STATE-OF-THE-ART OF DEVELOPMENT AND MANUFACTURE OF LOW-HYDROGEN ELECTRODES WITH DOUBLE-LAYER COATING IN CIS COUNTRIES (Review)

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The article gives generalised information on properties of low-hydrogen electrodes with a double-layer coating, as well as characteristics of metal of the welds made by using the above electrodes, including electrodes of the ANOD-1 grade, the technology of manufacture of which is oriented to the available feedstock.

Keywords: *arc welding, welding electrodes, double-layer coatings, development, manufacture*

Double-layer coating is one of the most effective means for increasing welding-processing characteristics of the electrodes with basic coating. In it a calcium fluoride, one of the main arc deionizer, is removed in peripheral layers [1]. An outer layer of the coating, isolated from main, high-temperature arc region, experiences an overheating in a smaller degree, its constituents have less intensive evaporation and dissociation, and influence on composition of arc atmosphere to a smaller extent. Namely this part of the coating flows into a weld pool and has less interaction with drop at the end of the electrode [2]. Removing of the fluorides outside the boundaries of inner layer reduces the possibility of occurrence of exothermal hardphase reactions in this layer of the coating. It mainly contains reactions of carbonate dissociation. They, being endothermic by nature, «subcool» a core, changing surface profile from convex to concave one that reduces a danger of drop yield outside the boundaries of a cap of non-melted coating and possibility of short circuits.

Studies [3–5] show that an application of the electrodes with double-layer coating provides a fine-drop electrode metal transfer as well as good formation and quality of weld metal including in low current welding. The latter has great importance in erection welding as well as using the electrodes with cores from high-alloy wire when an allowable welding current is often limited for preventing core overheating and reduction of heat input in the weld pool. Therefore, some electrodes, designed for welding of high-alloy steels, also have the double-layer coating.

Application of the double-layer coating allows increasing stability of arcing during welding at alternating current in using of the transformers with low open-circuit voltage [6].

The first known patent for the electrodes with double-layer coating appeared in Czechoslovakia [7]. The compositions of coatings and method for manufacture of the double-layer electrodes using simple presses were patented in Finland, Switzerland and Norway [8–10]. A technology of manufacture of the double-layer electrodes on the direct-flow presses [11] was patented by «Oerlikon» company. There are patents for the coated electrodes number of layers in which exceeds two [10, 12] or being operated from two current sources [13, 14].

Double-layer structure of the coating extends technological capabilities for regulation of efficiency, welding-processing characteristics of the electrodes, indices of arcing stability, chemical composition and mechanical properties of deposited metal, etc. For that, a distribution of constituents of the coating between the outer and inner layers and change of section area ratios of inner and outer layers, which judging on the patents and information data can vary in the ranges from 1:1 to 2:1 depending on solved tasks, are added to the tradition ways, based on changing of substantial composition of the coating.

The electrodes with double-layer coating are widely used in industry and building of many countries. Companies from Switzerland (Oerlikon), Sweden (ESAB), Japan (Kobe Steel), Austria (Boehler), Germany (Thyssen Draht, UTP), the Netherlands (Philips), USA (Selelectrode) and etc. organized manufacture of the electrodes with double-layer coating at different times. Oerlikon obtained among the first a patent for composition of the coating and method for manufacture of the electrodes with double-layer coating on direct-flow presses [11]. It manufactured almost 50 % of low-hydrogen electrodes with double-layer structure of the coating from total output of the electrodes of main type on their enterprise in Eisenberg (Germany).

Catalogue of Oerlikon shows 19 grades of double-layer electrodes of different designation (Tables 1–3). The low-hydrogen electrodes of general designation as well as designed for welding of high-strength, heat-

Table 1. Specification of the electrodes with double-layer coating according to the catalogue of «Oerlikon» company designed for welding of low-carbon and low-alloy steels

Electrode grade	Diameter, mm	Code		Mechanical properties of the weld				
		on EN ISO 2560	on AWS 5.1	σ_y, MPa, not more than	σ_t, MPa	δ_5, %, not more than	*KVC*, J/cm^2, at *T*, °C	
							+20	–60
Extra	2.5–6.0	E424 B32 H10	E7016	420	500–640	20	150	90**
Spezial	2.0–6.0	E382 B12 H10	E7016	380	470–600	20	150	100*
Tenax 50	2.5–5.0	E426 B32 H5	E7016-1	420	500–640	20	250	100
Tenacito	2.5–6.0	E426 B32 H5	E7016-1	420	500–640	20	180	70
Tenacito 38R	2.5–6.0	E466 1Ni B42 H5	E7018-G	460	530–680	20	190	70
Tenacito 65	2.5–6.0	–	E9018-G	560	630–720	20	160	70
Tenacito 65R	2.5–6.0	E506 1NiMo B42 H5	E9018-G	510	620–720	20	170	55
Tenacito 70	2.5–5.0	E506 1Ni B42 H5	E8018-G	510	590–690	23	200	60
Tenacito 70B	2.5–5.0	E466 2Ni B42 H5	E8018-G1	480	550–700	22	170	100
Tenacito 75	2.5–6.0	–	E11018-G	700	780–940	17	120	55
Tenacito 80	2.5–6.0	–	E11018-G	700	800–960	16	120	60
Tenacito 100	2.5–5.0	–	E12018-G	890	980–1080	14	70	60***
BOR-SP6	4.0–6.0	E506 B34 H10	–	460	530–680	18	160	60

*, **, *** – data given on impact energy relate to test temperatures –20, –30 and –40 °C, respectively.

Table 2. Specification of double-layer electrodes of «Oerlikon» company designed for welding of heat-resistant alloy steels

Electrode grade	Type on DIN 8575	T_{exp}, °C	Content in deposited metal, %				
			C	Si	Mn	Cr	Mo
Molycord Kb	EMoB20+	550	0.06	0.5	0.8	–	0.5
Cromocord Kb	ECrMo1B20+	570	0.06	0.6	0.8	1.0	0.5
Citochrom 2	ECrMo2B26+	600	0.06	0.5	0.8	2.4	1.0

resistant and stainless steels are represented in this list. A complex of methods for deoxidation and alloying of deposited metal was realized in series of developments at which the maximum yield of acicular ferrite in the structure of deposited metal is provided and exclusively high impact toughness of welds at negative temperatures (investigations made by G. Evans) is achieved.

The oerlikon double-layer electrodes are used for welding and repair of such objects of nuclear-power engineering as containment building of reactor (Tenacito 60, 65R, 70, Extra), reactor shell, steam generator and main pump (Tenacito 65R).

Electrodes with double-layer coating are used in power engineering, oil and power machine building, etc. This, as a rule, the electrodes of small diameter and it is very important to have contracted, rigidly oriented in space arc as well as good root penetration when using them for welding. There are exceptions when double-layer structure of the coating is used for electrodes of all diameters (from 2.0 up to 6.0 mm).

The grades of electrodes with double-layer coating, supplied on market by European companies, including ones that do not have press equipment allowing realization of the method of manufacture patented by «Oerlikon» company, are shown in Table 4. These compa-

Table 3. Specification of double-layer electrodes of «Oerlikon» company designed for welding of high-alloy stainless steels

Electrode grade	Type on DIN 8575	T_{exp}, °C	Content in deposited metal, %					
			C	Si	Mn	Cr	Ni	Nb
Basinox 308L	E199L B20+	350 (800*)	0.03	0.4	1.0	19.0	10.0	–
Basinox 347	E199Nb B20+	400 (800*)	0.03	0.4	1.0	19.0	10.0	0.4
Basinox 326 L	E19123L B20+	400	0.03	0.4	1.0	18.5	11.5	(2.7Mo)

*Temperature up to which formation of scale is not observed.

nies use the method of double coating: firstly on a core (inner layer) and then on preliminary dried electrode with inner layer (outer layer) [8, 9].

The following principles are used in development of the electrodes of Tenacito series [15]:

- proved alloying systems based on extensive technological database, now accepted for whole series;
- optimizing of deoxidation system for the purpose of achieving suitable inclusion morphology, and, respectively, obtaining of maximum high level of cleaning and impact toughness of deposited metal;
- extremely high cleanliness of rimmed carbon-manganese steel for electrode rods at rigid control of the level of impurity elements;
- careful selection of mineral constituent of the coating with the purpose of achieving of the necessary level of its basicity for E XX18 type electrodes;
- special binding agent for minimizing hygrosorption capacity of the coating for the purpose of achieving as low content of hydrogen in the deposited metal as possible (not more than 0.2 % of adsorbed H_2O during nine hours exposure of the electrodes in atmosphere with 80 % relative humidity of air at 27 °C);
- optimizing of operating characteristics of the electrodes in root pass welding of multilayer welds by using electrodes of 3.25 mm diameter and less.

Low-hydrogen electrode of general designation with double-layer coating of ANO-D type (E50A type on GOST 9467–75) [16, 17] was developed in the E.O. Paton Electric Welding Institute in 1970s. A modification — electrodes ANO-Ds [18, 19], designed for welding of shipbuilding parts, was developed on its basis. The technology was developed for industrial manufacture of the electrodes with double-layer coating for plants completed with the direct-flow extruding presses. Industrial lots of new electrodes were produced and tested at Rostov research plant «SPA Atomkotlomash» of the Ministry of Power Machine Building and Nikolaev plant «Okean» of the Ministry of Shipbuilding Industry of the USSR. The advantages of ANO-D electrodes over UONI-13/55 electrodes and other grades of similar designation were confirmed by tests. ANO-D and ANO-Ds electrodes were certified for welding of critical parts of NPP from 22K steel as well as ship structures according to the results of tests by Gosgortekhnadzor and Marine Shipping Register.

Unique components, i.e. synthetic mica ANS-1 and low-silicon granulated ferrosilicium of Fs-15gs grade, were used in the coating of electrodes ANO-D and ANO-Ds. This allowed solving the key problems of technology of their conveyer production. These types of raw materials are not manufactured at present time.

Table 4. Grades of the double-layer electrodes manufactured by companies, which do not have direct-flow presses

Company	Electrode grade	Diameter, mm	Code	
			on EN 499	on AWS 5.1
ESAB	OK 53.05	2.5–4.0	E424 B22 H10	E7016
	OK 53.16	2.5–4.0	E382 B32 H10	E7016
Thyssen Draht	Phoenix Spezial D	2.5–5.0	E423 B12 H10	E7016
Boehler	Fox EV 50A	2.5–6.0	E423 B12 H10	E7016
UTP	Spezial Z	2.5–5.0	–	E7016
Selelectrode	1162	2.5–5.0	E382 B12	E7016

In this connection the composition of coating of these electrodes was modernized with orientation towards available types of raw materials as well as widening of sphere of their application taking into account production experience and application of the double-layer electrodes in our country and abroad. Modernized in such a way the electrodes of ANOD-1 grade belonging to E50A type on GOST 9467–75 are meant for welding of structures from carbon and low-alloy steels. Welding is performed in all spatial positions except for vertical-down welds. Direct current of any polarity or alternating current from power sources with open-circuit voltage more than 65 V is used.

Reference designation of ANOD-1 electrodes on DSTU ISO 2560 is A E424 B22 or A E424 B22 H10 depending on electrode diameter [20].

Typical indices of melting of ANOD-1 electrodes are shown in Table 5, and content of gases in the deposited metal in — Table 6.

As follows from data given in Table 6, ANOD-1 electrodes are characterized by fine drop electrode metal transfer and its secure protection from ambient air. They have sufficiently low nominal U_n and, what is very important, considerably high threshold U_{th} arc voltage, achievement of which in the process of arc extension results in formation of pores in the weld. Thus, for electrodes UONI-13/55, arc voltage can be

Table 5. Typical indices of melting of ANOD-1 electrodes

Core diameter to coating diameter ratio, mm	Coefficient of coating mass, %	Coefficient of deposition, g/(A·h)	Efficiency of deposition, h/min	Yield of deposited metal, %
3.0/5.2	60.9; 61.5; 61.9 61.4	9.6; 9.9; 9.9 9.8	19.3; 19.6; 19.8 19.6	109.2; 110.2; 110.4 109.9
4.0/6.8	55.5; 56.5; 56.5 56.2	9.5; 9.6; 9.7 9.6	28.2; 29.0; 29.0 28.7	104.9; 106.5; 107.9 106.4

Table 6. Arc voltage, at which pores in the weld metal is formed in relation with gas content and characteristics of electrode metal transfer

Electrode grade (diameter, mm)	Content of gases in the deposited metal, %			$\tau_{s.c}$, ms	U_n/U_{th}, V	$\frac{U_{th}-U_n}{U_n}$, %
	$[H]_{total}$	[N]	[O]			
UONI-13/55 (3.0)	4.7	0.022	0.043	3.6	21.5/25.5	18.6
TsL-39 (2.5)	4.8	0.018	0.040	3.2	23.0/29.5	28.2
TsU-5 (2.5)	5.4	0.014	0.039	2.7	23.5/30.0	27.7
ANOD-1 (2.5)	3.9	0.013	0.037	2.3	21.5/30.0	39.5
ANOD-1 (3.0)	4.5	0.016	0.034	2.2	22.0/31.0	40.9

Notes. 1. Content of diffusion hydrogen (in milliliters per 100 g of molten metal), determined by chromatographic method [21], provides data, comparable with index of mercury method of IIW. 2. Contents of oxygen, nitrogen and residual hydrogen were determined by method of vacuum melting. 3. Average statistical time of short circuits was determined by TX-5000 device in downhand short circuit welding.

increased only by 18 % when extending the arc without a danger of porosity formation. TsU-5 and TsL-39 electrodes, designed specially for heat-power engineering, allow extending the arc without porosity occurrence until the arc voltage will not increase by a third in comparison with their nominal voltage. This index makes 40 % for ANOD-1 electrodes.

The results of evaluation, made in a laboratory of the Ministry of Health of Ukraine, for hygiene and sanitary properties of ANOD-1 electrodes, including calculated indices of intensity of air exchange, providing safe concentration of harmful substances in welder's breathing zone, are the following: emission of welding fume particulate matter (WFPM) — 17.0 g/kg and 0.64 g/min; specific emission of fluoric compounds — 0.83 g/kg of soluble and 1.37 g/kg of low-soluble fluorides; specific emission of manganese — 0.78 g/kg. Class on recommended intensity of air exchange (NHL) is 1 (3000 m^3/h); maximum allowable concentration of WFPM in welder's breathing zone — 4.5 mg/m^2; intensity of WFPM emission — 40 g/h.

Technology for industrial manufacture of ANOD-1 electrodes on direct-flow presses of «Oerlikon» company was mastered by OJSC «Mezhgosmetiz-Mtsensk». Two-position briquetting press was developed, manufactured and adjusted: a briquette for inner layer is pressed on one position and for outer layer on another. The double-layer briquette, which is put in a working cylinder of extruding machine, is obtained through inserting one blank into another.

All methods for providing technological and operational characteristics of electrodes and weld metal properties, which are used in manufacture of low-hydrogen electrodes with traditional coating structure, can be used during manufacture of the double-layer electrodes in the scope of mastered technology.

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