WEAR-RESISTANT ARC SURFACING OVER THE LAYER OF ALLOYING CHARGE

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Given are the results of study of structure, hardness and relative wear resistance of surface layers of parts, restored by submerged arc surfacing with addition of powdered materials and superposition of external magnetic axial field. Using powders of silicon carbide SiC and aerosil SiO_2 the paste-like mixture on the base of GF-021 primer was prepared and deposited by beads along the surfacing direction. During experiments the composition of mixture, number of layers being deposited, eccentricity in arrangement of layers relative to electrode wire axis, as well as induction of external magnetic field were varied. Coming from the obtained results, the highest values of hardness of the deposited metal were observed at $B = 20$–50 mT. Optimum pitch in deposition of layers is 4–6 mm. Hardness is growing with increase of number of layers being deposited. Regression equations of mentioned relationships are presented. Due to external magnetic field it became possible to decrease the heat effect on added powdered materials without melting of their particles. Analysis of microstructures proves the effect of magnetic field on crystallization. The uniform distribution of particles of powdered material was occurred, grain number reached 10–12 over 6–8 initial one. Wear tests revealed the least losses in mass of specimens, deposited with addition of SiO_2 particles. In this case the allowable plastic deformation and maximum increase in hardness of surface layers are occurred. 8 Ref., 4 Tables, 4 Figures.

Keywords: *submerged arc surfacing, external magnetic field, powders SiC and SiO_2, mixtures on the base of primer, analysis of microstructure, hardness, regression relationships, wear resistance*

The practice of restoration surfacing of parts in different branches of industry predetermined a great number of directions in development and improvement of methods of traditional arc consumable electrode surfacing. In different times the technology and equipment were offered, which allowed increasing the efficiency of surfacing, providing the deposition of layers in multi-layer coatings in various spatial positions and of different chemical composition, including composite ones [1].

At general tendency of applying non-deficit and inexpensive surfacing materials for restoration and hardening of parts, the main difficulty is encountered in attaining the high wear resistance of contact surfaces being restored. The increase in service characteristics of the deposited working layer is attained usually by the selection and optimizing the chemical composition of electrode or filler surfacing materials and, when necessary, by subsequent heat treatment [1–5].

To increase the term of service of parts, operating under conditions of abrasive wear, the updating of installation for automatic submerged arc surfacing was made, technology of surfacing over the layer of alloying charge was developed, surfacing of specimens was performed by the developed technology, microstructure and wear resistance of deposited specimens were examined.

The principle of offered changes consists in superposition of controlling axial magnetic field on welding arc during surfacing, which has a retarding effect on rate of molten metal flows in a pool and decreases the depth of base metal penetration [6–8]. The superposition of external magnetic field provides also the increase of transverse sizes of weld pool, thus giving possibility to deposit the powdered filler charge with shifting of its disposition from the arc axis in that weld pool area, where the temperature of molten metal is not relatively high. The latter is important from the point of view of prevention of complete melting of dispersed material, added for refining the structure of metal being deposited and increasing of its wear resistance. Silicon carbide SiO and aerosil SiO_2 with particles size of not more than 200 μm were used as dispersed materials. Aerosil is a colloid dioxide of silicon, easily crushed into powder, its technical name is pyrogenic dioxide of silicon.

To improve the conditions of adding and increase in efficiency of effect, the powders of silicon carbide and aerosil were mixed with iron powder ($Fe + SiC$, $Fe + SiO_2$). This allowed improving the assimilation of powders by deposited metal and providing their more uniform concentration in the deposited bead length. For better uniformity of powdered material falling into the bead being deposited, a paste-like mixture on the base of primer GF-021 was prepared, which was then deposited along the line of next deposition at 4–10 mm pitch in transverse direction (Figure 1).

As the powdered materials are differed by parameters (shape, bulk mass), optimum proportions and consumption of powders per unity of weld length were determined experimentally. The obtained data are summarized in Table 1.

Surfacing of specimens of steel 45 was carried out under flux AN-348A with wire Sv-08A of 3 mm diameter in the installation of UD-209 type. Surfacing mode: 400 A current, 32–36 V voltage, 160 m/h wire feed rate, 12–16 m/h surfacing speed, 6–8 mm surfacing pitch, direct current of reverse polarity. For examination of structure and measurement of hardness the flat specimens of 15 mm thickness were cut out from deposited plates, and the cylindrical specimens of external diameter from 30 up to 50 mm and 10 mm thickness were prepared for wear tests.

By changing the distance *N*, modes of surfacing and characteristics of magnetic field, it is possible to attain that the relatively refractory particles of alloying charge would not be melted completely in the weld pool and after crystallization of the deposited metal would be retained in it in a free state.

During experiments the central non-composition planning of the second order for four factors was made: mixture composition, number of mixture layers being deposited (one to one after drying the latter), eccentricity in arrangement of layer with respect to the torch axis, induction of external magnetic field. Processing of experimental data was carried out by using the package STATISTICA 6.0. Hardness was determined in meter TK-2. Coming from the obtained results, the highest values of hardness of the deposited metal were observed at magnetic induction B = = 20–50 mT (Table 2).

Table 1. Proportions of mixtures and their consumption per unity of weld length

Number of mixture	Composition of mixture	Ratio of components in mixture	Consumption of powder per bead of 15 cm length, g
1	SiC + Fe	0.04:1	0.06
2		0.08:1	
3		0.12:1	
4	SiO_2 + Fe	0.15:1	0.50
5		0.30:1	
6		0.45:1	

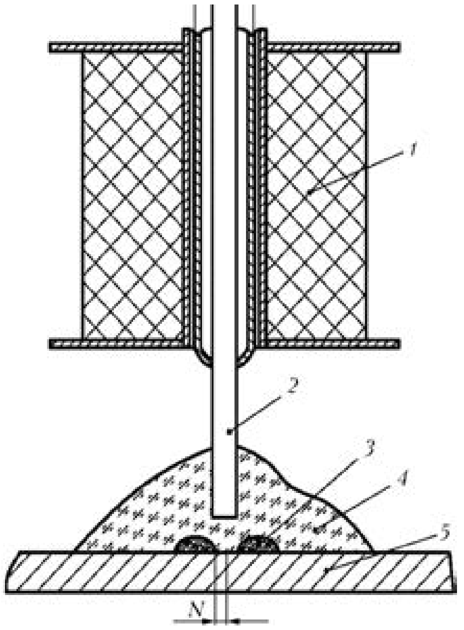

Figure 1. Schematic diagram of automatic submerged arc surfacing over the alloying charge, located out of zone of arc action with magnetic field superposition on arc: *1* — coil generating the magnetic field; *2* — wire; *3* — layer of alloying charge; *4* — flux; *5* — specimen being deposited; *N* — distance from arc center to alloying charge layer

Regression equations of relationships of hardness for two types of mixtures have a form:

$$HB = 156.974 + 29.190[c] + 22.605n - \\ - 2.638[c]^2 - 4.721[c]n - 1.829n^2, \quad (1)$$

Table 2. Results of determination of hardness of deposited metal of specimens

Number of specimen	Number of mixture	*N*, mm	Number of mixture layers being deposited	*B*, mT	*HB*
1	Without powders addition	7	–	20	213.5
2	Same	4	–	20	217.6
3	6	10	2	50	223.0
4	5	4	2	50	230.2
5	1	10	2	50	215.0
6	2	4	2	50	219.7
7	4	7	2	80	214.5
8	5	7	2	20	220.0
9	3	7	2	80	219.7
10	3	7	2	20	235.6
11	2	7	3	50	220.9
12	4	7	1	50	219.1
13	3	7	3	50	229.0
14	3	7	1	50	227.6

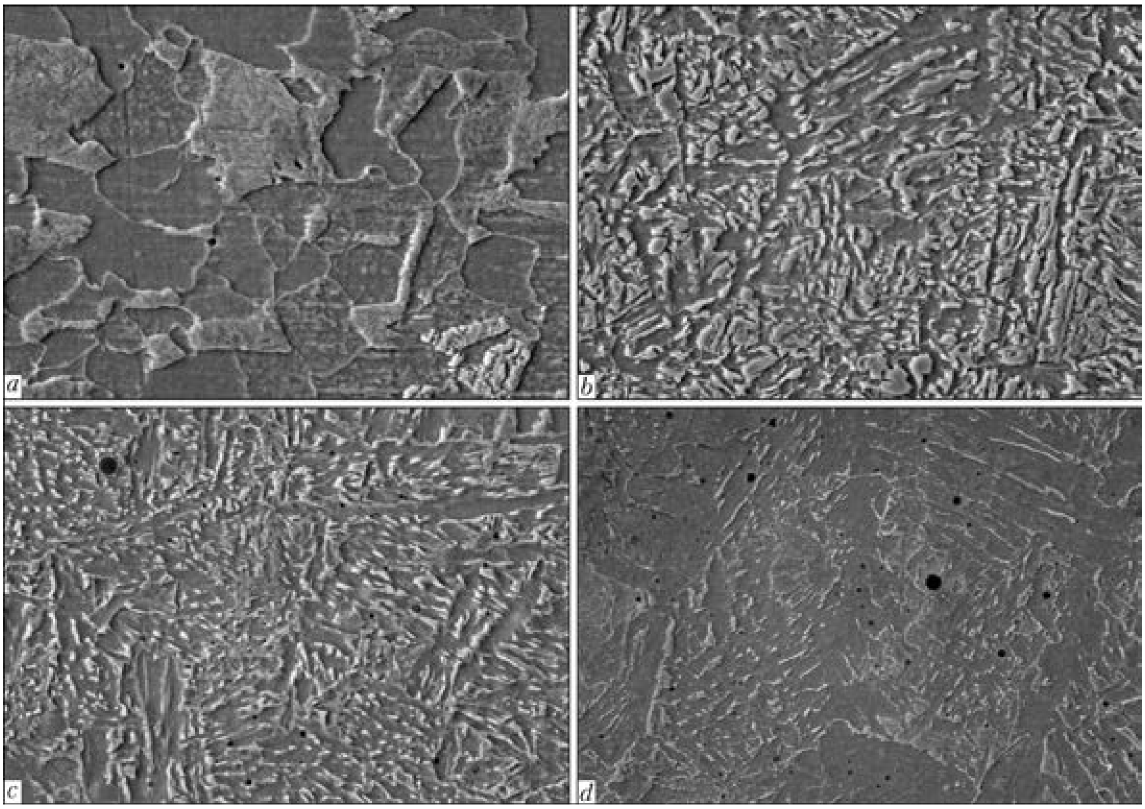

Figure 2. Structure (×1000) of deposited metal of specimens: *a* — base metal (steel 45); *b* — HAZ; *c*, *d* — deposited metal with mixture of powders SiC + Fe and SiO_2 + Fe (black spots — SiC and SiO_2 particles, respectively)

$$HB = 177.856 + 15.427N - 0.176B - 0.962N^2 - 0.039NB + 0.002B^2. \quad (2)$$

Equation (1) allows calculating hardness of deposited metal in use of mixture SiC + Fe. This mixture gives the highest growth of hardness ([*c*] is the concentration of SiC in mixture, expressed in fact by its number). Equation (2), respectively, allows calculating hardness of deposited metal in use of mixture SiO_2 + Fe.

Hardness is growing in change of mixtures composition in the following sequence: (without powder) < (Fe + SiO_2) < (Fe + SiC) and increase in number *n* of deposited layers of powdered materials up to three (1 < 2 < 3). Double applying of powder increases the hardness of deposited metal by 1.5 times, and three-time one increases by 1.05 times as compared with double one. Optimum shifting of layers of alloying charge *N* from weld centre is within the ranges of 4–6 mm.

Specimens were manufactured from deposited plates for examination of microstructure and wear resistance of the deposited metal.

Analysis of microstructures proves the positive effect of magnetic field on the deposited metal crystallization (Figure 2, *a*, *b*). Due to intensive stirring in magnetic field superposition the fer-

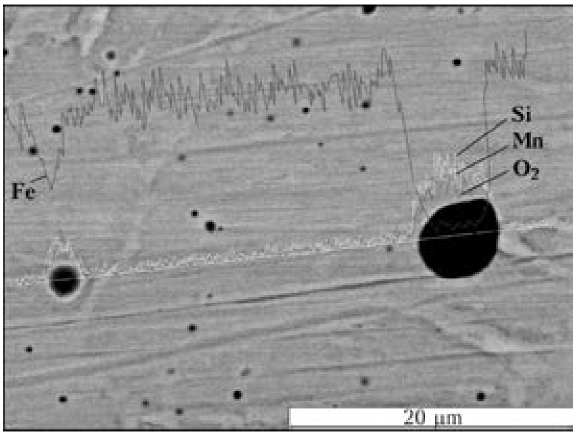

Figure 3. Scheme of scanning of deposited metal of specimens

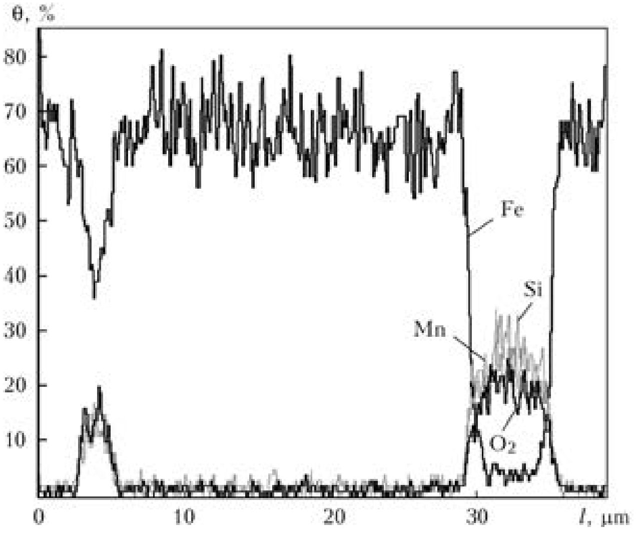

Figure 4. Distribution of elements along the scanning line

Table 3. Chemical composition of dispersed inclusions, wt.%

Number of mixture	C	O	Al	Si	S	Ti	Mn	Fe
3	14.74	35.72	4.61	15.14	1.18	0.30	26.81	1.49
6	7.15	33.08	2.56	17.76	0.97	0.28	31.59	6.61

Table 4. Results of investigation of wear resistance of deposited metal of specimens

Number of mixture	Hardness of surface layer *HB*		Loss of mass, g	
	Before test	After test	For roller, driving/driven	For contact pair
Without adding of powders	213.5	220	0.12170/0.08485	0.20655
3	235.6	269	0.06929/0.05520	0.12449
6	223	285	0.05345/0.02925	0.08270

rite-pearlite grains have a disoriented directivity. Moreover, the deposited metal has a very fine structure: the deposited metal grain number is 10–12. This is explained by effect of magnetic induction and presence of non-melted particles of silicon dioxide and carbide, which are rather uniformly distributed in the deposited metal.

Identification of inclusions was made by using the energy-dispersed analyzer in scanning electron microscope Zeiss EVO50 (Figures 3 and 4). Detailed examination of structural constituents was made at depth of 2, 4 and 6 mm from the bead surface at areas of 5 mm width symmetrically to its axis. The nature of distribution of dispersed inclusions, as well as their number remained approximately similar in all the cases. Size of particles was decreased by an order. The coarsest particles had the linear sizes in the limits of 10 μm. The obtained data (Table 3) prove that the particles retained partially their chemical composition.

Investigations of wear resistance of the deposited metal were carried out in unit MI-1M by roller–roller scheme (time of wear was 2 h, force of rollers pressing was 1 kN) (Table 4).

As is seen, the maximum loss of mass and minimum wear resistance were observed in a contact pair, deposited without adding of powders. The deposited metal had a minimum hardness, wear was occurred with plastic deformation and delamination of surface layers. Friction pair of specimens, deposited over the charge mixture with SiC particles, had the highest wear resistance.

Though the hardness of specimens of this type before and after tests was higher than that of non-hardened specimens, their wear occurred without noticeable plastic hardening. The best result was in specimens deposited over charge with aerosil particles. They were hardened to a larger degree in the wear process and had the highest hardness after tests.

Conclusions

1. The scheme of arc surfacing over the layer of alloying charge is offered with superposition of magnetic field on arc, allowing great (by 1.8–2.2 times) increase of wear resistance of deposited metal in use of non-alloyed wire and widely applied fluxes, as well as powders of silicon dioxide and carbide.

2. Optimum parameters of alloying charge supply relative to arc center (magnetic induction of 20–50 mT, shifting of charge layers relative to arc axis is 4–6 mm) are determined, at which the maximum reduction in losses of mass of specimens in wear (from 0.2065 to 0.0827 g) and grain refining of deposited metal are attained.

3. Local analysis of dispersed inclusions confirmed that non-melted particles retained mainly their composition (up to 17.76 % Si, up to 14.74 % C, up to 37.72 % O_2) at significant (by one order) decrease of linear sizes.

1. Ryabtsev, I.A., Senchenkov, I.K. (2013) *Theory and practice of surfacing operations*. Kiev: Ekotekhnologiya.
2. Chigarev, V.V., Malinov, V.L. (2000) Selection of sparcely-alloyed surfacing materials for different impact-abrasive conditions. *The Paton Welding J*., **5**, 55–57.
3. (2000) *Repair and increase in wear resistance and service life of machine parts*. Ed. by V.S. Popov. Zaporozhie: Motor Sich.
4. Lifshits, L.S., Grinberg, N.A., Kurkumelli, E.G. (1969) *Principles of deposited metal alloying*. Moscow: Mashinostroenie.
5. Frumin, I.I. (1961) *Automatic electric arc surfacing*. Kharkov: Metallurgizdat.
6. Razmyshlyaev, A.D., Mironova, M.V. (2009) *Magnetic control of formation of beads and welds in arc surfacing and welding*. Mariupol: Priazov. STU.
7. Ryzhov, R.M., Kuznetsov, V.D. (2010) *Magnetic control of welded joint quality*. Kiev: Ekotekhnologiya.
8. Peremitko, V.V. (2013) Development and investigation of repair surfacing technology of undercarriage rollers of caterpillar machines. In: *Proc. of 15th Int. Sci.-Pract. Conf. on Technology of Strengthening, Coating Deposition and Repair. Theory and Practice*, Pt 1, 168–172. St.-Petersburg: SPU.

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