MANUFACRURING DEFECTS IN WELDING CONSUMABLES INFLUENCING THE QUALITY OF WELDED JOINTS

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The characteristic defects of welding wire and steel studs for arc welding-on, influencing the quality of welded joints, were analyzed. The inadmissible defects of the wire are predetermined by increased total content of nitrogen, hydrogen and oxygen in them, high rigidity, low quality winding on the reels, and the defects of studs are caused by incompliance of chemical composition and mechanical properties with the requirements. 6 Ref., 1 Table.

Keywords: *arc welding, welding consumables, steel wire and studs, inadmissible defects of materials, quality of welded joints*

Though a great attention is paid to the quality of welding consumables [1–4], this problem still remains urgent. The analysis performed recently in a number of branches of industry showed that low quality of welding consumables causes the 35 % rejection of welded structures per year [5]. The industrial experience also shows that the properties of welding consumables, produced by different companies according to the same standard, are different, and their defects have a negative influence on the quality of welded structures. Due to this reason, it is recommended to apply the consumables of increased quality for critical structures instead of standard welding consumables, for example, the Thyssen K52 T electrode wire of type G3Si1 is recommended for welding using TIME method [6].

The purpose of this work is the determination of critical (inadmissible) defects of some welding consumables, which should serve as a reason for refuse from their application in industry. As the object of investigations the copper-plated solid wire of grade G3Si1 according to ISO 14341A (analogue of Sv-08G2S-0) was selected applied for MAG welding, and welding-on studs SD1 which are used in bridge construction.

Characteristics of defects of copper-plate electrode wire G3Si1. Determination of critical defects of wire was carried out basing on the results of comparative tests of quality of more than fifty 1.2 mm diameter welding wires of grade G3Si1 according to ISO 14341A of Polish and foreign production, with the Acceptance Certificate 3.1 or Act of plant tests 2.2 according to EN 10204.

Evaluation of quality of welded joints. The strength properties of joints of steel S355J2 + N (analogue of 17GS), made using wires G3Si1 by MAG method in shielding gas M21 (Ar + + 18 % CO_2) applying the standard modes, and by highly-efficient TIME method in gas mixture TIME-Gas (65 % Ar, 26.5 % He, 8 % CO_2 and 0.5 % O_2), correspond to the requirements of ISO 15614-1. However, the impact toughness of a number of welds is characterized by the significant scattering of test results caused by the presence of pores in weld metal in the plane of notch of specimens. Radiographic control of butt joints of type Y of 12 mm thickness showed that the level of porosity corresponds to the requirements of items B, C, D according to ISO 5817, but does not meet the requirements of item D.

According to the results of check analysis the chemical composition of all the wires as to content of carbon, silicon, manganese, phosphorus and sulphur met the requirements of standards EN 440 and EN ISO 14341. Using method of high-temperature extraction the content of nitrogen, oxygen and hydrogen in the as-delivered wires and after removal of surface copper-plated layer (rated wire diameter is 1.2 mm, and diameter without surface layer is 1–1.05 mm) was determined. The characteristic results of analysis of gases in the wires are given in the Table.

After removal of copper layer the total content of gases in wires decreased, difference ΔR amounts from 13.1 to 93.3 ppm. The decrease in content of hydrogen and oxygen after removal of surface layer proves that wire in the layer of copper and/or under this layer contains organic contaminations (technological lubricant). It can

Content of gases in welding wires of G3Si1 grade by ISO 14341A, ppm

Number of wire	Wire state	N_2	O_2	H_2	S	ΔR	K
3	+Cu	58	84	3.2	145.2	13.1	−4.8
	0	57	73	2.1	132.1		
5	+Cu	53	136	9.4	198.4	29.8	48.4
	0	53	110	5.6	168.6		
16	+Cu	28	67	5.2	100.2	27.9	−49.8
	0	25	45	2.3	72.3		
18	+Cu	65	145	6.1	216.1	55.9	66.1
	0	64	94	2.2	160.2		
22	+Cu	157	137	3.0	297.0	14.7	147
	0	157	123	2.3	282.3		
49	+Cu	30	28	3.7	61.7	22.3	−88.3
	0	25	12	2.4	39.4		
53	+Cu	67	163	4.1	234.1	93.3	84.1
	0	65	74	1.8	140.8		

Note. +Cu — zinc-plated wire; 0 — without surface layer; S — total content of nitrogen, oxygen and hydrogen in wire; $\Delta R = S_1 - S_2$, where S_1, S_2 — total content of gases, respectively, in zinc-plated wire and in wire without surface layer; $K = \Delta R + S_2 - 150$.

be assumed that the value ΔR is the criterion of evaluation of level of purity of the surface layer of wire before copper plating. During evaluation of the wire quality the total content of gases in it is also important. The carried out tests showed the intensified porosity of welds, produced using wires with $K > 50$ ppm (they include wires 18, 22 and 53 according to the Table). The $K \le 0$ requirement is fulfilled by wires 3, 16 and 49. In case when the K value of welding wire exceeds 50 ppm, non-destructive testing on the presence of porosity of welds, made by this wire, can be recommended depending on the requirements specified to welded joints.

Basing on the obtained results it can be considered that inadmissible defect of the investigated copper-plated wires is the total content of nitrogen, hydrogen and oxygen in them, exceeding 200 ppm, i.e. in case if the criterion $K > 50$ ppm. For critical structures it is recommended to apply wires with total content of these gases of not more than 150 ppm.

Evaluation of quality of wire winding. Standard ISO 544 requires that winding of wire on the reels should provide the uniform feeding of wire in mechanized welding methods. The most part of investigated wires were winded on the reels or wire frame cassettes with in-line winding-up according to the scheme «turn to turn» by the plants-manufacturers, and only two of them were winded without keeping of this requirement. However, even using some reels with wires, winded in-line, their non-uniform feeding in mechanized welding was observed. The reason was in incorrectly selected width of a reel, not taking into account the tolerance for the rated wire diameter, which resulted in violation of winding linearity. Disturbances and stop of electrode wire feed were observed also in case of welding using two wires without in-line winding. Non-quality winding of wire on the reels by the plant-manufacturer or consumer does not meet the requirements of standard ISO 544, item 5.2, and is an inadmissible defect.

Evaluation of rising (rigidity) of wire turns. The evaluation of rising of turns (planarity of a turn on horizontal surface of a plate) was carried out according to the results of hand unwinding of wire from the reel. Most of the wires meet the requirement of standard ISO 544, according to which the rising of turn should not exceed 50 mm for the reels with outer diameter of not more than 200 mm. In some wires the difference in rising of upper turns of cassette of 300 mm diameter and after consumption of almost half of the wire from the cassette was observed. Turns of the wire from the upper layer met the requirements of standard ISO 544, and turns of the middle layer of the same cassette did not met these requirements, that evidences of non-uniform rigidity of wire in the length, within the limits of one cassette. Extremely high rigidity of welding wire causes oscillations of end of electrode, which can be a cause of lacks of fusion, lacks of penetration of weld root, etc. Due to

this reason the non-uniform rigidity of wire is the inadmissible defect.

Evaluation of stability of wire diameter. The diameter of wire was evaluated by the requirement of standard ISO 544, according to which the admissible deviations of wire diameter of 1.2 mm amount from +0.01 to −0.04 mm. Only 5.7 % of wires (upper maximum deviation of diameter of wires amounted to +0.02 mm) did not meet the requirements of standard. The increased diameter of wire results in wear of channel of copper nozzle and can cause the need in its premature replacement. However, deviation of wire diameter from its rated size does not have a noticeable influence on quality of welded joints, and this disadvantage of wire is accepted as admissible.

Evaluation of roughness of wire surface. Roughness of the wire surface can result in increased wear of channel of current-carrying nozzle in welding. In the investigated wires the roughness of surface is within the limit from class 8 (parameter Ra = 0.63 μm) up to 10 (Ra = = 0.16 μm). Roughness of wire surface determines the service life of copper nozzles and flexible channels of electrode wire feed of hose holders of semi-automatic machines, but it does not significantly influence the stability of process and quality of welded joints. In this connection the increased roughness of wire surface is accepted as an admissible defect.

Other characteristics of copper coating. The quality of adhesion of copper layer with the steel wire and quality of wire surface are not regulated by the standards, but have an influence on evaluation of wire by welder, for example, according to uniformity of color of wire surface, amount of delaminated copper in the feeding mechanism and need in frequent cleaning of channel for electrode wire feeding. During tests the significant differences of these characteristics were noted in the investigated wires. In particular, on some wires during winding on core of diameter equal to wire diameter, the separation of copper coating was not observed, while on the other ones the cracks, tears and coating separation were rather intensive. However, the defects, connected with these characteristics, have no significant influence on the quality of welded joints and are not regulated by the standards, therefore, the decision about purchase of this wire is taken by the customer.

Welding-technological properties of wire. In practice, the evaluation of welding-technological properties is carried out on the basis of intensity of spattering and stability of the process. Coefficient ψ_s of losses for spattering was determined depending on welding mode (100–340 A current) in all the investigated wires. Measurements showed that for 56.6 % of wires being investigated ψ_s = 2.3–8.7 % (conditional estimate of wire is good), for 37.7 % — ψ_s = 5.9–12.3 % (satisfactory) and for 5.7 % — ψ_s = 7.0–15.5 % (not satisfactory). From the estimates of consumers (welders) the process of welding by wires of ψ_s = 7.0–15.5 % group was unstable, and these wires were subjected to reclamation. Excessively high spattering is inadmissible defect of the wire. In case of welding with 1.2 mm diameter wire of grade G3Si1 according to ISO 14341A in shielding gas M21 the inadmissible wire defect is the spattering with ψ_s > 12.3 %.

Characteristic of defects of steel studs for arc welding-on. Determination of inadmissible defects of steel studs for arc welding-on, manufactured by standard ISO 13918:2008, was carried out on the basis of results of comparative tests of quality of seven types of studs-rests SD1 of foreign and Polish production, of standard sizes of 10 × 100, 19 × 150, 22 × 150 and 25 × × 175 mm. These studs are used in critical structures, for example, in bridge construction. According to documents concerning the quality, the studs are manufactured of steel S235J2G3 + C450 (analogue to St3sp (killed)) by EN 10025:2002.

Visual inspection of studs. All the studs-rests being investigated meet the requirements of standard ISO 13918, item 5.3.6.1, and they have no manufacturing defects.

Checking of stud sizes. All the studs being investigated meet the requirements to shape and sizes of standard ISO 13918, item 5.3.6.1. The noted small deviations in length of studs or their diameter can be classified as a low-important defect if they correspond to inner diameter of ceramic rings UF for welding-on of studs of SD type.

Testing of mechanical properties of stud materials. Tensile tests showed that the yield strength and ultimate strength test of material of all the studs meet the requirements for steel S235J2G3 + C450 ($\sigma_y \geq 225$ MPa, $\sigma_t \geq 450$ MPa) and studs SD1 ($\sigma_y \geq 350$ MPa, $\sigma_t \geq 450$ MPa). Requirements to elongation ($A_5 \geq 24$ % by EN 10025:2002, Table 5, and $A_5 \geq 15$ % by ISO 13918:2008, Table 2) were not met by studs SD1 of 19 × 150 mm of production of company 1 conditionally, and SD1 of 22 × 150 mm of production of company 4 conditionally. Material of these studs did not meet also the requirements for value of energy of impact toughness of 27 J minimum (Charpy V-notch test) at −20 °C (for studs 1 — 8.8 and 6.0 J, for studs 4 — 5.5 and 5.0 J), and

all the rest studs met this requirement. Non-conformity of material of studs to requirements for mechanical properties is an inadmissible defect.

Control of chemical composition. Chemical composition showed that the material of studs being investigated (steel S235J2G3) corresponds to the requirements of standard EN 10025, except the above-mentioned studs 1 and 4. Content of silicon (lower than 0.07 %) and aluminium (lower than 0.02 %) in material of these studs does not correspond to content required for killed steel. Non-conformity to requirements for chemical composition of stud material is an inadmissible defect.

Conclusions

1. Inadmissible defects of copper-plated welding wire of G3Si1 grade by ISO 14341A are as follows:

- total content of nitrogen, hydrogen and oxygen in wires, exceeding 200 ppm (in welding in gas mixture M21);
- excessively high rigidity of wire, i.e. rising of wire turn on horizontal plane is more than 50 mm;
- non-quality winding of wire on reel or cassette;
- excessively high spattering (in welding with 1.2 mm diameter wire in mixture M21 the coefficient of losses for spattering $\psi_s > 12.3$ %).

2. Inadmissible defects of metal studs SD1 for arc welding-in are as follows:

- non-conformity to requirements for mechanical properties of material of studs, in particular by impact toughness;
- non-conformity to requirements for chemical composition of studs.

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