CURRENT CONSUMABLES AND METHODS OF FUSION ARC WELDING (Review)*

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State-of-the-art and existing problems in the filed of development of materials for welding carbon and low-alloy steels are analyzed, namely, coated electrodes, solid and flux-cored wires. Challenging technologies of their application, and also organizing and aspects of production and application of consumables are considered.

Keywords: *arc welding, carbon and low-alloy steels, coated electrodes, solid wires, flux-cored wires*

As a part of world economy, welding production related with manufacture of metal structures experiences significant influence of the declines and rises of financial and business activity in the recent years. The enterprises and organizations, scope of activity of which lies in manufacture and application of the electrode materials for fusion arc welding, tend to adjust to dynamically changing market requirements.

Manufacturers of welding consumables have to base on the statistical data and predictions concerning tendencies of change of the market requirements as a whole as well as regarding specifically manufactured materials with evaluation of competitiveness in each area of their application for planning and providing of stable operation of the enterprise.

Manual coated electrodes, solid and flux-cored wires make the main group of electrode materials of mass and special designation for welding and surfacing. Mechanized and automatic welding processes provide for application of additional filler and shielding materials (flux, gas), with exception of welding with flux-cored wires. Stable rise of application of the materials for mechanized and atomatic (including robotic) welding is a general tendency for a change in structure of manufacture and application of the electrode materials, especially in economically developed countries of South-East Asia (Japan, South Korea, PRC), America (USA, Canada, Brazil) and Europe (Great Britain, Germany, France, Italy, Holland etc.). Such technological processes as laser welding and series of hybrid and combined processes were among developing competitive methods of fusion welding. This was possible due to rapid development of microelectronics as well as application of modern systems of automatic control.

Coated electrodes. Manual coated electrodes are the most widely used consumables being multi-purpose from point of view of welding process organizing under plant and site conditions. Arrangement of a welding station does not require large investments in equipment and expenses on electrodes relatively small.

Small melting efficiency, caused by low current density, loss of material for the stubs as well as dependence of welding quality on qualification of a welder refer to disadvantages character for process of manual electrode welding. At the same time, the possibilities of control of the welding properties through change of composition of a coating are significant that allows preserving high competitiveness of this material for mechanized processes of welding.

Leading enterprises from CIS countries made a significantly increase in a level of electrode manufacturing technologies and delivery to customers. It was advanced to global on the main indices. The issues of quality of coating deposition, starting area, marking, pre-packing and packing were solved. A range of electrodes remains relatively narrow. This is partially related to the objective reasons of behavior of consuming market. However, insufficient release of the electrodes for welding of high-strength, stainless and heat-resistant steel, nickel, aluminum and copper alloys, cast iron and for surfacing leave a part of potential market free for import purchasing.

Modern methods of analysis and investigations, in particular, computer modelling using material data base, study of sensor-based devices for welding process using statistical data processing, achievements in area of materials science, for example, experience of series of foreign companies in application of the indicator marks on coating, showing the level of humidity or temperature of baking that is important for basic coated electrodes, are not sufficiently used in electrode development.

Classification of coated electrodes approaches to international standards (ISO 2560A, EN 757, EN 1600 etc.) on main requirements and characteristics making selection of necessary type and grade of the electrodes easier for consumers. Tendencies of world market in-

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dicate the necessity of increasing of scope of information support.

Data on X-ray density, cracking resistance, base metal penetration, spattering, separability of slag, characteristics of welding fume etc. are to be presented in addition to mechanical properties indices, chemical composition, hydrogen content and data on parameters of modes for welding in different positions. Detailed information in the advertisement materials and accompanying documents raises confidence of the consumers and reduce possibility of the claims connected with lack of information.

Forms of organization of economic ties with consumers play a part in stable production of coated electrodes as well as other consumables. It is relevant to stimulate the consumers to use modern power sources with a feedback allowing a welder to perform remote adjusting of welding parameters from an electrode holder.

Solid wires. Solid wires for arc welding make more than a half of all production of welding materials in leading economically developed countries. Areas of application on a type of shielding of melting zone are divided into shielded gas welding and submerged arc welding, on level of automation they are mechanized (semi-automatic), automatic and robotic. The wires are mainly used for welding of carbon, low-alloyed and stainless steels as well as aluminum and titanium alloys dividing on classes of metal to be welded. Regulation of indices based on composition of wire as well as shielding material (monogases or mixtures, agglomerated or fused fluxes) is possible for achievement of the required service properties.

Current density in welding with solid wires is significantly higher of that with manual electrodes that allows regulating melting characteristics in a wide range, realizing synergetic and combined controllable processes in welding of different metals and objects of application. In particular, control of transfer of electrode metal in a weld can provide stable characteristics during short-circuit metal transfer, non-short-circuit drop, axial and pulse spray metal transfer or modular-regulated one on surface tension of metal drop.

Modern systems of semi-conductor and inverter type power sources with programmable characteristics of the electric parameters connected by direct and reverse adaptive control with mechanism of wire feeding in the melting zone were developed based on application of the current physical and mathematical models as well as computer modelling of process of arc fusion welding. This allows providing secure performance of a welding algorithm as well as significantly reducing energy consumption and eliminating influence of a human factor. Efficient and programmable heat input in the metal allowed achieving increase of property values of the welded joints.

Group of international standards on wires, shielding gas, flux and their combinations (EN 440, EN 439, EN 760, EN 12072 etc.) presents a classification of solid welding wires. In this case the basic property indices correspond to ISO methodology (minimum value of yield strength and specified temperature of testing with guaranteed value of impact toughness).

There is a difference in level and range of wires, gases and fluxes with series of national standards that can result in difficulties, in particular, during product supply for export.

Only advance enterprises fulfill the requirements of the international standards as for forms of winding and packaging (requirements of European standard EN 759).

Great attention is paid to wire condition as delivered (allowances, accuracy of manufacture, winding, state and quality of surface) in the recent years. There are novel solutions for providing quality of coppered or noncopper-coated wires allowing improving indices of application in mechanized and automatic welding as well as significantly reducing gross emissions of welding fume.

Flux-cored wires. Application of the flux-cored wires requires in most cases the same equipment as for the solid wires. In the first case, however, some advantages in technological effectiveness, efficiency and metallurgical adjustment for welding of wide range of steels are present.

Flux-cored metal wire (weight fraction of non-metallic materials not more than 4 %) was for the first time implemented in the Great Britain Standard in 1974. Flux-cored welding wires are classified by European (EN 758, EN 12073) and ISO standards (ISO 17632, ISO 18276, ISO 17633) enforced in 2004–2005. There are separate national standards being adjusted to innovations, therefore, the flux-cored metal wires are often classified using standards for solid wire.

Countries of South-East Asia (Japan, South Korea, PRC) where production of flux-cored wires exceeds manufacture of manual electrodes and comes by volume to solid wires remain the leaders in production and application of the flux-cored wires in the recent years. Usage of the flux-cored wires in USA, France, Great Britain and Germany became equal with scopes of manual arc welding by coated electrodes due to development of own productions as well as admission of manufacturers from South-East Asia (Japan, South Korea) on their markets.

CIS countries significantly fall behind in this area that has promoted coming of products of Japanese, South-Korean and series of European manufacturers in this part of the market. Unfortunately, the same situation is observed in area of purchasing of equipment for mechanized and automatic welding.

Wires for gas shielded welding (rutile, basic and metal flux-cored wires) make the main portion in a structure of application of the flux-cored wires. Self-shielding wires make a separate group, allowing performance of welding process without additional gas

or flux shield. Therefore, they are the most applicable for welding-erection works.

Temporary decrease caused by the objective reasons (large diameter, excessive fume emission and insufficient level of property indices) was registered after rapid growth of consumption of the flux-cored wires (especially gas-shielded ones) in 1970–1980s. Use of flux-cored wires rises again in 2000 due to significant increase of production quality, property parameters and applicability for welding of different grade steels in the branches of industry and constraction.

Concerning the flux-cored wired for submerged-arc welding, area of their application is limited by high-strength steel welding where they compete with the solid wires.

Most types of flux-cored wire provide the better technological properties (shape of the weld and joint penetration) in comparison with the solid wires.

Gas-arc welding (welding of butt joints with forced weld formation) should be outlined among the erection methods of automatic welding using flux-cored wire. It excels the competitive methods in efficiency and quality.

Flux-cored wires are divided into rolled (manufactured by means of formation of cold-rolled strip of specified size in a round profile filled by flux mixture at intermediate stage of formation) and so-called seamless obtained by filling of long-length tubular billet with agglomerated flux on special vibration tables.

Filling of tubular strip billet directly before welding of longitudinal seam carried out by laser or high-frequency currents was mastered in the recent years. Further process of manufacture includes an additional formation by rolling and drawing on a scheme similar to that used in manufacture of the solid wire with application of the intermediate anneals. Such a technology allows achieving low content of hydrogen in the wire and surfacing any types of coatings.

Realization of this technology requires significant investments in the equipment and maintenance costs. In this connection price of the product increases twice at an average in comparison with the rolled wire.

Current flux-cored wires are supplied in a ready-for-use form (on EN 759 standard) and suitable for welding using commercial equipment.

Perspective technologies for consumables application. Synergetic systems as ones among intensively developing new welding technologies have relation to all electrode materials. Such systems can solve the tasks including monitoring, sensory control, modeling and programming of the electric processes, which determine the character of arcing and transfer of electrode metal, that allows optimization of the process based on welding-processing characteristics, effective use of energy and increase of quality of the welded joints.

Improvement of service characteristics, significant reduction of influence of welder's skill, decrease of spattering and level of emission of welding fume take place for the manual electrodes. Mechanized and automatic processes of welding by solid and flux-cored wires have wider possibilities due to simultaneous control of wire feed and electric parameters of the arc. Possibility of combining of melting characteristics and metal transfer arises at double and multiarc processes that allows regulating speed of welding and achieve better properties of a welded joint through combination of wires. Such processes are realized in automatic and robotic welding.

Combination of processes of laser welding and gas shielded flux-cored or solid wire welding is a direction being the most effectively developing among the hybrid processes. Joining of high values of penetrating capability of the laser beam and efficiency of melting of the filler material in a one weld pool allows designing shape and size of a weld which are most suitable for the welded joint. At that, high ionizing power of laser plasma increases arc discharge stability for melting of electrode wire.

Efficiency and adjustability of such a method exceed that of well-known narrow-gap welding. Increased requirements to accuracy of a joint assembly and significant costs on equipment can be referred to its disadvantages. Gas shielded tandem welding (two wires in one pool) in which mutual magnetic effect of arcs was electrically unbound due to application of two synchronized pulse power sources was successfully realized. Current miniature electromechanical drives allow making equipment for erection welding significantly lightweight and even installing wire feeder in a welding torch that is completely acceptable in using of small diameter wires.

Organizational and economic aspects of manufacture of the consumables. Manufacture of electrode materials consists of series of technological processes including (in less detail) raw preparation, manufacture of billet of product or component of billet, manufacture of marketable products, its processing and packaging, accompanied by procedures of initial (inspection), i.e. technological, and final (closing) control being part of a system of quality control.

Number of enterprises from CIS countries includes the operations which are not peculiar to basic technology of manufacture of marketable products in a structure of industrial processes. Chopping and milling of components, glass melting from a lump, treatment and initial drawing of wire from a roll, longitudinal division of strip rolls on bands etc. are referred to them, thus, transferring responsibility for risk of loss, costs of occupational safety and environment on main production.

Modern productions in developed countries work using specialization approach applying electrode, raw and auxiliary materials prepared by manufacturer requirements as well as utilities obtained based on schedule and long-term contracts with suppliers. The sup-

pliers readily sign such contracts directly or through branch enterprises (if raw finishing to required condition is necessary) according to world practice. International practice denied an opinion that the costs can be reduced during in situ processing.

Development of economic relations is effective using a futures-based designing with strict following of world market tendencies. Evolution and improvement of control for activities of enterprises using modern system of information technologies should substitute out-of-date order-supplier system.

Japanese economists related with welding engineering market of goods and services believe that a transfer of economic relations on new level through development of a stable triads manufacturer–dealer– consumer, allowing setting reasonable price and revenue sharing, is a priority. This, in particular, should be taken into account under conditions of passing of property rights and control over the plants of welding consumable manufacture to leading foreign companies on the territory of CIS countries and significant intensification of competitiveness in all range of products.

Low level of equipment and domination of out-of-date technologies arise some alert. In this connect manufacturers of welding consumables for all methods of arc welding should be directed on application of novel achievements in technique and technology, following the situation and also stimulating transfer of consumer to current level of equipment.

Own experience, addressing to printed technical and advertisement publications should not be solely relied upon in solving of arising problems. Specialists of leading research and design-and-technological institutes can provide qualified help, especially, in such questions as choose of reasonable solution, analysis of reasons of problem appearance and searching the ways of their elimination, professional development of personnel, estimation of innovation perspectives etc. All available possibilities are to be used in the world of rapidly developing information technologies.

ELECTRON BEAM WELDING OF MEASURING CHAMBER OF MAGNETIC PNEUMATIC GAS ANALYSER

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The selection of power and time parameters of electron beam for EBW of flat measuring chamber of magnetic pneumatic gas analyzer of stainless steel 12Kh18N10T was considered. Scheme of welding in general vacuum, welding-assembly device and conditions providing formation of overlap and circumferential welds with admissible distortions of gas channel geometric sizes and vacuum-tightness are given.

Keywords: *electron beam welding, stainless steel, overlap joint of (0.2 + 1.0) mm, heat input of welding, assembly-welding device, scheme of welding, vacuum-tightness, deformations*

In 1970 the Siemens (Germany) started the serial manufacture of magnetic-pneumatic gas analyzer of Oxymat type [1], consisting of a flat measuring chamber of stainless steel. It consists of a basement with slots in the form of a sheet 1.0 mm thick 164 × 52 mm in size, upper and lower plates of foil of thickness 0.2 mm, two exhaust pipes and two nipples (Figure 1). The design peculiarities of chamber are featured by the fact that exhaust pipes and nipples are welded-on to the upper plate by circumferential welds, and upper and lower plates are welded-on to the basement using straight-line overlap welds. During development of technology for EBW of measuring chamber of domestic gas analyzer applied for NPP it was necessary to consider that distortion of geometric sizes of gas channel in the form of ripples, sagging and buckling of upper and lower plates is admitted of not more than 0.1 mm, and drop of pressure at the level of $0.59 \cdot 10^3$ Pa for 30 min is not admitted at all.

Welding for the measuring chamber is applied for sealing the inner volume and installing of nipples and exhaust pipes. As is shown in Figure 1, longitudinal and transverse welds are produced at approximately 1 mm distance from the edge of slots. Welds pass along the whole length of the item and cross each other, thus increasing the rigidity of structure and excluding the rounding. As far as width of welds on the prototype was 0.23–0.25 mm, it can be suggested that in this case the EBW or laser welding was applied.

According to conditions of operation the measuring chamber of gas analyzer should be non-magnetic, corrosion-resistant and vacuum-tight.

Austenite Cr–Ni thin-sheet steel 12Kh18N10T (GOST 5632–72) can meet those requirements (wt.%: C < 0.12; 17–19 Cr; 9–11 Ni; 1–2 Mn). However its decreased heat conductivity and high coefficient of linear expansion predetermine the great distortion of structures and assemblies to be welded. To provide minimal postweld deformations and resistance to formation of solidification cracks, and consequently, decrease in overheating the metal of near-weld zone, it is necessary to select the conditions with the least energy input [2].