DOI: http://dx.doi.org/10.15407/tpwj2019.06.05

IMPROVEMENT OF TECHNOLOGICAL AND SANITARY-HYGIENIC CHARACTERISTICS OF GAS-SHIELDED ARC WELDING PROCESS

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The influence of kind and type of electrode wire, characteristics of its melting, as well as composition of shielding gas, on welding-technological properties and technological quality of welds in joints of low-alloyed steels of increased and high strength is considered. The ways and means of achieving a consistently high technological quality of welds, increasing the efficiency of the process and reducing the level of gross evolutions of welding fumes are noted. 14 Ref., 4 Figures.

Keywords: *mechanized arc welding, low-alloyed steels, electrode wire, welding and technological properties, weld quality, efficiency, welding fumes*

Current state of application of automatic and mechanized gas-shielded arc fusion welding is characterized by a significant widening of the fields of its application in development of various-purpose metal structures from increased and high-strength low-alloyed steels. The main factors promoting wider application of these welding processes are high efficiency and optimization of the cost, as well as high quality of welded joints [1–5].

Low-alloyed solid wires, as well as flux-cored wires with metal core became the most widely applied as electrode material for the above processes. Here, the shielding medium is most often created by carbon dioxide gas or argon-based gas mixtures with addition of carbon dioxide gas [6]. With widening of the application of mechanized gas-shielded fusion welding ever more attention has to be given to the main features of the process, which influence the welded joint quality characteristics, efficiency of operations, as well as improvement of sanitary-hygienic conditions of their performance, that is directly related to metal structure fabrication cost [7–10].

Investigations and experimental work performed at PWI in this field were aimed at clarification of the effect of electrode material kind and type, and shielding gas composition on their welding-technological properties and technological quality of welds in joints of low-alloyed steels. In addition, the influence of these factors on efficiency indices and sanitary-hygienic characteristics of the process was assessed. The electrode material used were solid wires, meeting the requirements of DSTU ISO 14341 standard [11], and flux-cored wires for arc welding of low-alloyed steels of increased and high strength to standards DSTU ISO 17632 [12] and DSTU ISO 18276 [13]. The shielding gas atmosphere was created in keeping with the recommendations of welding wire manufacturers and standard DSTU 14175 [14]. Used as the base material were plates from low-alloyed steel 09G2S from 6 to 18 mm thick, treated for making fillet and butt joints with the recommended edge preparation. Welding equipment included two main types of sets: thyristor VDU-506 and inverter TransSynergic 5000 Fronius with the respective feed mechanisms and automatic welding head. Welding mode parameters were established in keeping with the recommendations of wire manufacturer. The electrode materials selected were solid wire of G46 3C (M) type (ESAB), flux-cored wires of T50 (46) C (M) Z type (PWI PPWC, Alloy Rods, Oerlikon, KOBELCO).

Video filming was used to assess the characteristics of arcing and electrode metal transfer. Electrode metal losses were recorded by electrode material consumption and by evaluation of the level of spatter after the joint scraping. Sanitary-hygienic characteristics were assessed by the intensity of evolution of welding fume solid component (WFSC) and its composition [10].

Weld shape and dimensions were studied by measuring the transverse sections, cut out of welded samples after grinding and etching in nitric acid solution. Quantimet microscope was used to determine the cross-sectional area. Penetration depth, weld width, reinforcement shape, total cross-section area were selected as the main characteristics for comparison, and defects in the fusion zone were evaluated. Results of the conducted studies and authors' ideas for improvement of the process of mechanized gas-shielded welding are given below in the generalized form.

Influence of the characteristics of wire melting and metal transfer on welding-technological properties. Wire melting and electrode metal transfer into the weld pool are determined in the general case by the section (diameter) of the wire and parameters of the welding mode, as well as the composition of shielding gas atmosphere. The main kinds of transfer are classified as drop, spray and spray-drop transfer. A key role in the change of transfer characteristics is played by the impact of pinch-effect on the end portion of melting wire, caused by lowering of molten metal surface tension. Composition of shielding gas atmosphere, as well as the type and composition of electrode wire, affect the thermal conductivity, ion potential of the arcing zone and, thus, the nature of wire melting. Diameter (for solid wires) or thickness of current-carrying sheath of flux-cored wire determine the value of arc welding parameters, at which the influence of pinch-effect changes the nature of arc burning and melting of the wire tip face. Figure 1 shows the simplified schemes of metal transfer in welding with solid wire and flux-cored wire, characterized both as drop and spray (spray-drop) transfer.

The main difference at application of solid wire and flux-cored wire consists in that at spray transfer of solid melting wire the metal transfer is focused in the center of arc burning area, and that of flux-cored wire is focused across the sheath section, the core metal going into the weld pool in the central zone. Presence of slag-forming materials and powders of metals and chemical compounds with a low ionization potential in the composition of flux-cored wire core, which affect the properties of the slag melt, has an impact on surface tension of weld pool molten metal that allows regulation of weld surface shape. In gas-shielded arc welding flux-cored wires mainly with two types of powder core are used: slag-forming, which ensures slag protection and provides metallurgical treatment of the melt of the respective type (rutile or basic), and metallic, the base of which are powders of iron and alloys with a small fraction of active chemical compounds (less than 1.5 wt.%). The composition of shielding gas atmosphere has a key role, determining thermal conductivity of the arc gap and degree of development of oxidizing processes at electrode metal transfer and in the weld pool.

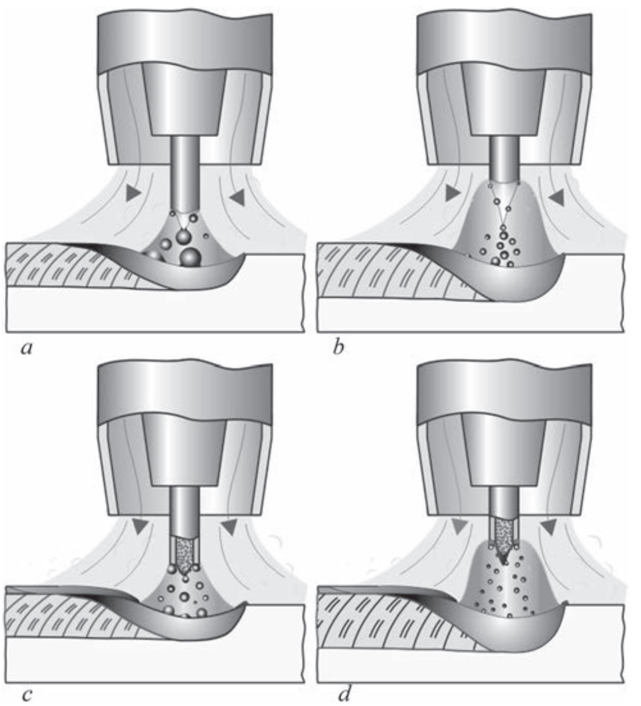

Figure 1. Modes of electrode metal transfer in welding with solid wire (*a*, *b*) and flux-cored wire (*c*, *d*) in welding in CO_2 (*a*, *c*) and in Ar + CO_2 mixture (*b*, *d*)

Solid wires have deoxidizing elements and alloying additives in their composition, which ensure producing weld metal of the specified composition, determining the level of mechanical properties of the welded joint according to the strength class of welded steels. Type of applied electrode material (wire), similar to shielding gas atmosphere composition, largely determines not only the values of mechanical properties of the metal of weld and welded joint, but also the technological characteristics and quality of welded joints.

Technological quality of welds. Formation of a sound weld in terms of technology is determined by its geometry (penetration depth and shape), correspondence to design dimensions, absence of base metal damage and complete filling of the beginning and end (crater) sections. Meeting these requirements is considerably simplified, if the recommended welding technique requires no further manipulations, in addition to torch movement along the joint trajectory, and even more so, additional adjustment of parameters of the welding mode, established by the process specification.

Shielding gas atmosphere has a significant role, both in the process of electrode metal transfer into the weld pool, and in the technological characteristics, determining the penetration depth and weld shape, as well as the efficiency of the welding process as a whole. Widely used shielding of the melting zone by carbon dioxide gas ensures sufficient depth of penetration and welding process efficiency, owing to high heat conductivity. Nonetheless, application of such gas shielding, having a high oxidizing potential, requires following the welding technique and mode parameters to ensure the specified dimensions and shape of the weld, because of the susceptibility to formation of base metal undercuts and convexity of the central part of weld surface. Moreover, change of welding mode parameters can lead to both increase of metal losses for spattering, and to greater loss of alloying elements from the wire.

Application of the still widely accepted process of solid and flux-cored wire welding in carbon dioxide gas is accompanied by loss of part of deoxidizing and alloying elements, released into the atmosphere together with welding fumes. A significant effect of welding mode parameters (particularly welding speed) on the weld shape and dimensions is also noted at application of solid wires. Use of wires with slag or metal powder filler allows an essential improvement of the technological properties due to the effect of the formed slag melt and specific characteristics of wire melting, ensuring refinement of the transferred drops of molten metal of the wire sheath and core, as well as technological properties of slag, which ensures protection of weld pool surface from oxidation. Nonetheless, spray-drop transfer of electrode metal is not achieved in either case. Moreover, application of flux-cored wire with slag-forming filler is associated with the need to remove the slag crust after each welding pass. Achievement of the characteristics of spray-drop transfer of electrode metal is possible only at application of small diameter wires at high parameters of the welding mode.

The main effect on the forms of electrode metal transfer is produced by thermal power, which is consumed in melting of electrode wire, fed continuously into the melting zone. Value of this thermal power depends on welding current polarity, welding mode parameters, as well as composition of the used shielding gas. Power required for stable maintenance of welding, is adjusted by the specified rate of wire feed into the melting zone. At small value of power, released in the wire melting zone, electrode metal transfer is performed by molten metal drops with short-circuiting of the arc gap. At the highest power electrode metal transfer takes the spray form (metal transfer by droplets without short-circuiting of the arc gap). Spray transfer is the most stable in terms of melting parameters and allows an abrupt lowering of electrode metal losses for spattering.

Argon is used as shielding gas to achieve spray mode of electrode metal transfer in all the ranges of welding mode. In welding in an argon-based gas mixture (for instance, Ar + CO_2) the beginning of transition from drop to spray type of transfer occurs, when the arc partially transfers from wire end face to side surfaces of wire tip. The wire tip takes the shape close to the conical one. In CO_2-welding it is necessary to increase the arc power through increase of arc voltage (as the welding current is related to wire feed rate). The most rational process in modern technology of gas-shielded solid wire welding is believed to be a process, where argon-based gas mixtures are used. The most widely applied are gas mixtures of M21 type to ISO 14175 — Ar + from 5 to 25 vol.% CO_2. CO_2 addition to argon allows lowering the adverse influence of too high thermal radiation on the operator-welder. Application of such argon-based mixtures allows a significant improvement of penetration shape and surface geometry of the weld, as well as minimizing electrode metal losses for spatter. Figure 2 shows typical sections of fillet welded joints, made with solid wire and flux-cored wire with metal-powder core in carbon dioxide gas and gas mixture of M21 type.

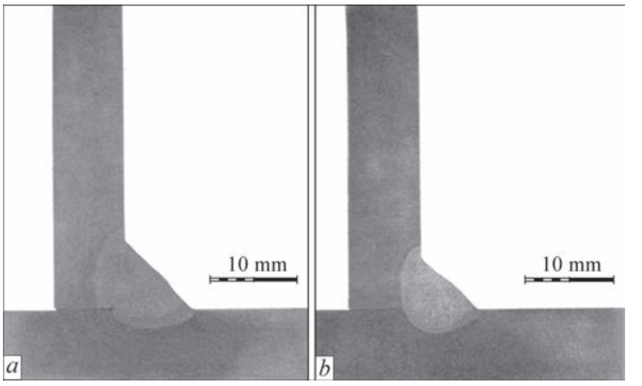

Figure 2. Sections of single-pass fillet welded joints of 8 mm thick metal, made by solid (*a*) and flux-cored wire (*b*) in shielding gas atmosphere M21 (Ar + 18 CO_2) in the automatic mode

World practice shows a considerable increase of the volume of application of mechanized welding in gas mixtures, in particular, at application of solid wires and flux-cored wires with metal-powder core type, ensuring spray-drop transfer of electrode metal in a broad range of welding mode parameters. Such a technology is less sensitive to the effect of the subjective factor, and readily applicable for high-efficient automatic welding processes.

Effect of electrode wire type and composition of shielding gas atmosphere on sanitary-hygienic characteristics and efficiency of the process. Electric arc fusion welding is always accompanied by welding fumes evolution. Assessment of the total amount of fumes and their composition are initial data for establishing the requirements on protection of welder-operator respiratory organs and organizing the work of the systems of welding fume removal from the working zone and gen-

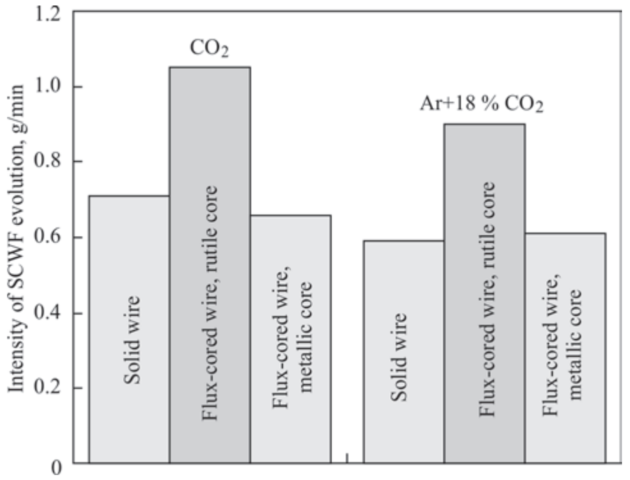

Figure 3. Typical intensity of welding fume evolution in gas-shielded welding with solid and flux-cored wires

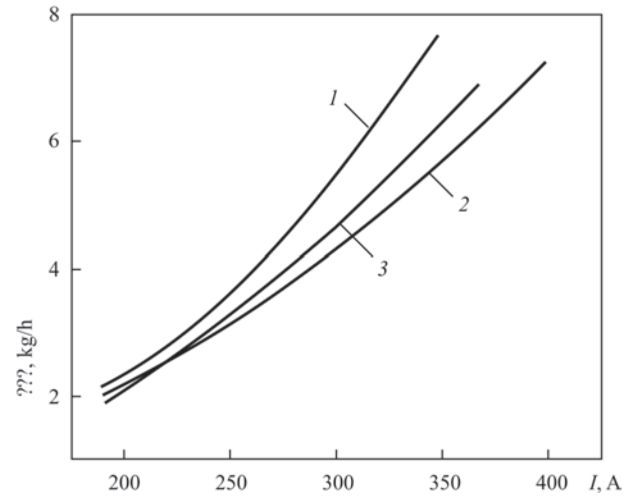

Figure 4. Typical efficiency of deposition with electrode wires of 1.2 mm diameter of different type in shielding gas atmosphere M21 (Ar + 18 CO_2): *1* — flux-cored wires with metal core; *2* — rutile core; *3* — solid wire

eral shop space. Main attention is given to presence and amount of the most toxic components. For the case of welding low-alloyed steels, manganese emissions are considered some of the most toxic. As the material type, composition of shielding gas atmosphere and welding mode parameters have an effect on the volume of welding fume evolution, assessment of the risk is performed in the entire range of welding modes, as the toxic effect of aerosol depends not only on composition and dispersity of particles, but also on the degree of their agglomeration during release, and a number of other factors.

Application of solid wires and flux-cored wires in CO_2-welding is associated with development of oxidizing reactions already at the stage of wire heating and melting that makes it necessary to allow for their losses for guaranteed achievement of the required composition of weld metal and obtaining the required quality and performance of the welded joint. Total level of gross evolutions in the case of application of flux-cored wires with slag-forming filler is higher, than at application of solid wires and flux-cored wires with metal-powder filler. However, presence of a slag melt leads to lowering of the level of burning out of deoxidizing and alloying elements that, eventually, allows lowering the level of fume toxicity.

In welding in an argon-based gas mixture, the level of gross evolutions of fumes and their toxic component is essentially lower. Application of flux-cored wires with a metal core type allows lowering the total level of gross evolutions of fumes to the level characteristic for application of solid wires (Figure 3).

The efficiency of the process of electric arc welding, assessed by the quantity of deposited metal (Figure 4), does not completely represent the real efficiency of making welds during metal structure fabrication, as it does not take into account the effect of possible deviation of weld dimensions from the design values, in particular, shape of the surface (reinforcement), extent of possible losses for electrode metal spatter in the real conditions. Comparative experiments showed that the speed of welding (time of performance) of welds of equivalent design size increases by 5 to 15 % in the case of application of welding in a mixture of gases of M21 type instead of carbon dioxide gas. This is achieved not only through lowering the burn-off and spatter losses, but also due to more precise correspondence of reinforcement size and shape to design values, that is reflected in economic indices of welded metal structure fabrication. Additional economic advantages can also be achieved at application of flux-cored wires instead of solid wires due to reduction of weld metal volume, for instance, when making single-pass fillet joints (Figure 2).

Conclusion

Analysis of the results of the conducted experimental studies on the influence of the kind and type of electrode wire, and shielding gas, can be the basis for selection of the most rational ways of improvement of the technological quality of welded joints, enhancing the welding operation performance and improvement of sanitary-hygienic characteristics.

Higher cost of welding consumables (flux-cored wires, gas mixtures of argon with carbon dioxide gas) are compensated not only by increase of welding process efficiency, but by lowering of total cost of making the welded joints due to elimination of electrode metal losses, as well as improvement of the shape and greater correspondence of the dimensions and shape of the weld to the design values. All this allows reducing the cost of welded metal structure fabrication and improving their quality.

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Received 12.04.2019

Samples of titanium alloy produced by xBeam 3D Metal Printer and product «Fly» — manual argon-arc welding