doi.org/10.15407/tpwj2017.11.01

MODERN FLUX-CORED WIRES FOR WELDING OF LOW-ALLOY STEELS OF INCREASED AND HIGH STRENGTH

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The paper studies the peculiarities of application of flux-cored wires for welding of metal structures of low-alloy steels of increased and high strength. The ways have been proposed for solving the problems existing in this field. The flux-cored wires developed in the recent years at the E.O. Paton Electric Welding Institute for these purposes were described. The directions of increase of quality and efficiency of flux-cored wire welding using modern equipment have been presented. 15 Ref., 2 Tables, 7 Figures.

Keywords: *electric arc welding, flux-cored wire, low-alloy high-strength steels, heat input, wire melting efficiency, automation and control of welding process*

In the world practice the most wide spread among the methods of mechanized or automatic electric arc fusion welding is gas-shielded welding with solid or flux-cored wire. Selection of the reasonable technology of welded structures production includes consideration of such factors as joint preparation for welding, qualification of production staff, determination of the leading welding process, equipment for its realizing and type of welding consumable meeting the requirements of international, national and branch standards. The assortment of welding consumables and equipment has been significantly renewed in the recent years that allows rising a level of welding technology from quality as well as economy point of view.

Application in production of the structural steels with increased service properties has expanded in the last twenty years. This predetermined the need in development of new generation welding consumables for welding of bearing structures with corresponding increase of strength and visco-plastic properties as well as improvement of technological processes of production and application of wires for gas-arc welding [1–4].

High-strength low-alloy steels with more than 550 MPa yield limit are, as a rule, on microstructure referred to ferrite-bainite-martensite or bainite-martensite class with high sensitivity to welding overheating. Taking into account the peculiarities of flux-cored wire application, it is necessary to limit the heat input in product being welded. It can make from 1.0 to 3.0 kJ/mm depending on thickness of metal being welded. Necessity of performance and temperature of joint preheating depends on structure rigidity, composition and class of steel strength, expected content of diffusion hydrogen in the weld metal. Following the need of stringent control of heat input in welding of high-strength steels, it is recommended to use solid wires of 0.8–1.2 mm diameter, flux-cored wires of 1.0–1.4 mm in combination with shielding gas of reduced oxidizing ability (a mixture based on argon Ar + CO_2) [5].

Welding of low-alloy steels of increased and high strength has been expanded through application of the flux-cored wires having high melting efficiency, technological suitability to automated processes with controlled heat input, providing low content of diffusion hydrogen in the weld metal to prevent cold crack formation. This required significant improvement of the technology of their production.

New generation flux-cored wires for gas-arc welding. During the last decade the E.O. Paton Electric Welding Institute together with State enterprise «Pilot plant of welding consumables of the E.O. Paton Electric Welding Institute» has carried out a complex of works on improvement of technology and quality of production of the flux-cored wires. It allowed significant improvement of quality and application characteristics of wires under production conditions. The improvements concerned all stages of technological production process. Among the main it is necessary to note introduction of a controlled calculation of composition of a powder filler based on real composition of raw materials using special software, permanent control of charge humidity at all stages of the production, improvement of processes of forming and filling of a profile with powder and reducing the wire stock to a finished size using two stage drawing technology. The introduction of indicated procedures in the production technology allowed increasing accuracy of filling and uniformity of wire filler distribution along its whole length, raising the characteristic of wire feed along the feeders' channels of welding semi-automatic and automatic devices, providing reliability of wire contact with a nozzle tip and accuracy of wire feed in a fusion zone to place of welding.

Increase of strength (rigidity) of a wire shell due to deformation strengthening at a two-stage drawing process is neglected by using calcium-sodium stearates and pastes as a lubricant at a calibration stage (which allow getting fine current-conducting protective film on a wire surface).

Winding of the wire on framed spools or plastic bobbins of K300 and BS300 type wind by wind and packaging into polyethylene film or foil for prevention of wire core damping in accordance with the international standards [6, 7] were realized. The basic diameter of the flux-cored wires for welding of steels of increased and high strength is 1.2 mm.

The small diameter flux-cored wires of new generation were developed for efficient application of powder core to increase the level of their welding-technological characteristics and process efficiency in automatic and semi-automatic welding. Presence of the powder core allows rising current density that is expressed in melting rate rise, change for spray-drop and spray electrode metal transfer, and allows providing high stability of weld technological quality.

The flux-cored wire with metal core of PP-AN61M grade for welding of steels of common and increased strength is produced in accordance with classification on DSTU ISO 17632 [8] standard. Welding is performed using CO_2 shielding medium or mixture of argon with CO_2.

The flux-cored wires designed for welding of structures of low-alloy high-strength steels, including heat-strengthened, using rutile and metal-core ones are classified on DSTU ISO 18276 standard [9]. They provide high indices of strength, ductility and impact toughness of the joints being welded applying gas mixture based on argon and CO_2. The fields of application include shipbuilding structures, structures of offshore drilling platforms, structures of heavy and transport machine building manufactured of 4–60 mm thickness steels. High application efficiency is achieved using the power sources and feeders with automatic control and feedback. They allow optimizing parameters of a welding mode, static and dynamic characteristics of arcing. High uniformity of the welds, deep and uniform penetration, minimum losses of electrode metal in combination with high penetration efficiency indicate preferability to application of the wires of such type for high-speed and automatic welding.

PP-AN75 flux-cored wire with rutile core type differs by high operating characteristics of welding in different spatial positions. Application of a gas shield based on a mixture of argon with carbon dioxide (M21 on standard ISO 14175 [5]) provides spray transfer of the electrode metal. The wire is designed for wide application in welding of joints of low-alloy high-strength steels with ultimate strength to 590 MPa at more than 4 mm thickness of welded metal. Uniform shape and smooth weld surface, minimum spattering, easy slag separability and high efficiency allow recommending the wire for welding of the wide range of metal structures of different designation.

PP-AN76 flux-cored wire with metallic core type is designed for semi-automatic welding of low-carbon low-alloy high-strength steels including heat-strengthened ones. High crack resistance and high indices of impact toughness at low temperatures are realized at that. Stable spray transfer of the electrode metal is typical for the wire. Separate slag spots of small thickness, which are easily removed, are formed on the weld surface. Weld surfaces do not require dressing in multilayer welding. The wire is recommended for welding of metal structures including operated under low temperatures, in shipbuilding as well as construction of drilling platforms.

Tables 1 and 2 show data on composition of the deposited metal and indices of mechanical properties of the weld metal and welded joint, respectively, made by flux-cored wires for welding of steels of increased and high strength. The flux-cored wires provide hydrogen content in the weld metal less than 5ml/100 g according to ANSI/AWS 4.3 standard [10] in keeping with the storage and application rules.

Classification of the flux-cored wires on mechanical properties of the weld metal and welded joint is similar in all national standards. International standards ISO 17632 [8] and ISO 18276 [9] provide

Table 1. Composition of metal deposited by flux-cored wires of different types*, wt.%

Grade and type of flux-cored wire	C	Mn	Si	Ni	Mo	Zr
PP-AN61M type ISO 17632-A-T 50 2 1Ni M M 2 H5	0.05–0.08	1.2–1.4	0.3–0.5	1.0–1.2	–	–
PP-AN75 type ISO 18276-A-T 62 2 Mn2.5NiMo P M 2 H5	0.05–0.09	1.4–1.6	0.3–0.6	2.4–2.7	0.10–0.15	0.007–0.010
PP-AN76 type ISO 18276-B-T 76 4 T1 1 M A N4C1M2 H5	0.04–0.07	1.7–1.9	0.4–0.6	2.2–2.6	0.10–0.20	0.005–0.007

*S and P not more than 0.02 wt.%.

Table 2. Mechanical properties of weld metal and welded joint produced using flux-cored wires of different types in a mixture of shielding gases based on ArM21

Grade and type of flux-cored wire	σ_y, MPa	σ_t, MPa	δ, %	Impact energy *KV*, J, at testing temperature, °C	
				–30	–40
PP-AN61M type ISO 17632-A-T 50 2 1Ni M M 2 H5	500–520	560–710	22–26	50–55*	52–60
PP-AN75 type ISO 18276-A-T 62 3 Mn2.5NiMo P M 2 H5	590–620	650–760	21–24	–	51–56
PP-AN76 type ISO 18276-B-T 76 4 T1 1 M A N4C1M2 H5	680–700	760–920	18–20	54–65	48–55

*In CO_2 welding.

classification on the guaranteed values of yield limit and minimum temperature, at which value of impact energy on Charpy V-notch specimens is assured. The indices of strength and impact toughness are not rigidly related between each other. This allows classifying virtually any new developments on these indices. At that the mechanical properties in all standards are determined on the all weld metal specimens. Tables 1 and 2 give technical characteristics of the new flux-cored wires, classified in accordance with the requirements of the international standards.

The efficiency indices of solid wire melting are lower than efficiency of welding using flux-cored wires, in particular, with metal-core, that in practice can be realized by increase of performance speed of set size welds.

Experimental comparison of the efficiency indices of performance speed of the fillet welds with the similar modes using solid wire and flux-cored wires of equal diameters show that application of flux-cored wires of rutile and metal-cored types of the new generation reduces the time for performance of the fillet welds of the same caliber (4, 6 and 8 mm) by 15–30 %. With automatic process this advantage rises since the process of flux-cored wire welding at spay metal transfer is less sensitive to welding speed variation and provides stable shape of penetration and weld size, guaranteed soft start (Figure 1).

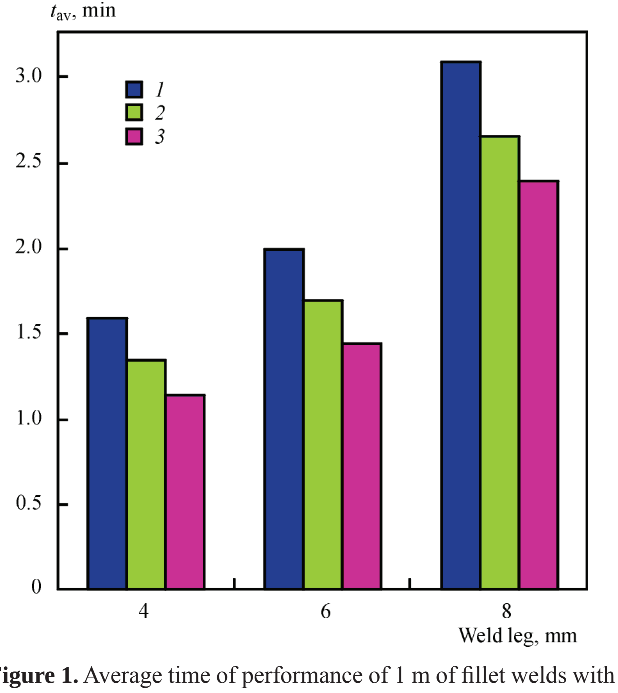

Figure 1. Average time of performance of 1 m of fillet welds with different leg using solid wire (*1*), flux-cored wire with rutile type core (*2*) and metal-cored wire (*3*) of 1.2 mm diameter on comparable welding modes (U_a ~ 28–30 V; I_w ~ 290–320 A)

Directions for increase of quality and efficiency of flux-cored wire welding using modern equipment. Significant amount of modern available on the market welding current power sources are based on inverter scheme [11–13]. At that such power sources are inseparably connected to specific type of equipment for electrode wire feed. In the simple design

Figure 2. Application of inverter arc power sources with corresponding feeder for flux-cored wire welding

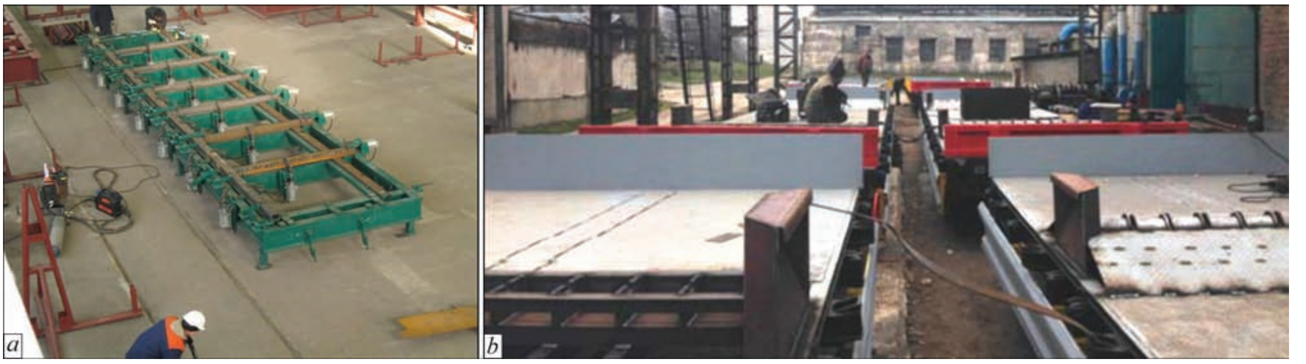

Figure 3. Typical objects of application of flux-cored wire welding: *a* — assembly-welding of frame of side wall of freight cars («Yugpromtekhmontazh» LLC, Kherson) [15]; *b* — welding of metal structures of platform for slabs, rails transporting («Verkhnedneprovsky machine-building plant» PJCS)

variant such a power source allows performing mechanized gas-shielded electrode welding of low-alloy steels of common and high strength.

The peculiarity of high-frequency inverters is high stability and quality of welding of different materials in a wide range of thickness with minimum metal spattering. Such equipment allows high-quality flux-cored wire welding with all core types.

The basis of a control system is interactive controller of the power source, combined with digital signal processor for acceleration of processing of the converted analogue electric signals of welding process in the digital data. These two blocks together perform all monitoring and regulation functions of welding process (adjustment of welding current and arc voltage on-line). Continuous measurement of the virtual values of welding parameters is carried out during welding and their any change provokes reaction in the control system. For example, control algorithms developed by «Fronius» Company provide support of the necessary set values in welding using wide range of the welding wires. This provides high repeatability of welding process and excellent welding characteristics.

The results of investigations of the indices of arcing stability based on statistical processing of data of the electric signals, analysis of shape of the curves of welding current and arc voltage probability distribution as well as the results of statistical processing of the data of arc welding electric signals showed significant differences of electrode metal mass transfer using the inverter type arc power sources in comparison with the traditional ones. The welding process using inverter power source virtually in all cases is characterized by higher stability indices.

Control of the electrode metal transfer directed on reduction of droplet size is realized in application of the inverter power source. At that electrode metal transfer takes place without rapid changes and variations of process parameters at total power inputs reduction.

To the largest extent it is observed in welding using the metal-cored wire. Software for control of the dynamic characteristics of arc welding process depending on wire type is used in control system of the inverter power source. Regulation of welding parameters is possible only within the limits being determined by the program for each wire type (Figure 2).

Some companies promote technologies for control of electrode metal melting. They program necessary reaction of power source and feeder to controlled changes of welding current and arc voltage that provides a set modified short-circuit electrode metal transfer in mechanized and automated gas-shielded welding. Application of such a process of controlled melting of the electrode wire allows 5–20 % decrease of heat input minimize spattering in comparison with the process having standard short-circuit electrode metal transfer. Mentioned phenomena are reached due to keeping the optimum characteristics of arc and accurate control of welding current during all welding process phases [14].

Application of modern equipment for semi-automatic welding with objective control of the main process indices is, as a rule, the major step to increase the quality stability indices of the welded structures (Figure 3). During semi-automatic welding this reduces effect of a subjective factor, related with performer qualification, but does not cancel the task of staff safety. The experience of automation relating to the welding technologies indicate the need of optimization and increase of quality of the whole complex of technologies of welded structure production including preparation and assembly of the units and structures for welding, determination of the leading welding process, selection of equipment and consumables as well as training of qualified personnel on control and methods of testing of quality indices in accordance with acting international standards.

Orientation to application of the process of semi-automatic and automatic gas-shielded flux-cored wire welding is one of the priority directions in the world's practice, in particular, in shipbuilding, power and heavy transport machine building, construction of drilling platforms, pipeline and other objects.

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Received 17.10.2017