DOI: http://dx.doi.org/10.15407/tpwj2018.09.06

EFFECT OF ALLOYING CHARGE AND EXTERNAL MAGNETIC FIELD ON STRUCTURE AND PROPERTIES OF DEPOSITED METAL

V.V. PEREMITKO, V.L. SUKHOMLIN, O.L. KOSINSKAYA and **A.I. PANFILOV**
Dniprovsk State Technical University
2 Dneprostroevskaya Str., 51918, Kamenskoe, Ukraine. E-mail: welding@dstu.dp.ua

Effect of inducing the external magnetic field in arc surfacing over preliminary deposited alloying charge (carbon-containing fibers + SiO_2) on hardness and structure of metal, as well as on change in the above-mentioned indices within the limits of single beads was investigated. It was found that the carbon-containing fibers applied to the part surface being deposited cause during surfacing the local enrichment with carbon of a liquid phase, which is decayed in cooling for ferrite-carbide mixture, that leads to the increase in metal hardness. Additional inducing the external magnetic field in process of surfacing promotes intensive stirring of weld pool that results in producing the more uniform structure and hardness. The analytical dependencies of hardness of deposited layers on amount of carbon-containing fibers, SiO_2 + Fe and magnetic field induction were obtained. The results of investigations can be used in development of technology for manufacture and restoration of parts operated under the abrasive wear conditions. 9 Ref., 1 Table, 10 Figures.

Keywords: *submerged-arc surfacing, carbon-containing materials, modifying components, external magnetic field, deposited metal, hardness, microstructure*

Submerged electric arc surfacing over the alloying charge is one of the simplest and most economical methods to produce wear-resistant layers on the surface of parts, operated under the conditions of different types of abrasive wear [1–3]. It is also known that using this method of surfacing, the producing of deposited metal of a preset and homogeneous chemical and microstructural composition depends to the greatest extent on the mode of surfacing, chemical and fractional composition of alloying charge, over which the surfacing is performed [4, 5].

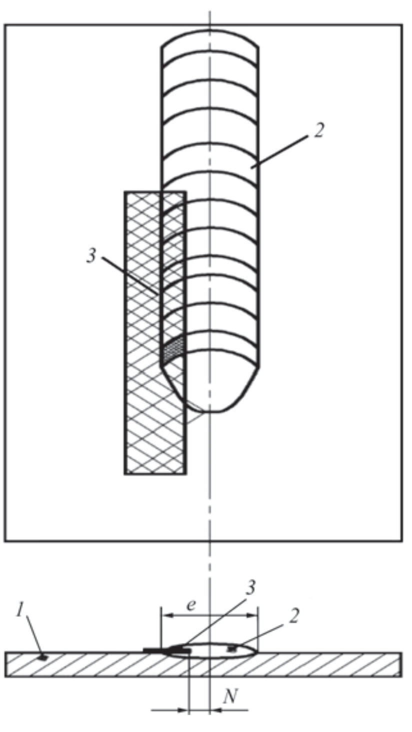

Figure 1. Scheme for the introduction of additional materials: *1* — specimen; *2* — deposited bead; *3* — carbon-containing material; *N* — displacement; *e* — bead width

The aim of this work was the improvement of this method of surfacing by the use of carbon-containing and modifying materials as the alloying charge. As the basis the scheme of arc surfacing of high-carbon coatings over the layer of charge was taken, where it was used in the form of carbon fibers [6]. Additionally, in order to improve the chemical and structural homogeneity of the deposited metal, the effect of an external magnetic field on this parameter was investigated, which according to some data [7, 8] has a positive effect on these properties.

In the course of experiments, the carbon fibers 3 were preliminarily put on the surface deposited in strips (Figure 1). During surfacing, the electrode wire was placed so that the depositing bead 2 overlapped the carbon-containing strip approximately by 25–35 %.

As a material, which fixes the placement of carbon fibers (2–4 fibers T 700SC Torey per the bead) on the surface deposited, a primer-based mixture was used, to which iron powder (15–25 wt.%) and aerosil (0.6–1.2 wt.%) were added. The layout of carbon-contain-

Effect of amount of carbon-containing fibers and magnetic induction on deposited metal hardness

No. of specimen	Induction B, mT	Amount of SiO_2 + Fe, %	Amount of fibers n, pcs	Hardness, HRC^*		
				1	2	3
1	60	1.2	2	18.0	21.0	16.0
2	60	0	2	24.1	25.0	21.9
3	0	1.2	2	24.8	26.2	22.5
4	0	0	2	17.5	20.1	15.2
5	30	0.6	2	22.5	23.8	20.7
6	60	0.6	4	28.7	30.0	26.5
7	60	0.6	0	21.2	22.0	18.8
8	0	0.6	4	23.0	24.5	21.2
9	0	0.6	0	15.0	16.5	14.0
10	30	0.6	2	22.5	24.1	20.3
11	30	1.2	4	26.4	29.0	24.2
12	30	1.2	0	19.0	20.2	16.9
13	30	0	4	24.0	26.0	22.0
14	30	0	0	18.0	18.3	15.7

*Places of hardness measurements (see Figure 3).

ing fibers on the surface deposited is shown in Figure 2.

In the experiments on surfacing, the automatic welding machine ADS-1000 with the rectifier VDU-506 was used. The surfacing was performed with the wire Sv-08A of 3 mm diameter under the flux AN-348A at a direct current of reverse polarity. The surfacing mode: current is 400–420 A, arc voltage is 32–36 V, wire feed speed is 160 m/h, surfacing speed is 12–16 m/h, pitch is 6–8 mm. The material of the specimens is steel 09G2S (hardness as-delivered is *HB* 128–143). In order to induce the external magnetic field, a special coil was used, which was fixed on the torch nozzle of the automatic machine ADS-1000. The coil was supplied by direct current.

During the experiments, the second order central noncompositional planning for three factors was performed: the concentration of SiO_2 + Fe, the amount of introduced carbon-containing fibers and induction of external magnetic effect. From the deposited beads the specimens were cut out to investigate the microstructure and hardness.

Based on the obtained data, the highest values of hardness of the deposited metal are fixed at the periphery of the deposited beads, an expressive maximum is observed at the magnetic induction B = 60 mT; SiO_2 + Fe — 0.8–1.0 wt. %; n — 4 pcs (see Table and Figure 3).

The processing of the experimental data was carried out using the program STATISTICA 6.0 (Figures 4 and 5). Having compared the diagrams shown in Figures 4 and 5, it can be concluded that at the point 2 (the place, where additional materials were applied) at the same modes of surfacing, the increase in the hardness *HRC* by 8–10 units is observed.

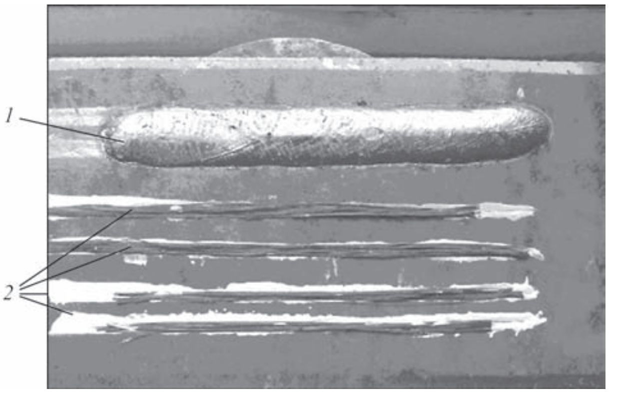

Figure 2. Scheme for the introduction of additional materials: *1* — deposited bead; *2* — carbon-containing fibers fixed by the primer before surfacing

With the increase in the number of carbon-containing fibers and magnetic induction, the hardness of the weld metal also increases. However, as the practice shows, at the magnetic induction values higher than 70 mT, the pores appear due to intensive stirring of the molten metal pool. The equation, describing the influence of all factors, has a form:

$$HRC = 14.17 + 0.14[c] + 2.72[SiO_2] + 2.57B -$$
$$-2.03[SiO_2]^2 + 0.1B^2 + 0.0027[c][SiO_2] -$$
$$-0.035[c]B + 0.49[SiO_2]B,$$

where [c] is the number of carbon-containing fibers in the deposited layer, pcs; $[SiO_2]$ is the concentration of aerosil, wt. %; B is the induction of magnetic field, mT.

Figure 6 shows the diagrams of changes in the hardness of metal on the deposited bead according to the traditional scheme of surfacing and that used in the investigations.

Thus, when adding additional materials in the form of aerosil and carbon-containing fibers T 700Sc Torey, 1.5–2.0 times increase in the hardness is observed, the highest hardness is fixed at the periphery of the beads.

After measuring the hardness, the analysis of microstructures was carried out. Figures 7–9 show the microstructures of specimens 1, 3, and 6 in the zones 1, 2, and 3 (see Figure 3 and Table). Comparing the structure of specimens 1 and 3 in the zone 1, it is possible to note a noticeable refining of both ferritic component, as well as the areas with the ferrite-cementite mixture.

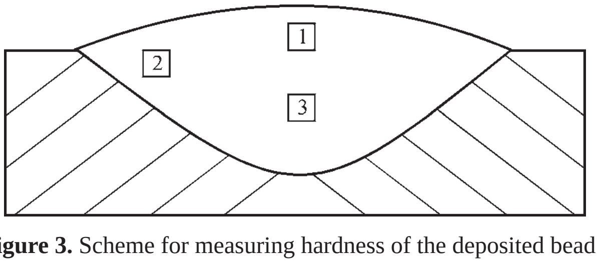

Figure 3. Scheme for measuring hardness of the deposited bead

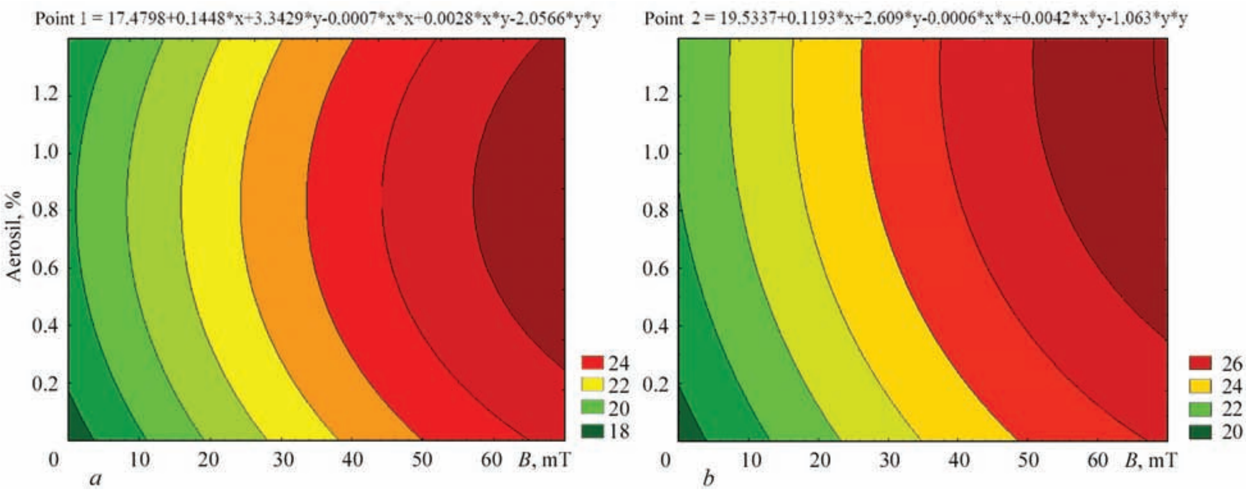

Figure 4. Dependences of hardness (*HRC*) at the points 1 (*a*) and 2 (*b*) on the amount of aerosil and magnetic induction value

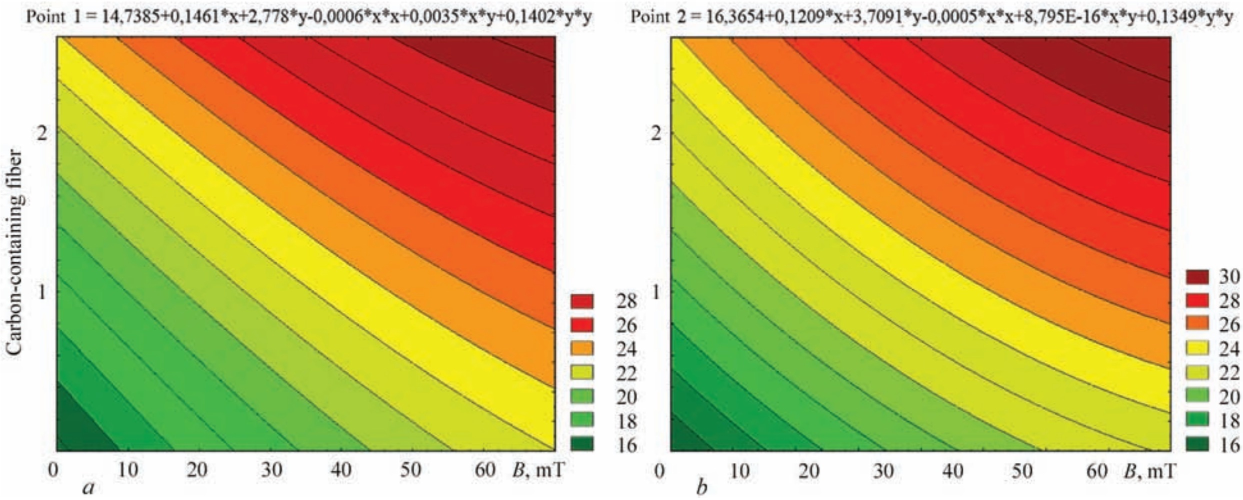

Figure 5. Dependences of hardness (*HRC*) at the points 1 (*a*) and 2 (*b*) on the amount of carbon-containing fibers and magnetic induction value

In the specimen 1, the size of quasi-polygonal grains of ferrite is 20–40 μm, and in the specimen 3 it is 10–30 μm. The grains of ferrite-cementite mixture have a size of 40–60 μm in the specimen 1 and 30–40 μm in the specimen 3 (Figure 7, *a*, *b*).

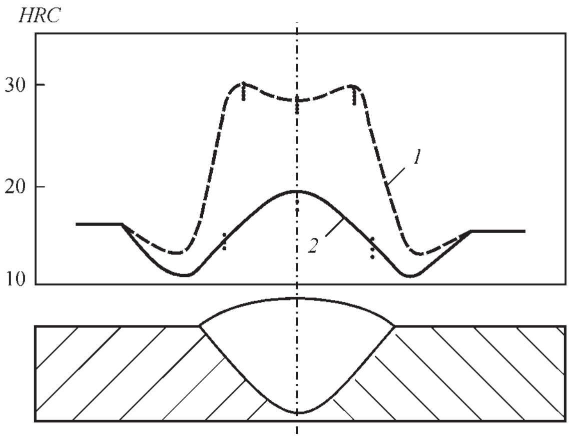

Figure 6. Diagrams of changes in the hardness of deposited bead metal: *1* — with the introduction of additional materials; *2* — without introduction of additional materials

Such refining of structural elements in the specimen 3 is explained by the influence of an external magnetic field during arc surfacing [8]. The additional stirring of the molten metal in a pool facilitates the growth of cooling rate, and, therefore, increases the degree of overcooling during solidification and refining of all the structural components.

In the zone 2, the formation of a structure is influenced not only by carbon-containing fibers and aerosil, but also by an intense heat removal to the base metal. Under its influence, the primary ferrite partially changes its morphology: the acicular ferrite appears in the structure [9]. Also under the effect of a directional heat removal the ferrite-cementite mixture acquires a noticeably elongated shape. The pearlitic structures are formed in the form of thin interlayers between the laths of acicular ferrite or in the form of coarse grains of a quasi-eutectoid. The ferritic formations in zone 2 of the specimen 1 have a width of 30–40 μm and are elongated by 150–200 μm, in the specimen 3 they are elongated, respectively by 15–20 μm and 80–150 μm.

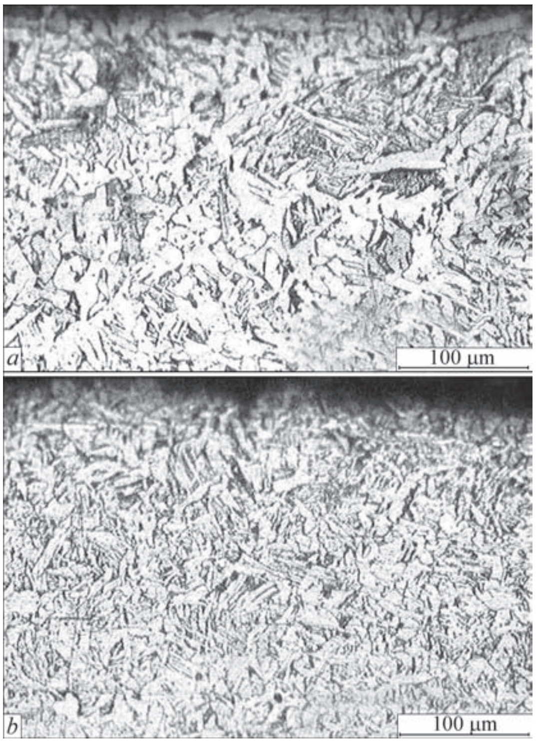

Figure 7. Microstructure of specimens 1 (*a*) and 3 (*b*) in the zone 2

The factor of the magnetic field (for the specimen 3) facilitates stirring of weld pool metal and a more uniform distribution of SiO_2 particles, which play the role of a modifier of the second type, increasing the amount of solidification centers, and the carbon-containing fibers in the zone 2 supply carbon for the formation of a carbide phase. These two factors not only facilitate the refining of the final structure, but also increase the fraction of ferrite-cementite mixture in the specimen 3 (Figure 8, *a*, *b*). The hardness in this zone is maximum.

In the zone 3 of the specimen 1, the lowest hardness is noted. Without additional magnetic effect, the formation of gradient structures occurred almost without the participation of aerosil SiO_2 particles. The width of the ferritic areas in this zone is 25–35 μm, the length is 180–250 μm. The areas of the ferritic-pearlitic mixture have a width of 50–80 μm and a length of 250–300 μm. The width of the acicular ferrite lath is 20–40 μm at an average length of up to 90 μm.

The structure of specimen 3 in the zone 3 was formed with the participation of SiO_2 particles and an external magnetic field. In this zone, the width of the ferritic areas in the structure of columnar crystallites reaches 20–35 μm with a length of 140–180 μm, the width of the areas of ferritic-pearlitic structure is 35–50 μm with a length of 200–230 μm. The width of the acicular ferrite lath is 15–20 μm at an average length of up to 45–70 μm (Figure 9, *a*, *b*).

In the specimen 6, unlike the specimen 3, twice lower content of SiO_2 and twice higher content of carbon-containing fibers were used. First of all, these changes affected the zone 1. The structure in this zone, due to a smaller amount of modifier, intensive stirring by a magnetic field and additional amount of carbon, has a uniform distribution of quasi-polygonal ferrite areas of 20–30 μm in size, grains of ferrite-cementite mixture with sizes of 35–55 μm and acicular ferrite at a width of the lath being 10–20 μm and a length of 30–55 μm.

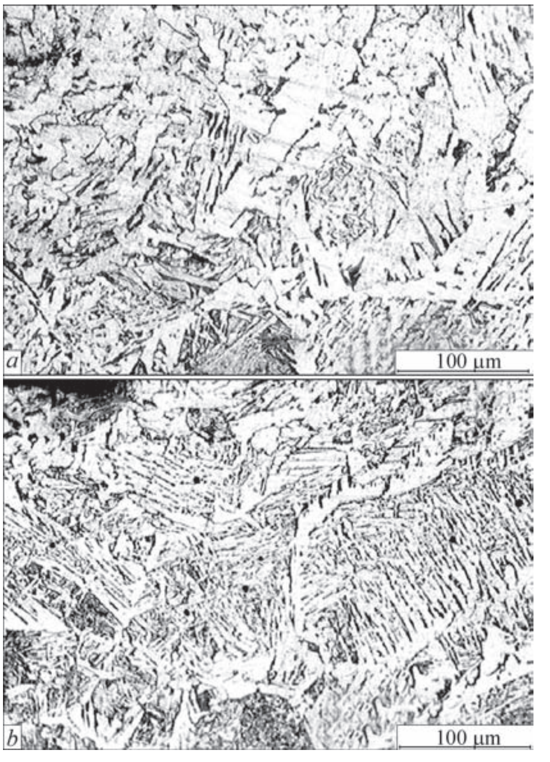

Figure 8. Microstructure of specimens 1 (*a*) and 3 (*b*) in the zone 2

Figure 9. Microstructure of specimens 1 (*a*) and 3 (*b*) in the zone 3

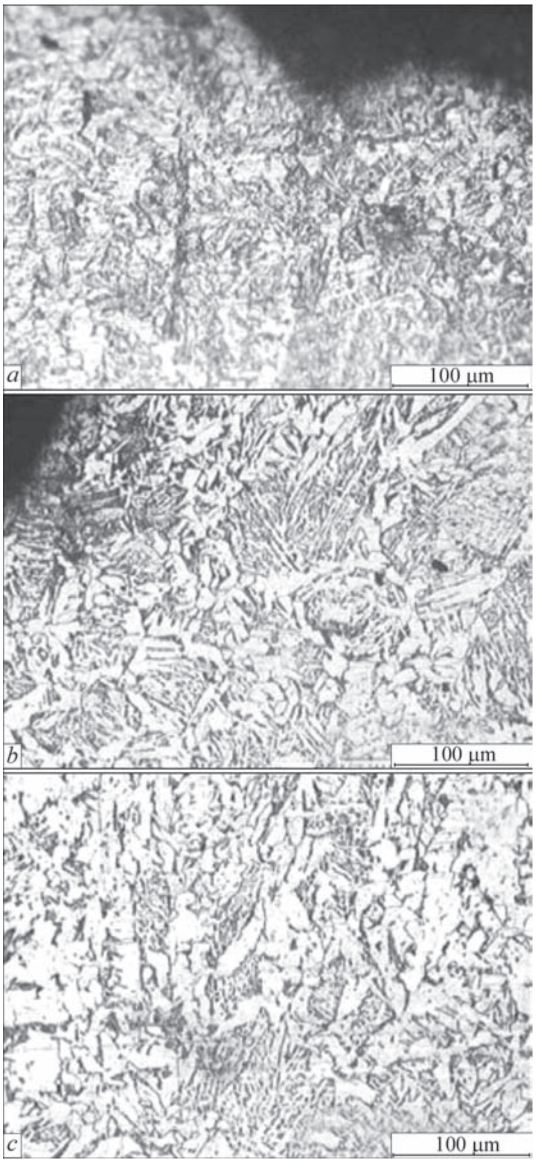

Figure 10. Microstructure of specimens 1 (*a*) and 3 (*b*) in the zone 3

A large total volume of ferritic-carbide mixture (up to 50 %) in combination with acicular ferrite (up to 20 %) contributed to an increase in the hardness *HRC* of the specimen in the zone 1 by 3.9 units as compared to the specimen 3. In the zones 2 and 3, the increase in hardness is also predetermined by the refining of both the ferritic component of the structure, and the areas of the quasi-eutectoid and the acicular ferrite laths, which led to higher *HRC* values among all the specimens (Figure 10, *a*–*c*).

Conclusions

1. The analytical dependences were proposed to determine the hardness of deposited layers on the number of carbon-containing fibers, previously applied on the surface deposited, the concentration of SiO_2 + Fe, and the external magnetic field induction.

2. It was established that carbon-containing fibers applied on the parts surface deposited cause a local carbon enrichment of the liquid phase during surfacing, which decomposes into a ferritic-carbide mixture during cooling, thus leading to an increase in the hardness of the metal. The additional inducing of external magnetic field in the process of surfacing promotes an intensive stirring of the weld pool, which results in a more uniform structure and hardness of the deposited metal.

3. The use of aerosil SiO_2 as a modifier is the most justified in the combination with the inducing of an external magnetic field during surfacing. The hardness of metal after using this technology is increased in the near-surface area of the deposited metal by about 20 %.

4. The obtained results can be used in the development of technology of surfacing the parts operated under the conditions of intensive abrasive wear.

1. (2002) *Restoration and improvement of wear resistance and service life of machine parts*. Ed. by V.S. Popov. Zaporozhie, OJSC Motor Sich [in Russian].
2. Peremitko, V.V. (2014) Wear-resistant arc surfacing over the layer of alloying charge. *The Paton Welding J*., **8**, 54–57.
3. Kuznetsov, V.D., Stepanov, D.V. (2015) Wear-resistant surfacing with feeding of nanopowders in welding pool. *Ibid*., **5-6**, 47–51.
4. Frumin, I.I. (1961) *Automatic electric arc surfacing*. Kharkov, Metallurgizdat [in Russian].
5. Ryabtsev, I.A., Senchenkov, I.K. (2013) *Theory and practice of surfacing works*. Kiev, Ekotekhnologiya [in Russian].
6. Savulyak, V.I., Zabolotny, S.A., Shenfeld, V.J. (2010) Surfacing of high-carbon coatings using carbon fibers. *Problemy Trybologii*, **1**, 66–70 [in Ukrainian].
7. Razmyshlyaev, A.D. (2000) *Magnetic control of weld formation in arc welding*. Mariupol, PSTU [in Russian].
8. Ryzhov, R.M., Kuznetsov, V.D. (2010) Magnetic control of welded joints quality. Kyiv, Ekotekhnologiya [in Ukrainian].
9. Bolshakov, V.I. (2015) Acicular ferrite. *Visnyk Prydnipr. Derzh. Akademii Budivnytstva ta Arkhitektury*, **9**, 10–15 [in Russian].

Received 02.07.2018