MODERN FLUX-CORED WIRES FOR ARC WELDING OF METAL STRUCTURES FROM LOW-ALLOYED STEELS, DEVELOPED AT THE E.O. PATON ELECTRIC WELDING INSTITUTE AND OJSC "TM.WELTEC"

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Flux-cored wire arc welding is becoming more and more popular due to its efficiency and ease of use. PWI specialists, who initiated development of such an electrode material as flux-cored wire and its application technology, have more than sixty years of experience, both in the field of fundamental investigations on metallurgy of flux-cored wire welding, and of problems of its manufacture and use [1–4]. The accumulated experience shows that at selection of a specific technology of flux-cored wire welding all its advantages and disadvantages should be taken into account. Taking a correct well-balanced decision requires deep knowledge and extensive practical experience for evaluation of both the positive aspects of a particular technology or certain wire grade, and also the possible negative consequences. Choice made on the basis of previous experience, guarantees that the flux-cored wire welding technology will be the best variant in a specific situation.

The growth in the popularity of this technology of flux-cored wire arc welding was based on a number of essential advantages, inherent to the welding technology proper. Scientifically substantiated selection of the core composition opens up wide possibilities for controlling the kinetics of metallurgical processes in the welding arc. That is why the flux-cored wires can be used for welding practically any type of metal, making this technology more versatile, compared to other methods.

Flux-cored wires, which are released to the market by certified manufacturers, owing to their high efficiency and productivity allow reducing the labour costs for auxiliary operations, providing an economic substantiation for their application. The flux-cored wires themselves are a high-tech welding consumable, and their quality is guaranteed by a complex of special technological operations of their manufacture and quality control. High-quality flux-cored wires can only be produced by competent specialized companies. In Ukraine OJSC "TM.WELTEC" is the leading manufacturer of flux-cored wires for welding and surfacing. PWI experience on development and use of flux-cored wires, gained over many years, is finding practical implementation in cooperation with such a manufacturer of welding consumables as OJSC "TM. WELTEC". Flux-cored wire production is located in a specially designed for this purpose shop of more than 3 thou m^2 area in the city of Dnipro. This is one of the most technologically sophisticated enterprises on welding consumables manufacture in the country. In addition to several automated lines for wire manufacture, the production facility includes a laboratory, where engineers and technical specialists continuously monitor compliance with the technological parameters of equipment operation, and product quality indices. Research and development is continuously carried on, which is aimed at improvement of the technological operations of manufacture, and creation of new grades of flux-cored wires, in keeping with the user inquiries and needs.

OJSC "TM.WELTEC" and PWI specialists are constantly working to improve the currently available and develop new compositions of flux-cored wires, in order to guarantee the high quality of welded joints by increasing the stability indices of the arc process, as well as improving the technological and sanitary-hygienic characteristics of the wires.

Assessment of the danger of the generated welding fumes is conducted in the entire range of welding modes, as the toxic impact of the fumes depends not only on the particle composition and dispersity, but also on the degree of their agglomeration during emission and a number of other factors. The volumes of welding fumes emission are influenced both by the type of the flux-cored wire, and the composition of the shielding gas atmosphere, as well as the welding mode parameters.

In welding in an argon-based gas mixture the level of gross emissions of the fumes and of their toxic component is significantly lower. Use of flux-cored wires of metal-core type allows lowering the total level of gross fume emissions to the level characteristic for solid wire application. The total level of gross emissions is higher in the case of application of flux-cored wires with slag-forming core, than at application of solid wires or wires filled with metal powder filler. When using such wires, it is necessary to particularly strictly follow the respective recommendations on safety as regards cleanliness of the air in the working area of welding. However, presence of the slag melt leads to lowering of the overall level of burnout of deoxidizing and alloying elements, which eventually allows lowering the level of fume toxicity [5].

Presence of special stabilizers in the core composition allows significantly increasing the welding process efficiency, and lowering the level of molten metal

Table 1. Some characteristics of commercial flux-cored wires, proposed by OJSC "TM.WELTEC" for electric arc welding of low-alloyed steels

Wire grade, diameter and type, in keeping with the standards	Mechanical properties and chemical composition of weld metal	Purpose	Typical applications
FCWw-TMW1 ISO 17632-A: T 35 A Z N3 1.0–2.8 mm diameter	*UTS* ~ 460–550 MPa; *YS* ~ 330 MPa; $A_5 \geq 16$ %; $KCV_{+20\,°C}$ ~ 40 J/cm^2 C ~ 0.08; Si ~ 0.1; Mn ~ 0.8; S ≤ 0.035; P ≤ 0.035 wt.%	Semi-automatic arc welding of metal structures from general purpose low-alloyed steels, also of contaminated metal	Building metal structures, technological containers, parts of agricultural machinery, railway equipment and machines
FCWw-TMW3 ISO 17632-A: T 42 2 1Ni Y N 3 1.6–2.4 mm diameter	*UTS* ~ 490–660 MPa; *YS* ~ 400 MPa; $A_5 \geq 20$ %; $KCV_{+20\,°C} > 80$ J/cm^2; $KCV_{-20\,°C} > 35$ J/cm^2 C ~ 0.12; Si ~ 0.2; Mn ~ 1.2; Ni ~ 1.0; Al ~ 0.85; S ≤ 0.02; P ≤ 0.02 wt.%	Mechanized arc welding in the field of metal structures from general purpose low-carbon and low-alloyed steels	
FCWw-TMW -mk5A ISO 17632-A: T 42 2 M M 1 H10 AWS A5.18 E70T-6C 1.2–1.6 mm diameter	*UTS* ≥ 520 MPa; *YS* ≥ 430 MPa; $A_5 > 24$ %; $KCV_{+20\,°C} \geq 160$ J/cm^2; $KCV_{-20\,°C} \geq 110$ J/cm^2; $KCV_{-50\,°C} \geq 40$ J/cm^2 C ~ 0.06; Si ~ 0.45; Mn ~ 1,5; S ≤ 0.02; P ≤ 0.02 (wt.%)	Automatic and semiautomatic high-speed single- and multipass gas-shielded welding of metal structures from carbon and low-alloyed structural and shipbuilding steels	Special-purpose structures, of which higher requirements are made to weld ductility characteristics at low temperatures (down to minus 60 °C)
FCWw-TMW29 ISO 17632-A: T 42 3 1.2 – 2.4 mm diameter	*UTS* ≥ 490 MPa; *YS* ≥ 420 MPa; $A_5 > 22$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-40\,°C} \geq 35$ J/cm^2 C ~ 0.12; Si ~ 0.4; Mn ~ 1.3; S ≤ 0.03; P ≤ 0.03 wt.%	Welding of metal structures from low-carbon and medium-strength steels. Multipass welding without intermediate slag removal is possible, due to its small quantity and easy detachality of the crust. High efficiency of welding operations and good appearance of the welds	General mechanical engineering, metal structure plants, transport and lifting machinery
FCWw-TMW7 ISO 17632 A: T 42 4 P C 1 H5 AWS A5.18 E71T1-C1A4-CS2-H4 1.2–2.4 mm diameter	*UTS* ≥ 490 MPa; *YS* ≥ 400 MPa; $A_5 > 22$ %; $KCV_{+20\,°C} \geq 120$ J/cm^2; $KCV_{-20\,°C} \geq 90$ J/cm^2; $KCV_{-40\,°C} \geq 70$ J/cm^2 C ~ 0.08; Si ~ 0.3; Mn ~ 1.3; S ≤ 0.03; P ≤ 0.03 wt.%	Gas-shielded welding of metal structures from low-carbon and low-alloyed steels, including D32-E40 shipbuilding steels, unalloyed S235, S355 structural steels. Excellent welding-technological properties. Deposited bead has a smooth surface with easily detachable slag crust	Manufacture of metal structures, with higher requirements to low-temperature ductility characteristics of weld metal
FCWw-TMW57 ISO 18276-A: T 55 2 R C 2 1.2 – 2.4 mm diameter	*UTS* ~ 650–800 MPa; *YS* ≥ 590 MPa; $A_5 \geq 16$ %; $KCV_{+20\,°C} \geq$ 65 J/cm^2; $KCV_{-30\,°C} \geq 35$ J/cm^2 C ≤ 0.12; Mn ~ 1.3; Si ~ 0.3; Cr ~ 0.30; Mo ~ 1.2; V ~ 0.3; S ≤ 0.03; P ≤ 0.03	Gas-shielded welding of critical metal structures from low-alloyed high-strength steels, as well as alloyed structural steels with not less than 580 MPa yield limit	Repair welding of castings from higher-strength steels, repair of various-purpose equipment, building metal structures, mechanical engineering, metallurgical industry units
FCWw-TMW14 ISO 17634-A: T CrMo R C 1 1.2–2.4 mm diameter	*UTS* ~ 500 MPa; *YS* ≥ 430 MPa; $A_5 \geq 22$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-20\,°C} \geq 50$ J/cm^2 C ≤ 0.06; Mn ~ 0.8; Si ~ 0.3; Cr ~ 1.0; Mo ~ 0.5; S ≤ 0.014; P ≤ 0.012	Mechanized gas-shielded welding of metal structures, building-up and repair of defects in castings from high-alloyed steels and corrosion-resistant, heat-resistant and high-temperature alloys operating at up to 545 °C temperature	Transport engineering, technological containers, vessels, tanks and pipelines, metal structures, etc.
FCWw-TMW11 ISO 17633-A: T55 2 R C 2 2.4–3.0 mm diameter	*UTS* ~ 520 MPa; *YS* ≥ 400 MPa; $A_5 \geq 30$ %; $KCV_{+20\,°C} \geq 80$ J/cm^2; $KCV_{-20\,°C} \geq 50$ J/cm^2 C ≤ 0.12; Mn ~ 14.0; Si ~ 0.2; Cr ~ 10.0; Ni ~ 9.0; S ≤ 0.025; P ≤ 0.025	Mechanized open-arc or gas-shielded welding and surfacing of low-carbon and low-alloyed steels, as well as welding alloyed structural steels to austenitic steels	Welding pearlitic steels to high-manganese steels, as well as welding and repair of mining excavator buckets

spatter [6]. The slag phase, forming at core melting, allows not only protecting the molten metal from undesirable interaction with the environment, but also realizing the necessary metallurgical reactions to improve the performance of the metal of the weld and the welded joint as a whole.

The main difference of the process of flux-cored wire welding in the spray transfer mode from solid wire welding consists in that the electrode metal transfer takes place on the wire edges (over the sheath cross-section), and not in the central zone, focused on the center of the arc burning. Presence in the flux-cored wire core of slag-forming materials and metal powders, as well as chemical compounds with a low ionization potential, influences the surface tension of molten metal of the weld pool, which allows regulation of the weld surface shape. For gas-shielded arc welding flux-cored wires with the following types of powder core are mainly used. Mineral-powder (slag-forming) core provides slag protection and performs metallurgical processing of the melt of the respective type (rutile or basic type). Metal-powder core, based on powders of iron and alloys with a small fraction of active chemical compounds (usually less than 1.5 % by weight), ensures active alloying and microalloying, as well as modifying of the weld metal structure. Here, the composition of the shielding gas atmosphere has a key role, determining the thermal conductivity of the arc gap, and degree of oxidizing process development at electrode metal transfer and in the weld pool.

As a rule, the cost of welding consumable for making a certain welded joint is higher in the case of using semi-automatic flux-cored wire welding, than in the case of coated-electrode manual arc welding or semi-automatic gas-shielded solid wire welding. However, even without allowing for a higher welding efficiency, the real cost of welding operations also includes the labour costs for postweld heat-treatment of the produced joint, and metal stripping along the weld. They take up from 50 up to 55 % of the total operation cost. The efficiency of the electric arc welding process, assessed by the quantity of the deposited metal, does not fully reflect the actual productivity of making the welds during metal structure fabrication. The influence of the possible deviation of weld dimensions from the design ones, in particular surface shape (reinforcement), and extent of the possible losses of electrode metal for spatter under the actual conditions should be also taken into account. For instance, the time spent for making welds of equivalent design size increases by 5–15 % in the case of application of a gas mixture of M21 type instead of carbon dioxide gas in gas-shielded welding. This is achieved not only due to reduction of burnout and spattering losses, but also due to a more accurate correspondence of the reinforcement dimensions and shape to the design values, which influences the cost indices of fabrication of welded metal structures. Additional economic advantages can be also achieved at application of flux-cored wires instead of solid wires owing to reduction of the weld metal volume, for instance in welding single-pass fillet joints.

Higher cost of welding consumables (flux-cored wires, gas mixtures of argon with carbon dioxide gas) is compensated not only by increase of welding process efficiency, but also by lowering of overall costs for making the welded joints due to elimination of electrode metal losses, as well as improvement of the shape and more complete compliance of the weld shape and dimensions with the design values. All this allows lowering the cost of fabrication of welded metal structures and improving their quality.

The main properties of some commercial flux-cored wires, manufactured by “TM.WELTEC” are shown in the Table 1.

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