FORMATION OF STRUCTURE AND PROPERTIES OF 316 TYPE STEEL AT SUCCESSIVE CIRCUMFERENTIAL ELECTROSLAG SURFACING WITH LIQUID METAL

A.A. POLISHKO, L.B. MEDOVAR, V.Ya. SAENKO, S.I. STEPANYUK, A.Yu. TUNIK, I.N. KLOCHKOV and **I.V. BEREZIN**
E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

The paper gives the results of metallographic investigations of structure, chemical composition and physical-mechanical properties of high-alloy 316 type steel (AISI) model ingot, produced under laboratory conditions by a method of enlargement using a successive circumferential electroslag surfacing with liquid metal.

Keywords: *electroslag surfacing, liquid metal, model two-layer ingot, high-alloy steel, microstructure, physical-mechanical properties*

The reliability and service life of modern machines and mechanisms are defined mainly by the quality of their separate parts. Special requirements are specified to the critical machine parts, operated under severe and extremely severe conditions at elevated and high temperatures (rotors and discs of steam and gas turbines). Fulfillment of these requirements leads to the complication of the chemical composition of metals and alloys, causes the need in improving the quality of the billet metal. Strength and ductile properties of the cast metal are of a special importance today [1].

Using the traditional methods it is not always possible to produce products of the required quality, it refers in particular to large ingots of high-alloy steels and alloys, as there are the significant limitations in ingot diameter due to the risk of formation of defects of liquation origin [2].

In this case the electroslag technology has a clear advantage, allowing producing metal with high values of density, physical and chemical homogeneity, isotropy of properties, uniform distribution of non-metallic inclusions, characterized by high level of purity and fine-dispersed structure. All this is important for critical parts, operated under severe conditions, when the stable high values of physical and mechanical properties are required.

Wide opportunities for the formation of the required structure and properties of large ingots of 316 type high-alloy steels are opened by the application of one of the varieties of electroslag technologies, namely the successive circumferential electroslag surfacing with liquid metal (ESS LM) for the enlargement of ingots. Application of ESS LM allows decreasing greatly the section and volume of solidifying metal, successively deposited on the ingot being enlarged and, thus, preventing the developing of liquation processes in each deposited layer [3–5].

The present work presents the results of metallographic investigations of structure and properties of two-layer model 110–180 mm diameter ingot of high-alloy steel of 316 type (10Kh17N14M2), produced

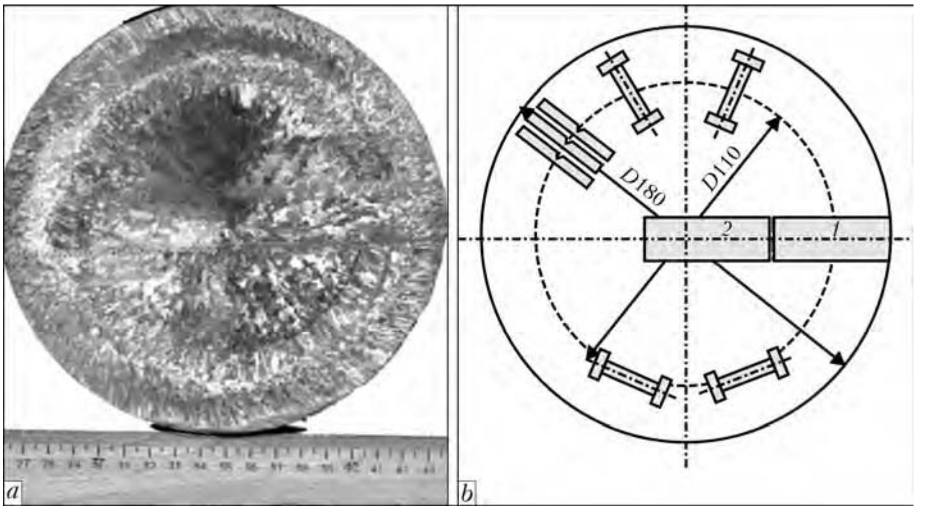

Figure 1. Macrostructure of transverse template of model two-layer ingot of steel 316 + steel 316 after ESS LM (*a*), and scheme of cutting out of specimens *1* and *2* for further investigations (*b*)

Table 1. Chemical composition of model two-layer ingot in the zone of layers fusion, wt.%

Object of investigation	C	Mn	Si	Cr	Ni	Cu	Mo	Nb	P	S
Deposited layer	0.059	1.13	0.31	15.6	11.9	0.20	2.2	0.20	0.027	0.006
	0.069	1.02	0.15	15.5	12.0	0.21	2.2	0.23	0.029	0.005
	0.058	1.13	0.32	15.5	11.6	0.21	2.2	0.20	0.027	0.006
	0.065	1.00	0.15	15.3	11.7	0.21	2.2	0.22	0.033	0.005
Central ingot	0.052	1.20	0.43	16.3	11.7	0.21	2.2	0.19	0.022	0.011
	0.073	1.03	0.16	15.9	12.1	0.23	2.2	0.23	0.029	0.005
	0.044	1.17	0.41	16.3	11.4	0.21	2.2	0.19	0.023	0.010
	0.069	1.01	0.15	15.6	12.1	0.21	2.2	0.23	0.028	0.005

under laboratory conditions using a successive circumferential ESS LM.

After melting the model ingot for further investigations, a transverse template was cut out of it (Figure 1, *a*).

The macrostructure of the transverse template was characterized by a homogeneous and dense structure (Figure 1, *a*) without defects of a shrinkage and liquation nature. Thickness of deposited layer in a transverse section of the ESS LM model ingot was almost similar.

The chemical composition of metal was determined by the method of a spectral analysis (GOST 9717–75). Using the emission spectral analysis in the diffraction photometric spectrometer, the distribution of elements in the transverse section of the model ingot in the zone of fusion of metal layers of similar chemical composition was studied. Zones were examined on the side of the deposited layer and central ingot in four points on each side. The obtained results are presented in Table 1.

As is seen from the Table, the distribution of elements in the transverse section of a model two-layer ingot is almost uniform with a slight scattering within the ranges of allowable error in measurements of up to 2 %.

The metallographic examinations using the metallographic microscope «Neophot-32», equipped with an attachment for digital photographing of etched sections (solution of chromic acid H_2CrO_4) in accordance with the scheme of cut out (see Figure 1, *b*), showed that the microstructure of fusion zone metal of the two-layer model ingot is austenitic with orientation of crystallites, typical of polycrystalline materials with a dendritic shape of crystals both on the side of a central ingot (along fusion line) and also in the deposited layer (Figure 2).

Specimens for investigation of physical and mechanical properties were cut out of metal of the model

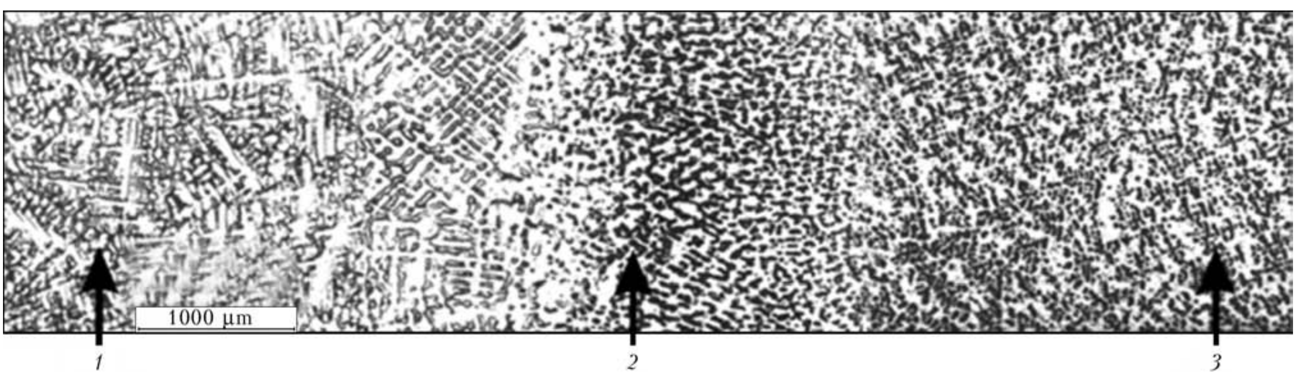

Figure 2. Microstructure of fusion zone of metal of model two-layer ingot: *1* — deposited layer; *2* — fusion zone; *3* — central ingot

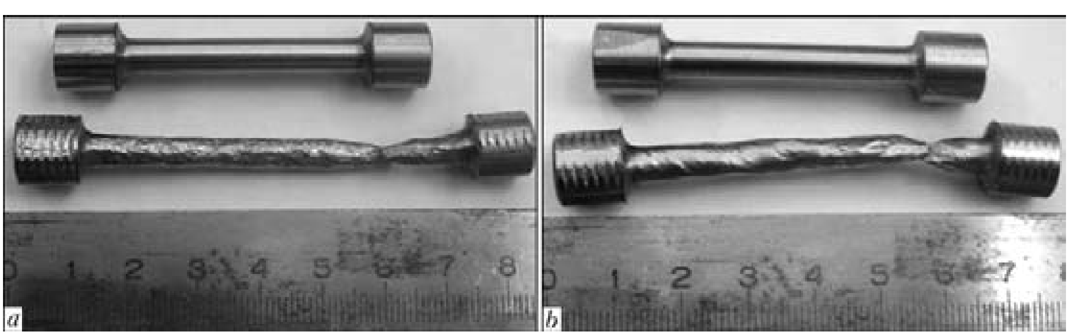

Figure 3. Specimens of metal of model ingot of 316 type steel before and after static (short-time) tensile tests in tangential (*a*) and radial (*b*) directions

Table 2. Physical-mechanical characteristics of metal of transverse specimens of model two-layer ingot of 316 type steel

Direction of specimens cutting out from ingot	σ_t, MPa	σ_y, MPa	δ, %	*KCV*, J/cm^2	k_{σ_t}	k_{σ_y}	k_δ
Tangential	491.0	201.5	55.0	–	0.98	1.01	1.05
Radial	502.4	198.8	52.5	240–298*	0.98	1.01	1.05
Requirements of Metals Handbook (9th ed.) of American Society for Metals for wrought metal	480.0	170.0	40.0	182–312	–	–	–

Notes. 1. Mean values of σ_t, σ_y, δ are given. 2. Coefficients of anisotropy k_{σ_t}, k_{σ_y}, k_δ are equal to ratio of values of characteristics of specimens cut out in tangential and radial directions. 3. Values of *KCV* are obtained for specimens after testing the cast metal with a notch in the HAZ at the distance of 2 mm from the fusion line.

two-layer ingot after ESS LM in transverse section at two levels in ingot height in radial and tangential directions (see Figure 1, *b*).

Static (short-time) tensile tests were performed according to requirements of GOST 1497–84 in servo-hydraulic test machine MTS 318.25 (USA) at maximum force 250 kN. The results were processed using the software TestWorks4 of MTS company. The error in obtained results was ±0.5 %, while it is allowable up to 1 % according to the GOST 1497–84.

Bend impact tests for determination of impact toughness *KCV* were performed according to requirements of GOST 9454–78 on specimens with a sharp notch (stress raiser) in the middle using one impact of a pendulum hammer. The notch on the specimens was made at the 2 mm distance from fusion line in the HAZ. Experiments were carried out using a pneumatic pendulum hammer of 2130-KM-03 type at a rated potential energy of pendulum of 300 J at 20 °C temperature (Table 2, Figures 3 and 4). Results of investigations showed the stable high level of strength characteristics of fusion zone metal of model ingot, and also homogeneity of metal properties both in section in tangential and radial directions and also in height at two levels.

It should be noted that the authors of this article studied the physical and mechanical properties on cast metal of the model two-layer ingot of 316 type steel, while in all the handbooks of steels and alloys the data are given for the wrought metal. Therefore, it is important for us to compare the obtained results for cast and wrought metals.

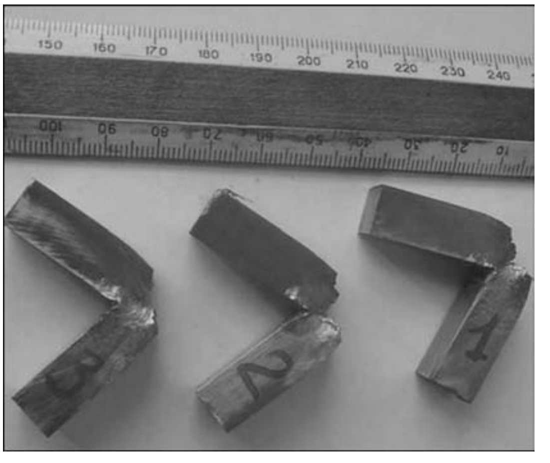

Figure 4. Specimens of metal of model two-layer ingot of 316 type steel after bend impact tests

The specimen fracture surfaces were investigated after static tensile and impact bend tests using the JEOL scanning electron microscope JSM-35CF and the Oxford Instruments X-ray spectrometer with a dispersion in energy of X-ray quanta (model INCA Energy-350, UK).

The fractographic analysis (Figure 5) showed a pit fracture, confirming a tough character of fracture, thus proving the high quality of fusion zone metal of the model two-layer ingot after ESS LM.

Structural homogeneity of fusion zone metal of the two-layer ingot, the absence of defects of shrinkage and liquation natures, as well as formation of homogeneous structure were revealed. Isotropy of strength characteristics and high level of impact toughness *KCV* of cast metal (240–298 J/cm^2) is typical, while

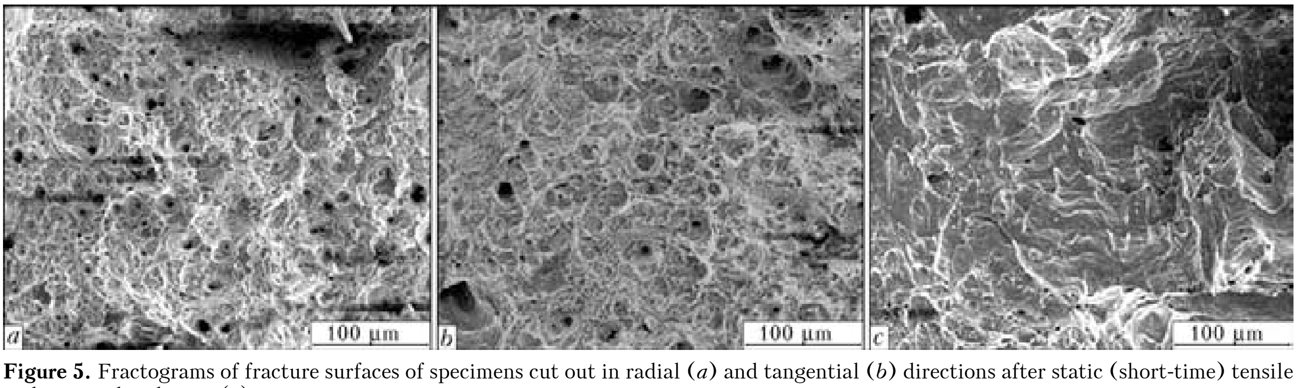

Figure 5. Fractograms of fracture surfaces of specimens cut out in radial (*a*) and tangential (*b*) directions after static (short-time) tensile and impact bend tests (*c*)

for the wrought metal the standard level of *KCV* amounts to 182–312 J/cm^2.

The obtained results of investigation of peculiarities of formation of structure and properties of high-alloy steel show the high level and isotropy of physical and mechanical properties of cast metal of the model ingot after the successive circumferential ESS LM without post high-temperature heat treatment, usually used after the electroslag welding. This shows the challenges in application of the described method for the enlargement of ingots of high-alloy steels and alloys.

1. (1981) *Electroslag metal*. Ed. by B.E. Paton, B.I. Medovar. Kiev: Naukova Dumka.
2. Volkov, S.E., Volkov, A.E., Zabaluev, Yu.I. et al. (1979) *Nonmetallic inclusions and defects in electroslag ingot*. Moscow: Metallurgiya.
3. Polishko, G.O., Remezov, O.G., Shevchenko, M.T. et al. (2007) Assessment of possibility to produce the steel ingots of 60 t weight on the base of 20 tons ESR furnace. In: *Coll. of reports of students and graduates of chair FKhOTM «Special Metallurgy: Yesterday, Today, Tomorrow», dedicated to 30th anniversary of chair of FKhOTM IFF of NTUU KPI*. Kiev: Politekhnika.
4. Paton, B.E., Medovar, L.B., Saenko, V.Ya. et al. (2007) New technological process of producing of super-large steel ingots by ESC LM method. *Advances in Electrometallurgy*, **1**, 2–5.
5. Medovar, L.B., Stovpchenko, G.P., Saenko, V.Ya. et al. *Method of production of large-tonnage metal ingot*. Pat. 94333 Ukraine. Int. Cl. B 22 D 19/16, C 22 B 9/18, B 23 K 25/00 C 6/00. Publ. 26.04.2011.

EFFICIENCY OF THE USE OF PROTECTIVE EXTENSION IN PLASMA SPRAYING

A.P. MURASHOV, A.P. GRISHCHENKO, N.V. VIGILYANSKAYA, A.N. BURLACHENKO and **I.A. DEMIANOV**

E.O. Paton Electric Welding Institute, NASU, Kiev, Ukraine

It was established that the use of the protective extension provides a 25 % increase in average velocity of spraying particles, improves heating of the particles, and decreases the required specific energy of the spraying process by 20 % due to increase in size of the high-temperature zone of the plasma jet. The content of oxides in coatings deposited by using the extension is 10 % lower, the content of pores in them is 4 times lower, and the coating to substrate adhesion strength is 20 % higher.

Keywords: *plasma spraying, plasma jet, extension, properties of coatings, material utilisation factor, experimental design*

In deposition of coatings by the plasma jet in open atmosphere, formation of a coating is affected by an admixture of ambient gases to the jet. The initial region of the jet measured from the plasmatron nozzle with diameter d_0 to boundary *I–I* is characterised by the constant values of velocity u_0 and temperature of the flow, as well as by their equality to the initial values up to x_0 (Figure 1) [1]. In addition, the ionisation and dissociation energies are intensively released in the initial region of the plasma jet. Efflux of the electric current, additional release of the energy and turbulisation of the flow caused by the processes of large- and small-scale shunting of the arc take place sometimes. Static pressure in the initial region is not equal to zero because of electromagnetic compression

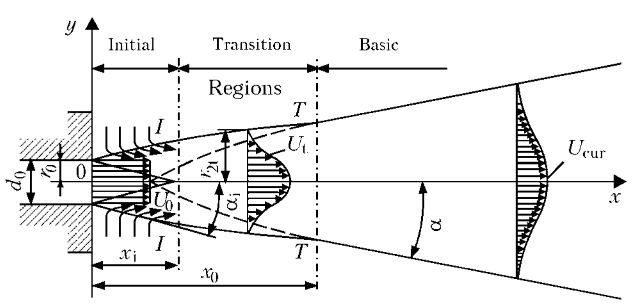

Figure 1. Flow diagram of plasma spraying with free-expanding plasma jet

of the ionised gas in the electric arc. That is why, depending on the shape of the outlet part of the nozzle, the jet dramatically expands near its exit section. The mixing zone, where a radial transfer of impulse and energy takes place, and where parameters of the plasma jet continuously change from their initial values to the values characteristic of the ambient atmosphere, forms in the peripheral region of the jet starting from the exit section of the nozzle. Therefore, the transition region of the jet, and then the basic one, forms outside the initial region to boundary *T–T*. The temperature and velocity of the plasma jet decrease as a result of its dilution with cold air, this deteriorating heating of the spraying material. The spraying material actively interacts with the atmosphere components (O_2, N_2) already in the initial region. For example, for standard plasmatron UMP-4 the concentration of argon in the jet at a distance of (2–3)d_0 is 50 %, and in the zone where the spraying particles interact with the workpiece surface at a distance of 70–100 mm ((10–15)d_0) the concentration of argon is 20 %. This leads to formation of oxide and nitride inclusions in the coatings, that deteriorate properties of the latter (porosity, cracking, exfoliation) [2, 3].

To prevent the processes causing admixture of the atmosphere components to the jet, plasma spraying is performed in normal-pressure shielding atmosphere (APS), in rarefied controlled atmosphere (VPS), under a layer of liquid (WPS) and in increased-pressure