appear during surfacing owing to deviations and the effect of residual and operational tensions [2-3]. These factors can lead to accelerated destruction of coatings [4-7]. Modern methods of surfacing allow regulating the cooling rate of coating



material and controlling the processes of their melting and crystallization, formation of the structure and physico-mechanical properties [8-14]. Therefore, an important task is to investigate the influence of technological surfacing modes on mechanical and operational characteristics of coatings by using new additive materials, modifying the formed melt, and pulsed processes that reduce heat input and structural heterogeneity of the metal.

In case of electroslag hard-facing, it is necessary to solve a number of complex tasks – selection of material providing properties necessary for operational conditions, a possibility of surfacing of this material directly onto the base metal of the part, a choice of a surfacing mode and a shape of surfacing materials.

At present, almost all possibilities of enhancing the strength and wear resistance of weld metal have already been exhausted. Additional possibilities appear when creating new composite powders subjected to modification before being added to surfacing materials [3]. This method consists in the intensive mixing of powders and allows obtaining compositions without significant limitations on the composition and the number of components [10-14]

Thus, for example, during the operation of heavy-duty quarry machinery, when destructing rock, the main effort is applied to their operating devices. The most wearable articles that destroy rock and at that are subjected to the most intensive impact and abrasive wear are bits of buckets of excavator teeth and ripper-doers. At that, wear of the bits is one of the key problems in exploitation of mining equipment in the Far North regions. Because of wear of operating devices of digging and quarry machinery, the loads on the machine as a whole increase, the productivity of labor decreases, the number of downtimes and the amount of expenses on repair of worn-out parts increase. Losses of metal owing to wear of operating articles of mining equipment make many tens of thousands of tons per year.

One of the ways to improve the operational reliability of road construction and quarry machinery of the North is application of repair-and-renewal and strengthening treatment based on different methods of electric arc and electroslag surfacing. Application of powders, based on dispersed particles of carbides, borides and nitrides of chromium and titanium, as modifiers can be very promising. Varying the compositions of electrode material, it is possible to change the composition of built-up metal possessing different properties after surfacing.

Thus, restoration of working surfaces of articles and increasing their wear resistance are an urgent problem. Surfacing is one of the most effective ways of restoration of lost geometry and strengthening of articles.

The purpose of the work: Enhancement of properties of surfaced coats by applying pulsed arc methods of surfacing when modifying molten metal by composite powder materials with a submicrocrystalline structure.

## **2. Materials and methods of research**

To achieve the set goal, built-up layers, obtained by surfacing with application of T590 and EN60M electrodes, melted in modes of direct current and pulsed change of energy parameters, were studied. Samples from steel 09G2S, St.3 and 12C18N10T were investigated during the work. Surfacing was carried out using power source FEB-315 "MAGMA" with a remote control "Pulse" for implementation of the pulsed arc process. In this case, current modulation frequency was adjusted within 1–5 Hz. The microstructure was studied by means of an optical microscope "NEOPHOT-21". The microhardness of surfaced coats was measured using a microhardness tester "Leika". Measurements of the coating microhardness, the metal of the heat-affected zone, and the base metal were carried out with an indenter load of 0.5 N.

Powders of carbides and nitrides of chromium and titanium were used as a dispersed component. A mixture of granules with binding liquid glass was applied on the electrodes coatings in the form of a thin layer. Electrodes T590 and EN-60M were used. These electrodes have a chemical composition shown in table 1.

Corrosion resistance tests of surfaced coats were carried out in a medium of highly concentrated (100%) HNO<sub>3</sub>. The resistance of coatings, surfaced onto steel 09G2S, to corrosion was compared with that of steels St.3 and 12C18N10T.

**Table 1.** Chemical composition of surfacing electrodes and provided hardness.

Electrode grade	Chemical composition of built-up metal, %					Hardness (by certificate)
	Si	Mn	Cr	Mo	B	HRC
T590	3.2	2.2	1.2	25.0	1.0	55-62
EN-60M	0.8-1.2	0.4-1.0	2.3-3.2	0.3-0.7		53-63

When analyzing the nature of surface wear, it was taken into account that the destruction occurs as a result of shear fracture and spalling owing to repeated plastic deformation. At that, the wear intensity was determined depending on the properties of the worn coating, the travelling speed of the abrasive medium, as well as the shape and properties of abrasive particles.

### 3. Research results and their discussion

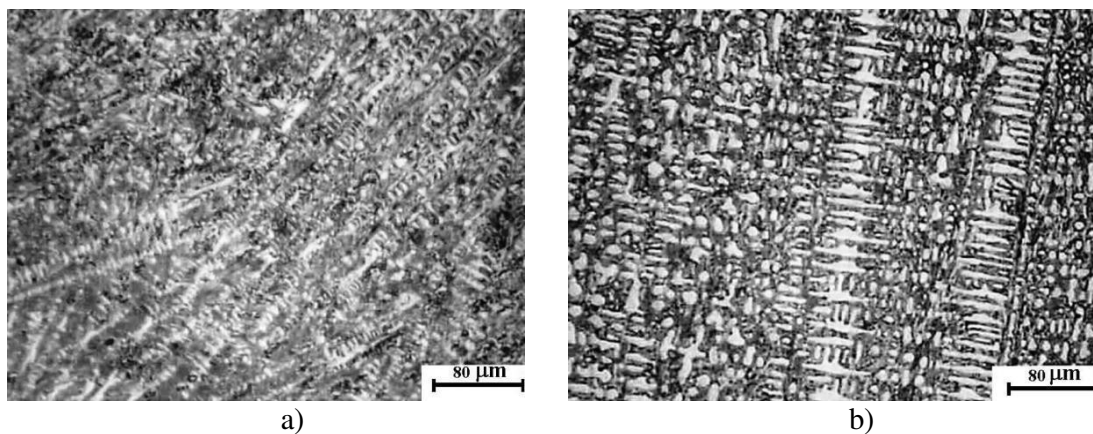
In the initial state, the structure of steel 09G2S is lineage ferrite-pearlitic. The volume fraction of perlite is  $\approx 20\%$ . The average microhardness is  $\sim 1450$  MPa.

When surfacing in the direct current mode, a large-dendritic structure of the built-up metal of coating is formed, and when using the surfacing mode with a low-frequency change of energy parameters (HMT), a fine dendritic structure is formed (figures 1 and 2).

In the initial state, the base metal – steel 09G2S – has hardness of  $\sim 250$  HV; the hardness of surfaced coat material is  $\sim 270$ - $300$  HV,  $\sim$ HAZ –  $210$ - $230$  HV.

Microsections for metallographic analysis were made according to a cross-section, which is perpendicular to the longitudinal axis of the weld. To obtain the compared images, the microstructure was studied in the central part of root and cap welds, in the transition zone of the cap weld towards the base metal: in the areas of overheating and normalization.

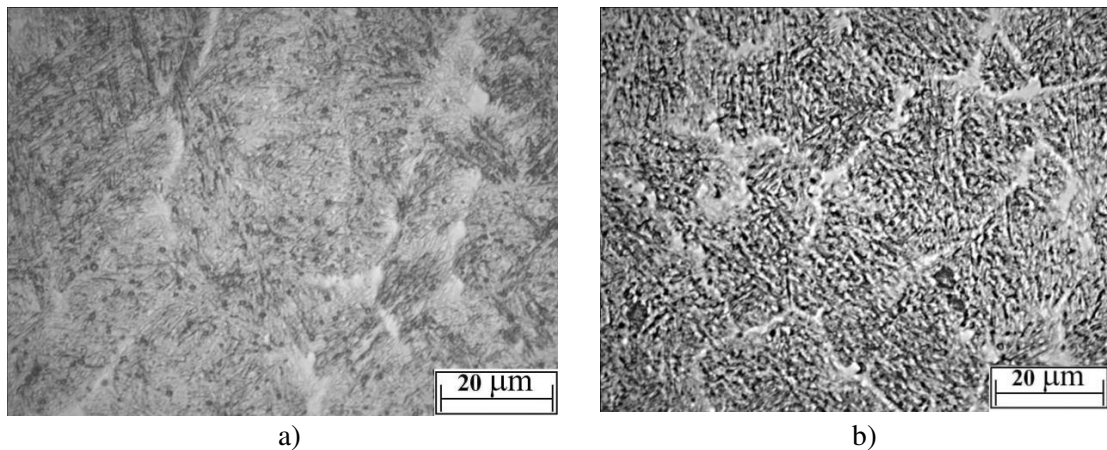
The microstructure of the base metal represents perlite and ferrite with a grain size of 12-13 points on the GOST 5639-82 scale, which corresponds to an average grain size of  $\approx 4.7$   $\mu\text{m}$ .



**Figure 1.** A microstructure of the built-up layer of coating obtained by T590 electrodes after surfacing using: a) direct current, b) pulsed mode.

When surfacing using direct current, the zone with the enlarged grain size is wider than it is during welding with current modulation, which allows speaking about higher heat inputs and duration of thermal action of the arc [2].



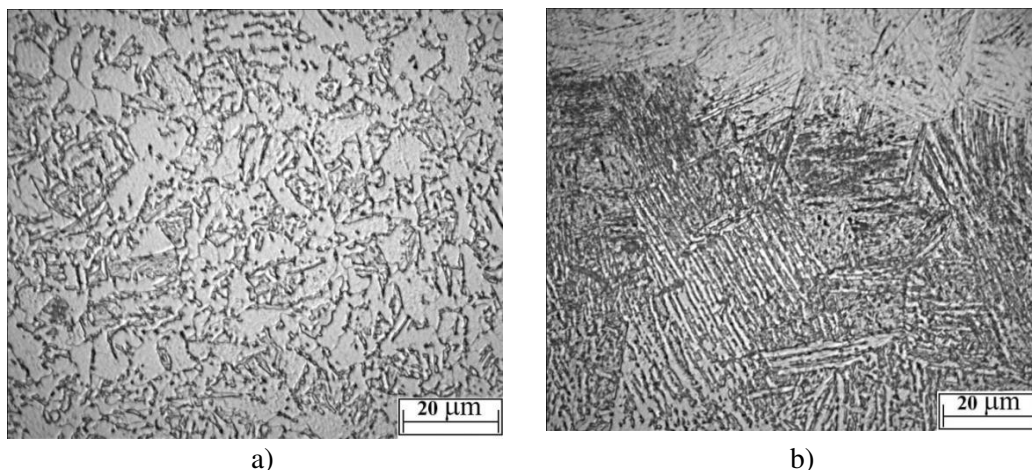


**Figure 2.** A microstructure of the built-up layer of coating obtained by electrodes EN-60 M after surfacing using: a) direct current; b) pulsed mode.

The microstructure of the heat-affected zone consists of several sections: a superheat zone with a widmanstatten structure and a normalization zone with a characteristic more fine-grained ferrite-perlite structure (figure 3).

Metallographic studies of the surfaced coats revealed a ~1.5-time refinement of structural constituents of the welding material in samples melted using the pulsed mode (figure 1).

This is explained by peculiarities of the pulsed arc mode of surfacing, when intensive melt mixing occurs with formation of new nucleation centers. Samples, surfaced in the pulsed mode, have less HAZ width and a smaller grain size. This improves the quality of the surfaced coat. In case of direct current, the heating temperature is higher, and as a consequence there is a larger grain growth. Thus, the mode of pulsed arc surfacing allows providing a more enhanced complex of strength and plastic properties of the surfaced coat in comparison with the technology using direct current.



**Figure 3.** A structure of the heat-affected zone of steel 09G2S: a) a structure of the transition zone «surfaced coat EN 60M - steel base (09G2S) with a superheat zone of steel with a widmanstatten structure, b) a normalization zone with a ferrite-pearlite structure.

By means of targeted high-energy influence of the arc on the melt of the surfaced coat, its constant reciprocating motion is achieved owing to periodic force action of the arc with the current modulation frequency. Such behaviour of the surfacing process provides a cyclicity of physical and metallurgical processes at the stages of formation of a molten pool and contributes to its active mixing.

This mixing of the melt contributes to the equalizing its heat content and ensures finding the required amount of molten metal under the arc by the beginning of the current pulse action, enabling a decrease of penetration depth. Periodic movement of the metal in the melt also contributes to a more even distribution of alloying elements over the volume of the molten metal.

The use of pulsed arc surfacing technology allows one through the programmable input of heat into the surfacing zone to control the processes of weld metal formation from the melt and, as a consequence, to refine the structure of the coating metal and to enhance its properties.

In the course of the research, the optimal modes of preparation of the surface of steel electrodes and surfacing of coatings were worked out. Surfacing of coatings was carried out using nano-sized powdered modifier of titanium nitride applied on the surface of steel plates 09G2S. The influence of nano-sized particles of titanium nitride on the structure and strength properties of iron-based composite coatings, surfaced using the pulsed mode, was studied. As a rule, when surfacing carbon steels, hardening occurs due to formation of a new surface layer. The properties of the built-up surface of steels depend on the type of alloying elements determining the phase composition, the boundaries of phase transitions, and mechanical characteristics. One of the ways to improve the strength of coatings is to refine the grain. The structure of the built-up metal and its properties are influenced by technological parameters of the surfacing process, the number and the size of alloying elements. When changing the surfacing mode, the process of material melting and chemical homogeneity of the built-up layer change. The properties of the coatings are affected by the carbon content (table 2), the intact state in the process of surfacing of strengthening phases (carbides, borides, nitrides), the sizes and their location in the matrix material.

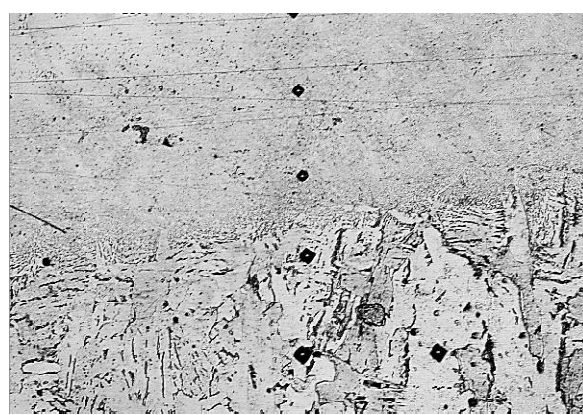
**Table 2.** Carbon content in surfaced coats.

Electrode type	Welding mode	Carbon content, mass. %
EN-60M	direct current	2.58
EN-60M	pulsed mode	3.66
T-590	direct current	3.96
T-590	pulsed mode	3.893

The results of the studies were verified when testing parts restored using pulsed arc surfacing. Working elements of mechanisms operated in the extreme climatic conditions of the North are subject to severe wear. The coating, surfaced in the pulsed mode, has a more homogeneous structure (figures 4-5).



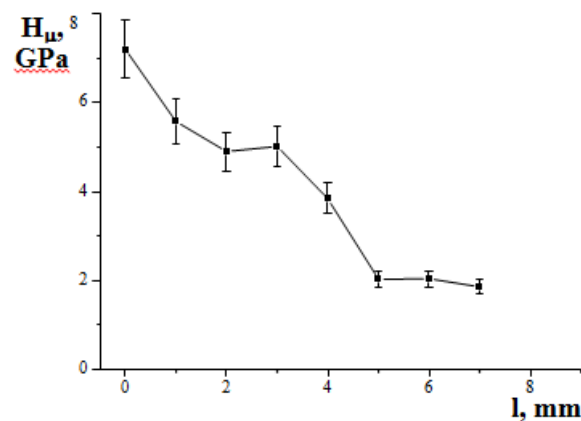
**Figure 4.** A structure of the transition zone “surfaced coat T590 - steel base (09G2S)”,  $\times 500$ .



**Figure 5.** A pattern of microhardness impressions in the transition zone “coating (top) – base”,  $\times 400$

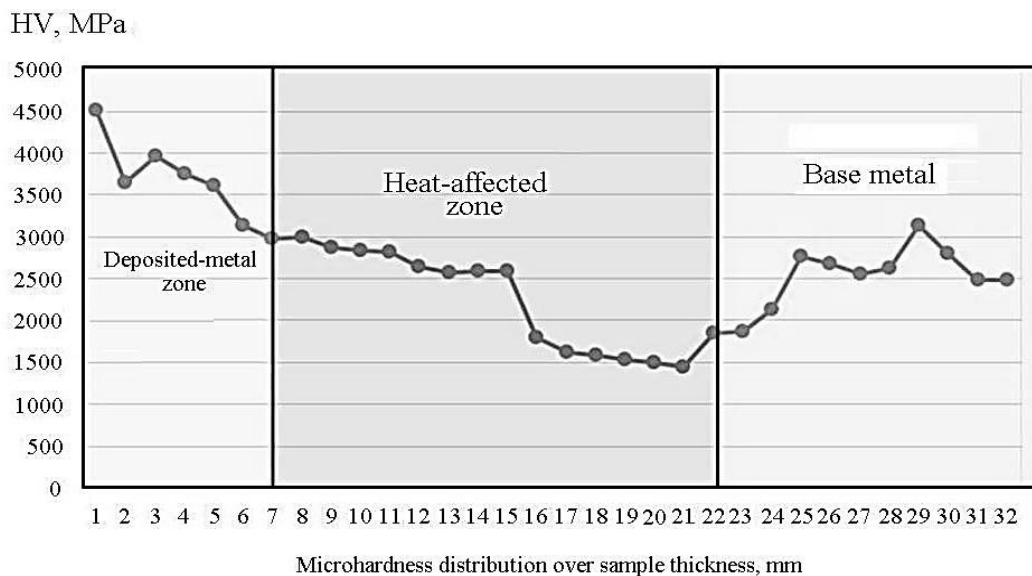
As a rule, in the process of a thermal deformational cycle of surfacing, cracks (hot and cold) are formed, which leads to a decrease in properties. When refining the structure, the properties of the coatings are enhanced.

Refining of the structure of the built-up metal structure is possible when introducing refractory compounds into electrode materials, as well as into the molten pool of particles. Such refining of the structure of the built-up metal affects its hardness, wear resistance and other properties [1-3]. Introduction of dispersed powders into the coating melt contributes to modification of the built-up metal. This conditions enhancement of strength, plasticity and a decrease of the friction coefficient [4, 5]. The temperature in the range of heat source during surfacing even exceeds the melting temperature of refractory compounds. This leads to their dissolution in the molten pool.



**Figure 6.** Change of microhardness in depth of the steel base and surfaced coats EN-60M.

Graphs of the microhardness of coatings, surfaced by EN-60M and T590 electrodes, and heat-affected zones shown in figures 6 and 7, testify to a very complex nature of the presented dependences.



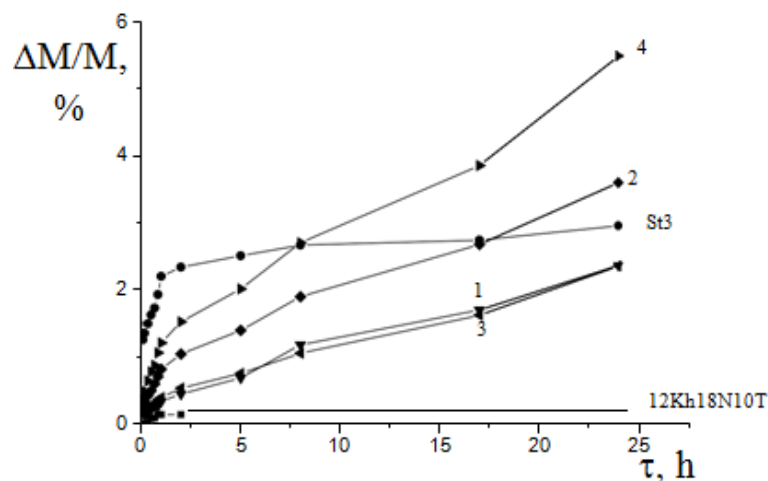
**Figure 7.** Distribution of microhardness throughout the layer thickness of surfaced coat T590.



The formation of a surfaced coat metal with a homogeneous fine-grained structure has been achieved. The averaged value of the microhardness of the built-up metal is 4500 MPa.

Microhardness of coatings surfaced by T590 electrodes, represented by perlite grains makes 3500-7000 MPa, and by grains of troostito-bainitic type – 4500-5200 MPa (figure 7).

It has been established that during pulsed arc surfacing by T590 electrodes, the content of the main alloying elements (manganese, silicon, nickel, chromium) in the built-up layer is greater than when surfacing using direct current approximately from 7 to 15%.



**Figure 8.** Time variation of corrosion resistance in highly concentrated (100%)  $\text{HNO}_3$  of test steels (St.3 and 12C18N10T) and coatings surfaced with T590 electrodes: 1) and 2) two layers, an HMT mode with application of different installations; 3) two layers using direct current; 4) one layer using direct current.

Graphs of time variation of the corrosion resistance of steel and coatings surfaced by T590 electrodes are shown in figure 8.

The results of the carried out tests, as well as the subsequent operation of the restored articles at enterprises of Yakutia, have shown their high working capacity and provision of a significant economic effect of the results of introduction of promising materials and technologies of repair-recovery and strengthening treatments of high-loaded articles operating under low climatic temperatures of the North.

#### 4. Conclusion

- A complex approach to enhancement of properties of surfaced coats by applying the method of modifying their materials by compounds of carbide and titanium nitride with a submicrocrystalline structure using pulsed modes of surfacing has been proposed.
- The influence of modification by dispersed particles and electric arc impact on the structure, physical – mechanical and operational properties of coatings have been studied. It has been established that the modification by refractory compounds with the submicrocrystalline structure allows enhancing the dispersity of the structure and coatings hardness.
- It has been shown that application of the pulsed arc surfacing method with the modification of the molten metal by the composite powder material of carbide and nitride of chromium and titanium with submicrocrystalline structures allows preserving these strengthening phases in the surfaced coat. Modification of the coating material by compounds of carbide and nitride of chromium and titanium with the submicrocrystalline structure during pulsed arc surfacing



allows increasing the homogeneity of the structure of the surfaced coat, leads to an increase of its hardness and wear resistance.

- The structure of the coating metal, performed by pulsed arc surfacing, does not contain a significant number of extensive dendrites in contrast to the seam, performed by arc welding using direct current. Application of surfacing made by electrodes T590 and EN-60M of low-carbon steel 09G2S according to the technology with low-frequency modulation of energy parameters of the mode allows forming coatings with a more fine-grained structure as compared to those obtained using direct current.

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### References

- [1] Oparin L N 1992 *Built-up metal. Composition, structure, properties* (Kiev: IES n. a. Paton, NAS of Ukraine) p 85
- [2] Kivineva E I, Olson D L and Maltock D K 1995 *Welding Journal* **3** 83
- [3] Komshukov V P, Cherepanov A N and Protopopov E V 2008 *News of Higher Educational Institutions. Ferrous metallurgy* **8** 10
- [4] Cantor B, H Chang I T, Knight P and Vincent A J B 2004 *Materials Science and Engineering* **213**
- [5] Zhou Y J, Zhang Y, Wang F J, Wang Y L and Chen G L 2008 *Journal of Alloys and Compounds* **466** 201
- [6] Guo Sheng, Chun Ng, Jian Lu and Liu C T 2011 *Journal of Applied Physics* **109** 103505
- [7] Sheng Guo and Liu C T 2011 *Progress in Science: Materials International* **21** 433
- [8] Yeh Jien-Wei, Chang Shou-Yi, Hong Yu-Der, Chen Swe-Kai and Lin Su-Jien 2007 *Materials Chemistry and Physics* **103** 41
- [9] Saraev Y N, Bezborodov V P, Grigorieva A A, Golikov N I, Dmitriev V V and Sannikov I I 2015 *Welding International* **29** 131
- [10] Grigorieva A A, Saraev Y N and Bezborodov V P 2014 *Applied Mechanics and Materials* **682** 26
- [11] Saraev Y N and Bezborodov V P 2013 *Welding International* **9** 678
- [12] Saraev Y N, Bezborodov V P, Shtertser A A, Ul'yanyskii V Y, Orishich A M, Il'yushchenko A F and Skakov M K 2012 *Welding International* **11** 881
- [13] Saraev Y N, Bezborodov V P and Selivanov Yu V 2009 *Welding International* **4** 20
- [14] Saraev Y N, Bezborodov V P, Durakov V G, Dampilon B V, Orishich A M and Ulyanitsky V Y 2013 *Welding International* **27** 969