EVALUATION OF SUITABILITY OF WELDING WIRE OF Sv-10GN1MA TYPE PRODUCED BY ESAB FOR MANUFACTURING NPP EQUIPMENT

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In order to extend the service life of commissioned NPP reactors, more stringent requirements are made of welded joints of equipment from 10GN2MFA steel, in particular, as regards limitation of impurities in weld metal. Evaluation of wire of Sv-10GN1MA type produced by ESAB was made to determine its suitability for manufacture of above-mentioned equipment. Comprehensive evaluation of deposited metal chemical composition, weld metal mechanical properties after respective heat treatment, radiographic testing of joints, determination of critical brittleness temperature allowed recommending the wire for application in nuclear engineering. 4 Tables.

Keywords: *arc welding, power equipment, life extension, requirements to welded joints, welding wire, testing, recommendations*

In keeping with the currently valid normative documents, welding wire of 10GN1MA grade supplied to TU 14-1-1549–76 specification should be applied for welding structures of nuclear power plants from steel of 10GN2MFA grade. This wire was manufactured by Russian companies «Serp i Molot» (Moscow) (this enterprise is not working now), «Elektrostal» (Elektrostal, Moscow region), and «Izhstal» (Izhevsk).

In view of the need to extend the service life of newly commissioned NPP reactors up to 60 years, higher requirements began to be made of steel welded joints, in terms of the content of impurities, not only such as sulphur, phosphorus, but also a number of others, in particular, cobalt, copper, arsenic, tin, antimony, vanadium, niobium, etc.

To ensure meeting these requirements, OJSC NPO TsNIITMASH developed special specifications for Sv-10GN1MA wire, allowing for all the limitations on composition.

For a number of reasons Russian enterprises are unable to ensure manufacturing of Sv-10GN1MA wire, in view of considerable tightening of requirements to impurity content, as the price for such a wire would rise several times. Therefore, its application was becoming not cost-effective.

ESAB Company, which is manufacturing wire of Sv-10GN1MA type, in one of its enterprises, allowing for all limitations and at a quite acceptable price, became involved, by its own initiative, in finding a solution of this problem.

Normative documentation requirements on wire composition and actual chemical composition of manufactured wire are given in Table 1.

In keeping with the normative documentation, currently in force in RF, application of foreign-made welding consumables for manufacture of NPP equipment is only possible after obtaining the appropriate resolution. Mechanism of obtaining such a resolution requires performance of a number of procedures, including testing of welded joint (determination of deposited metal composition and weld metal mechanical properties).

With this purpose «Izhora Welding Consumables» (IWC) conducted respective testing. The following materials were used for testing:

- Sv-10GN1MA welding wire of 4.0 mm diameter, melt 382418, manufactured by ESAB;
- FTs-16 fused flux manufactured by IWC.

Plates from VSt3sp (killed) steel of 700 × × 150 × 30 mm size with preliminary surfacing of edges by PT-30 electrodes, simulating 10GN2MFA steel, were used as base material.

The following scope of testing was conducted:

1. Determination of deposited metal composition. In order to determine deposited metal composition, controlled combination of welding consumables was used to perform 8-layer deposition on a plate from VSt3sp steel. Composition was determined by X-ray fluorescence method in ARL-1600 instrument. Results of determination of deposited metal composition are given in Table 1.

Table 1. Composition of 10GN1MA wire, wt.%

Source	C	Si	Mn	Cr	Ni	Mo	V	S	P
TU 14-1-1549–76	0.08–0.12	0.15–0.35	1.1–1.5	≤0.3	1.6–1.8	0.60–0.75	–	≤0.02	≤0.02
TU 2730.09.033–2012	0.08–0.12	0.15–0.30	1.1–1.5	Same	1.5–1.8	0.60–0.75	≤0.02	≤0.01	≤0.01
TU 2730.09.045–2013	0.08–0.12	0.15–0.30	1.1–1.5	»	1.5–1.8	0.60–0.75	≤0.02	≤0.01	≤0.01
Melt 382418	0.102	0.24	1.27	0.12	1.65	0.65	≤0.009	≤0.0015	≤0.007

Table 1 (cont.)

Source	N	Nb	Ti	Cu	As	Sb	Co	Sn	Al
TU 14-1-1549–76	–	–	–	–	–	–	–	–	–
TU 2730.09.033–2012	≤0.01	≤0.02	≤0.05	≤0.06	≤0.02	≤0.005	≤0.02	≤0.005	≤0.05
TU 2730.09.045–2013	≤0.01	≤0.02	≤0.02	≤0.06	≤0.02	≤0.005	≤0.02	≤0.005	≤0.02
Melt 382418	≤0.007	≤0.005	≤0.001	≤0.04	≤0.003	≤0.002	≤0.011	≤0.005	≤0.013

Table 2. Results of static tensile testing of weld metal

Sample marking	T_{test}, °C	Tensile strength, MPa	Conventional yield strength, MPa	Relative elongation, %	Reduction in area, %
175P-1	20	610 600	495 490	26 24.5	71 71
	350	560 570	430 425	18.5 21.5	64 65
175P-2	20	600 600	475 480	28 28	70 73
	350	550 550	400 410	26 23	66 66
PN AE G-7-010–89 requirements (not less than)	20	539	343	16	55
	350	490	294	14	50

2. Determination of mechanical properties of weld metal after heat treatment for the following modes:

• tempering at the temperature of 650 + 10 °C with soaking for 9–10 h (175P-1 marking);

• tempering at 620 + 10 °C with soaking for 5–6 h + tempering at 650 + 10 °C with soaking for 36–38 h (175P-2 marking).

Produced welded joints were subjected to visual examination, measurement and radiographic testing. Examination results were positive. In order to determine mechanical properties of weld metal, the following samples were made:

• type II to GOST 6996–66 for static tensile testing at 20 and 350 °C;

• type IX to GOST 6996–66 for impact bend testing and for confirmation of critical brittleness temperature.

Results of determination of weld metal mechanical properties at static tensile testing are given in Table 2, and those for confirmation of critical brittleness temperature are given in Table 3.

In keeping with the requirements of normative documentation two values of critical brittleness temperature (T_{cr}), depending on structure operating conditions of +15 and –10 °C, have been specified for combination of welding wire Sv-10GN1MA + flux FTs-16. Critical temperature confirmation is performed by a special procedure, when impact toughness is determined at con-

Table 3. Results of testing for confirmation of weld metal brittleness temperature

Sample marking	T_{test}, °C	Impact toughness KCV, J/cm^2	Ductile component, %
175P-1 (T_{cr} ≤ 15 °C)	+15	167–219	94–95
	+45	176–225	100
175P-1 (T_{cr} ≤ 10 °C)	–10	125–156	62–81
	+20	174–210	94–97
175P-1 (T_{cr} ≤ 15 °C)	+15	147–183	76–92
	+45	166–228	88–100
175P-1 (T_{cr} ≤ 10 °C)	–10	100–168	56–76
	+20	135–181	78–90

Table 4. Results of impact bend testing of weld metal

Sample marking	T_{test}, °C	Impact toughness KCV, J/cm^2	Ductile component, %
175P-1 ($T_{cr} \le -40$ °C)	10	157–181	77–91
	0	123–168	70–94
	–20	127–140	72–81
	–30	95–111	55–59
	–40	68–96	44–48
175P-2 ($T_{cr} \le -40$ °C)	10	142–196	74–83
	0	117–152	62–77
	–20	84–125	52–63
	–30	77–113	47–59
	–40	43–87	34–48

firmed temperature (+15 and –10 °C) and at temperature by 30° higher than the confirmed one, i.e. at +45 and +20 °C. Depending on the obtained results and values of weld metal yield point, critical brittleness temperature is confirmed or not confirmed.

In addition to confirmation procedure, there is the procedure of T_{cr} determination, when in order to determine the temperature, at which transition from ductile to brittle fracture takes place, impact toughness testing of weld metal in a broad temperature range from +50 to –100 °C is performed.

Obtained testing results confirmed complete correspondence to normative documentation requirements on deposited metal composition and weld metal mechanical properties (Table 4).

Test results provided confirmation of $T_{cr} \le -40$ °C. To determine critical brittleness temperature, testing should be performed at lower temperature. However, testing was interrupted because of insufficient number of samples.

Thus, welding wire Sv-10GN1MA supplied by ESAB Company fully meets the requirements of national standards applied in nuclear engineering, and can be approved for welding of NPP equipment.

Received 15.04.2014