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To the 70th anniversary of the creation of electroslag welding

ELECTROSLAG WELDING PROCESS. ANALYSIS OF THE STATE AND TENDENCIES OF DEVELOPMENT (Review)

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The paper presents the results of analytical review of investigations and commercial application of electroslag welding and surfacing in Ukraine, as well as foreign countries from the beginning of the XXI century. Analysis showed that the volume of application of electroslag welding of thick metal (more than 100 mm) in different branches of industry has noticeably decreased. However, stable growth of its application in the recent years has been noted in construction of bridges and high-rise buildings, ship building, as well as repair of large parts of machines on-site. The developed steels having low sensitivity to grain growth in the heat-affected zone, allowed expanding the range of products made by electroslag welding. There is a considerable increase of the volume of application of electroslag surfacing with strip electrode for anticorrosion coatings in pressure vessels, separators, steam generators, compressors and other equipment, being operated in oil and gas, power, metallurgical, paper-and-pulp and chemical industries. 51 Ref., 5 Figures.

Keywords: *electroslag welding, electroslag surfacing, welding equipment, technology, wire electrode, consumable nozzle, strip electrode, specific energy input, heat input, steel, heat-affected zone, impact toughness*

Electroslag welding process in Ukraine. Seventy years ago [1], a new method of electric fusion welding, named electroslag welding (ESW), was developed and successfully implemented at the E.O. Paton Electric Welding Institute (Kyiv) for welding vertical butt joints of blast furnace casings. This method featured a whole range of technical and technological advantages compared to the available industrial methods of fusion welding [2].

The phenomenon of emergence, development and subsequent application of the methods of ESW and electroslag surfacing (ESS) in industrialized countries is attributable to the high potential of the process [3, 4] for development of the economy.

Its successful application was promoted by cooperation with leading industrial enterprises of the USSR, CMEA, as well as many other foreign companies [2, 5].

On the threshold of the XXI century, the high scientific and technical level of the currently available methods, welding equipment, fixtures and technologies of ESW and ESS in welding production of various industries of mechanical engineering and construction allowed successfully solving the important tasks. For instance, development of the technique and technology of consumable nozzle ESW of structures from stainless steels of 18-8 type; investigation and development of the technology and technique of ESW of steels for elements of superconducting magnetic systems of ITER thermonuclear reactor; development of the technology and technique of ESW of position butt joints in titanium ring blanks of 1000 mm diameter with 100 mm wall thickness; welding of copper to chromium-zirconium bronze by large cross-section electrode in manufacture of powerful current conduits of the power system of Tokamak fusion reactor, etc. [3, 4, 6].

Tendencies in ESW development over 10–15 years, starting from 1990 and analysis of information (about 3000 titles from 37 countries) [3] allowed determination and systemizing the main directions:

- development of low-alloyed steels with good weldability, the welded joints of which at up to 200 mm thicknesses have the required properties without subsequent heat treatment;
- improvement and development of new filler materials for welding;
- application of new low-alloyed steels (up to 30 to 40 % of the total material volume), used in structures made by ESW;
- development of requirements to the quality of metal and thick initial billets (up to 3000 mm) from higher strength alloyed steels;
- improvement of the technique and technology of ESW of circular butt joints predominantly for large billets of more than 2500 mm diameter;
- investigation and development of new types of welded joints at lowering of specific unit costs;
- development of the techniques and methods of producing permanent joints of a compact cross-section with application of the electroslag process and liquid filler metal.

Forecast estimates of future welding production envisaged, first of all, development and application of new generation welding equipment with program

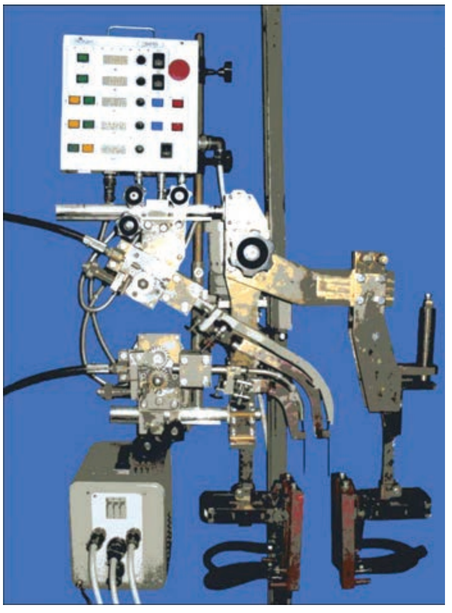

Figure 1. Two-electrode AD-381Sh machine for ESW of 30–100 mm thick metal

control of ESW technological process. Here, at introduction of new welding equipment, it is rational to provide the maximum possible level of mechanization and automation of assembly and auxiliary operations, as they take up to 50–70 % of the time of total cycle of welded metal structure fabrication [3].

In order to realize the technologies of ESW and ESS of large nontransportable metal structures in site, mobile groups were set up, fitted with the required set of equipment, including local heat treatment means.

The following two processes became the most widely accepted in welding production in mechanical engineering sectors and construction: electroslag welding with wire electrode (ESW WE) and with consumable nozzle (ESW CN). They are used to make the main types of the joints (butt, fillet, tee) and types of welds (straight, circular, variable profile). For these processes, PWI developed a whole range of welding machines, including batch-produced machines of A-535, A-1304 and A-820K type [2, 3].

Figure 2. Two-electrode ASh 115M2 machine for ESW of position circular and curvilinear butts joint of 40–200 mm thickness

In 1990 a new machine was developed for ESW with wire electrodes for metal of up to 450 mm thickness (instead of A-535), which was designated ASh-112 [3]. For ESW of butt joints of low-alloyed steels of 09G2S type 30–100 mm thick, new generation assembly welding machine of AD-381Sh type was designed (Figure 1) [7].

In 2004-2006 a two-electrode machine ASh 115 M was developed for ESW of position circular welds of large metal structures of 14000 mm and larger diameter, which has no analogs in the world practice of welding production (Figure 2) [8].

In order to perform ESW CN, machines of ASh-110, ASh-113 and AShP113 M2 types (Figure 3) were developed, which ensure duplication during welding of practically all the elements of the welding circuit (mechanical and electrical) [3, 9, 10]. New generation machines of modular type are fitted with systems of welding process control, and enable continuous monitoring and certification of the mode parameters [11].

ESW development in Ukraine and in the world practice is going on, both as regards investigations of welding process proper and its industrial application.

An important direction in development of the electroslag process is regulation of input and distribution of thermal energy in the welded joint zone to ensure thermal cycles, not lowering the strength characteristics of the HAZ metal without subsequent high-temperature treatment [12].

Application of higher-strength structural materials opens up the possibilities for increasing the scopes of ESW application [13]. These steels have low sensitivity to overheating in the HAZ [2, 14–16].

Studies of electrode and base metal melting in the welding zone [17–19] showed that electrode surface melting in interelectrode gap of the slag pool is accompanied by formation of higher temperature energy nugget. Dimensions (volume) of the nugget vary cyclically due to electrode metal inflow to it. Nugget contact with the metal pool surface is accompanied by electrodynamic shock, as a result of which the metal pool, absorbing the thermal energy of the nugget, shifts towards the edges being welded, and performs their partial melting. It is shown that the dimensions of the energy nugget, welding current values and metal pool shapes have common regularity of a cyclic nature. Each cycle is completed by formation of a «discharge» into the metal pool. Welding current oscillogram at the moment of such a «discharge» shows peak increase of current 3 to 5 times [17, 18]. If this is confirmed by further studies, it will be possible to determine the optimum conditions of energy nugget existence and improve process control system.

The high level of service properties of welded joint metal is achieved under the condition of reducing the heat input. Specific energy input E_w of the electroslag welding process is in the range of 104–208 kJ/cm^2 for most of the cases of ESW of low-alloy steel metal [2].

At ESW with wire electrode, E_w lowering is limited by the conditions of preservation of the stability of running of the process proper and satisfactory weld formation.

It is shown that:

- at E_w < 45.0 kJ/cm^2 sound welds (without solidification cracks) are produced for metal of 30–60 mm thickness using one electrode (V_w = 3.0–5.0 m/h, V_e up to 600 m/h);
- in the range of V_w = 1.0–3.0 m/h E_w lowering from 90 to 55 kJ/cm^2 is observed, respectively. Here, even V_w increase up to 7–8 m/h does not allow lowering E_w below 45 kJ/cm^2;
- ESW in forced modes (V_w > 4.0 m/h) can be performed with new generation machines at complete automation of the process;
- it is recommended to perform ESW in forced modes in a narrow gap (24–18 mm) with flux-cored wire of 2.6–1.8 mm diameter, as well as solid wire of 2.0–1.6 mm diameter;
- metal of the welded joint produced at values E_w (75–45 kJ/cm^2) of ESW is characterized by higher quality.

Lowering of the specific energy input E_w (by 23 %) in ESW of titanium into a narrow gap (22 mm) leads to reduction of the HAZ width and lowers the probability of running of undesirable structural transformations in the base metal.

Noteworthy is the work aimed at further development and improvement of the technique and technology of repair of large metal structures directly on site. Processes have been developed for restoration of defects (predominantly, through-thickness cracks), arising in service of large-sized nontransportable metal structures by the method of multipass ESW with consumable nozzle [20, 21].

Technologies and technique have been developed for refurbishment of working elements of rapidly wearing machine parts using ESW, such as large gear teeth, heavy hammers of coal mills, steel and cast iron hot rolling rolls. Welding equipment was designed and practical recommendations on their application were issued [22, 23].

A method was proposed for ESW or ESS by corrosion-resistant stationary consumable sectioned electrodes of a large cross-section in a narrow gap for rectilinear and curvilinear butt joints of thick metal [24]. Large cross-section electrode and wire electrode, powered from different sources, are used in the welding zone. Such a scheme of welding process running allows an effective application of the advantages and eliminating the disadvantages of the above welding processes [2]. The gap between the edges being welded and stationary sectioned electrode is equal to 1.5–3.0 mm and it should be filled with a ceramic type dielectric. The optimum material of the insulators are fluxes of AN-9U or AN-45 type, applied on the surface of electrodes in the form of powders, flux paper or flux board with binder additives (3–8 % of liquid glass). Investigations of ESW conditions showed that at a narrow gap and large cross-section of the stationary electrode, the area of existence of the stable process becomes narrower and shifts towards lower stresses in the slag pool (for the canonic method U_w = = 52–40 V; for this method U_w = 40–25 V). The effectiveness of using the new method will be ensured by applying for stationary electrodes the power sources with program control of the main parameters of the welding mode (U_w, I_w, P_w) within the specified limits, both in the manual and in the automatic cycle. This ensures reduction of the amount of deposited metal; satisfactory conditions for weld formation at smaller E_w. There is a change in the distribution of thermal energy across the thickness of the edges being welded, in the technological capabilities of producing the welded joints, including those from dissimilar materials, in repair operations on restoration in large-sized parts in heavy engineering.

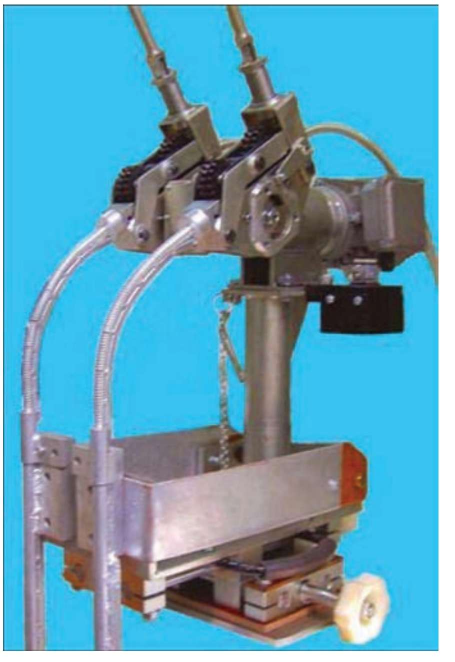

Figure 3. Portable two-electrode AShP 113M machine for ESW with consumable nozzle of 40–120 mm thick metal

ESW by wire electrodes and consumable nozzle is widely applied for joining metals of 30–100 mm thickness [25, 26]. PJSC NKMZ together with PWI created a unique installation for ESW CN (Figure 4) of metal, the welded cross-section of which can reach the dimensions of 4000×6000 mm [9]. The machine was brought into operation in 2002. The production section, where

Figure 4. Appearance of an installation for ESW with consumable nozzle for joining metal, the cross-section of which can reach the dimensions of 4000×6000 mm. (G.Z. Voloshkevich Section of ESW of thick metal at PJSC «NKMZ», Kramatorsk)

the machine operates, was named after G.Z. Voloshkevich, who made the most significant contribution into ESW creation, development and introduction. Over the last almost twenty years the installation welded unique metal structures [27] of rolling mill bed plates, and other heavy engineering equipment (Figure 5).

Electroslag welding process abroad. In major Russian enterprises the scope of ESW application for manufacture of traditional products has markedly decreased by now. Increase of this process application for repair purposes, as well as for joining oversized parts of a large thickness in site is noted. The range of products, restored using electroslag surfacing (ESS) has changed [28]. Known are examples of revival of ESW sections in mechanical engineering plants. For instance, in 2016, the market demand for drums for modular power boilers and pressure vessels (cylinders) increased. In 2017, an installation based on A-535 machine for ESW of circular welds of drums was restored at LLC «Sibenergomash-BKZ» [29]. It allows making welds of up to 2000 mm diameter with up to 150 mm wall thickness. ESW of the drum of BKZ-160-100 GM boiler of the capacity of 160 t of steam per hour was performed, and work on manufacture of the drum for E-550-13.8-560 KT boiler and pressure vessels (cylinders of hydraulic type BG-10000/32) is conducted. Technology of ESW of vessels is successfully applied instead of multilayer automatic submerged-arc welding.

Figure 5. Welded billet of the hydraulic press beam. Billet weight is 150 t, cross-section of a weld (shown by an arrow) made by ESW with consumable nozzle, is 2490×3860 mm

In 2016 ESW was applied to manufacture an oxygen converter of the capacity of 320 t of liquid metal for JSC «EVRAZ-ZSMK» for the first time in Russia and in the South-Ural Machine Building Plant [30]. Advanced technology of ESW of thick metal was mastered. A-535 machines are used to make rectilinear butt joints of 40–160 mm thickness, and curvilinear position welds of 40–160 mm thickness are made using ASh-115M2 machines, developed at PWI [8].

JSC «Atommash» uses the technology of electroslag surfacing by strip electrode, allowing a significant reduction of the time for surfacing operations. Welds of up to 10000 mm length and up to 300 mm thickness are made in ESW installation, including those for manufacturing thick-walled spherical bottoms. Investigations are performed in order to improve the quality of NPP products from pure 10GN2MFA and 15Kh2NMFA steels with application of ESW [31].

JSC «Tyazhmash», OJSC «Uralmash» and OJSC «Penzkhimmash» operate installations, using A-535 machines for ESW of circular and rectilinear butt joints of up to 350 mm thickness. At OJSC «Tyazhmekhpress» the bed tables of hot stamping presses with nominal force of 153 MN of 240 t weight are made from cast parts using ESW CN of up to 400 mm thicknesses [32]. At OJSC «Uralkhimmash» ESW with strip electrode of 60 mm width was mastered and applied for the first time in manufacture of the bottom and casing shells of the equipment. Application of this method allowed significantly reducing the labour intensity due to the fact that surfacing was performed without the transition zone in one layer. Application of this process allowed reducing welding material consumption and improving the processed surface quality. OJSC «Baltiysky Zavod», as a result of joint work with PWI, mastered ESW of panels of 4000×9000 mm up to 7000×9000 mm size from 08Kh18N10T steel of 40–50 mm thickness, using AD-381Sh machine in construction of tanks for metal-water protection. At OJSC «Volgotsemmash» three ESW shop sections, based on A-645, A-535 and A-433R machines are in operation, where welding of jaw crusher frames, cement kiln bands, band shells, mill covers, etc. of 45 to 1200 mm thickness is performed [33]. LLC «Pneumatic conveying equipment Plant», together with LLC «Remax» use precision ESW of bands of rotary cement kilns and metallurgical furnaces directly at customer enterprise. Longitudinal butt joints of metal shells of 60 to 120 mm thickness are made, as well as repair of service cracks by multipass ESW in cement kiln bands without their dismantling [34].

The mechanical-repair plants of Bratsk TIC, OJSC «Severvostokzoloto» and OJSC «Yakutskugol», together with PWI, set up reconditioning sections with application of ESS of worn helical gears of Swedish debarking drums, combs of lugs of Komatsu caterpillar tractors and platform swing drive gear of Japanese excavators Marion-204. Setting up the repair sections allowed reducing import purchases of wearing parts.

Portal «naplavit.rf» demonstrates electroslag surfacing (ESS) in the current-conducting sectioned mold of stamps, punches, working ends of mandrels of a piercing mill and other products of up to 100 mm diameter. The installation for ESS of flat surfaces of products in the horizontal position allows forming a thin (from 3 mm) and wide (up to 55 mm) layer of deposited metal at minimum (from 1 mm) and uniform penetration depth [35].

A stable growth of the scope of ESW and ESS investigations and application in different industries is observed in Western countries.

In the USA the method of narrow-gap consumable nozzle ESW was used to make twenty welds in the support tower of San-Francisco-Oakland bridge under construction [36]. The length of each single-pass weld was 10 m, butt thickness was 100 and 60 mm. Five types of edge preparation were used. ESW technology (equipment and training) was provided by Electroslag Systems (EST & D), Portland, Oregon within the framework of cooperation with the University of Portland and American Bridge Company. Welding was followed by ultrasonic and X-ray inspection of welded joints. The total time of welding all the butt joints was two months. ESW application allowed a significant reduction of the time and labour intensity of welding operations, as proceeding from preliminary calculations, the total time of welding the butt joints with the arc method was six months. Ultrasonic testing of quality of 200 m of welds was repeated in 2013.

According to the materials of a review paper [37], the latest modification of narrow-gap ESW (ESW-NG) has currently being recognized by AASHTO in the USA to be suitable for welding regular types of bridge steels and was included into the bridge welding code (AWS D1.5: 2010 c). Work is in progress on inclusion of ESW-NG welding into AWS D1.8 Structural Welding Code — Seismic Supplement. It is shown that the process of narrow-gap ESW is stable both at direct and at square sine wave alternating current. Linde Union Carbide Division and Hobart Brothers Company patented two designs of the consumable nozzles and method of ESW with oscillating consumable nozzle. Flat plates of the consumable nozzles, having a channel for welding wire passage, which replaced the round cross-section nozzles, allowed reducing the gap from 32 to 19 mm. ESW-NG method is designed for application during mounting at the site of construction of the steel structure. It is particularly acceptable for welding W-shaped extended heavy flanges, with 45 to 50 deg. deviation from the vertical. Welding a heavy column with application of submerged-arc welding takes 30 h or more. For comparison, it takes about 30 min. to weld both the flanges of any thickness, using ESW-NG. Thus, the authors of review [37] summarize the following. ESW is no longer considered as the only variant for joining thick plates in the shop. It can be used and be cost-effective in site, in welding stiffeners and support plates to steel section flanges, as well as in joining the diaphragms to inner walls of box-type columns. Modern achievements in ESW field, implemented in ESW-NG, are used in the construction sites of large high-rise buildings and in bridge construction. ESW-NG has established itself as the most cost-effective method for many joints, including large thickness welds in steel bridges and buildings.

Arcmatic Welding Systems Company (USA) specializes in modular systems with computer program control of the welding process, specially developed for ESW of thick plates [38]. Portable systems are proposed for consumable nozzle ESW with manual control of the console, which carries the ducts for electrode wire feeding, power cables and hoses for cooling water supply. Installations based on a two-position manipulator are also used, providing its fast (5 min) readjustment from the arc welding method to ESW of metal of up to 300 mm thickness. The above equipment is proposed for fabrication of wind towers, off-shore platforms, heavy pressure vessels, beams and columns from structural steel, bridge beams and other structures. These installations are becoming the most widely accepted in ESW CN of construction column diaphragms.

Transportation Research Board (TRB) of the National Academy of Sciences of the USA conducted studies on welding the railway rails using ESW. Comparison and analysis with ESW showed that thermit welding of rails is a less capital intensive, less expensive, more portable process, but the weld quality is poor. Average cost of making thermit welds is 350 USD for each butt joint. Joints produced by other welding processes are more costly, of the order of 500 USD each. Flash-butt welding is highly capital intensive and, therefore, costly, requires application of trains for transportation of rail-welding machines. It is anticipated that ESW will take a position between the two above-mentioned processes, and will be comparable with them as to quality and cost (about 250 USD).

Typical areas of application of electroslag welding in Japan in the XX century, included the following objects: joining large castings, stiffeners of the upper deck of ships, longitudinal welds in cylindrical pressure vessels, housings of blast and oxygen furnaces. However, the low impact toughness of metal of the weld HAZ was the greatest obstacle to wider introduction of ESW in Japan. Studies were performed to increase the impact toughness of HAZ metal [39, 40] due to application of steel, insensitive to grain growth in the HAZ, with the purpose of expanding the range of products manufactured using ESW, [15, 16]. In order to increase the scope of application of ESW of steels with ultimate tensile strength of 490–590 MPa, Nippon Steel Corporation developed a new technology of improving the impact toughness of HAZ metal, which is called Super High HAZ Toughness Technology with fine microstructure (HTUFF®). With this technology, thermally stable oxides and sulphides, containing Mg and Ca, are dispersed in the steel in the form of fine particles, and growth of γ-grains in the HAZ metal near the welded joint line is significantly delayed by the fine particles, which results in manifestation of the effect of grain refinement and in achieving ≥ 70 J Charpy impact toughness in the HAZ metal at 0 °C. In keeping with the developed technology, metal of 60 and 80 mm thickness, is widely used in fabrication of shelf structures, pipes, buildings and in civil engineering, with ESW application. Total mass of steel used for ESW was about 280 000 t [16]. From the beginning of the XXI century, production of large sea container ships, in which the loading hatches had to be made from steel sheets of 70 to 100 mm thickness, has markedly increased in Japanese shipbuilding [41]. TMCP technology of steel production was developed, which includes controlled rolling and heat treatment in A_{c1}–A_{c3} temperature range, in order to perform single-pass welding of steel of such thickness using welding processes with a high heat input (arc welding with forced formation and ESW). This technology allows markedly increasing the strength and impact toughness by grain refining with formation of bainite or martensite with addition of microalloying elements, such as titanium and niobium. High-strength steels with the yield point of 390 and 460 N/mm^2 have been developed, in ESW of which formation of a coarse structure in the HAZ metal is excluded. Steels developed with application of TMCP and HTUFF technologies are applied in production of tankers, cargo ships, ships for liquefied petroleum and natural gas transportation that allowed lowering the ship weight and increasing the transportation effectiveness.

Over the recent years the process of ESW of aluminium busbars was developed [42] in Canada. CANMEC Company (Quebec Province) purchased Linde Company developments on application of ESW technology for welding 50 mm aluminium. For welding busbars of 275 mm thickness, CANMEC Company together with CQRDA (Quebec Center for Research and Development of Aluminium) and National Research Council of Canada (NRC) developed new machines, capable of feeding three- … five-electrode wires and ESW technology. New technology was applied in construction of an aluminium plant (346 000 t/y) in Iceland. Aluminium busbars were welded by ESW 4 times faster, compared to the traditional welding method (arc method of «chequered plate»). The welds ensured the high quality of the welded joints, electric conductivity of busbars in the weld zone was increased at least by 20 %. Electric losses were lowered due to complete penetration of the edges.

Chinese companies offer machines and units of console and gantry types for ESW with wire electrodes and consumable nozzle, as well as HJ431 flux [43]. The above equipment is designed for ESW of housing covers of construction beams and transverse partitions of columns. Thickness of welded butts is mainly equal to 16–65 mm. Research group of the Academy of Construction of the Hunan Province performed extensive analysis of weldability of high-strength R-bars HRB400, both theoretically and experimentally. ESW of R-bars from strengthened steel of 20MnSiV grade is applied [44]. Kingarc Autopweld Company, Taiwan demonstrates a simplified machine for consumable tubular nozzle ESW of construction column diaphragms.

In Turkey the paper on «Electroslag Welding Process and Its Application» was published, where the history of ESW creation and development in industrialized countries was described [45]. Turkish experience of ESW application and prospects for its application in the future are also described there. ESW is currently used for welding of circular butt joints of presses, furnaces, engine housings, wheels for asphalt machines. Butt joints of ship plates and castings of parts of 13 – 400 mm thickness are welded in chemical, petroleum, marine and power plants. Examples of application of ESW of low-alloyed carbon steels are given, namely, pressure vessels, tank cars, boilers, compressors, bridges, tankers with double-hull. In Turkey ESW is used as the welding process, providing more effective results, compared to the traditional methods. The most often used electrode wire diameters are 2.4 and 3.2 mm. In addition, wires of 1.6 up to 4.0 mm diameter are also successfully applied. Electrode wire reels of two types are used: small ones for winding 27 kg and large ones for 270 kg of wire. It is planned to apply ESW for manufacturing nuclear reactors, construction of industrial buildings, double-wall fuel tanks and other structures.

In Italy ESW by three wire electrodes is used for joining low-carbon steel plates of 25 to 300 mm thickness in the vertical or close to vertical position [46].

Voestalpine Boehler Welding Company, Austria, proposes equipment, technology and welding consumables for electroslag cladding (ESSC) with strip electrode 15–120 mm wide [47]. Advantages of this process are shown, compared with submerged-arc cladding with strip electrode for instance, ESS deposition rate is up to 23 kg/h, and that of electric arc cladding is not more than 14 kg/h. Deposited metal dilution by base metal does not exceed 7 %. In electric arc cladding it reaches 18 %. It is noted that an ideally smooth outer surface of the deposited metal and sound overlapping of the layers are ensured owing to electromagnetic control of the process of deposited metal formation, in ESS with strip. Examples of ESS with strip electrode of unalloyed, low-alloyed, martensitic, and stainless steels, nickel alloys, as well as cobalt and copper alloys, are given. In the oil and gas industry ESS with strip electrode is applied for deposition of anticorrosion coatings of a large area in such equipment as pressure vessels, separator vessels and high pressure separators. Electroslag facing is also widely used for cladding the inner surface of pipes, and valves for oil and gas transportation. In chemical and pulp and paper industry this process has found application in equipment, exposed to corrosive media, high pressures and temperatures. This process is the most efficiently applied for anticorrosion cladding of vessels, tanks, valves, pumps, compressors, drums for production of paper, mixers, etc. In power industry, ESS with strip electrode is applied for facing the internal surfaces of reactor vessels, steam generators, etc. In Belgium, Germany [48], India [49] and Poland [50] the process of ESS with strip electrode became accepted in similar industries instead of flame surfacing and submerged-arc strip cladding. ESAB (Sweden) applies ESS with strip electrode (60–90 mm width, 0.5 mm thickness) for anticorrosion cladding of carbon steel with 316L or 347 steels [51]. ESS of stainless and nickel layers is applied for repair of corroded equipment and improvement of corrosion properties of the new structures. In Norway ESS with strip electrode is applied for facing the inner surfaces of CLAD metallurgical pipes of up to 254 mm diameter and up to 12.5 m length. Typical dimensions of strip electrodes from Inconel 625, 825, 316 alloys, are 15/20/30×0.5 mm. Surfacing deposition rate is 12 to 24 kg/h, depending on the strip size.

In Estonia, a section for reconditioning worn teeth of large-modular gear shafts of the drive of rotation of the platform of stepping excavators ESh 15/90 and ESh 10/70, using ESS, was set up on the base of «Estonslanets» Concern, as a result of joint work with PWI. Gear shafts reconditioned without subsequent machining of involute profile, are successfully operating in Narvsky and Aidu open-pit mines.

Conclusions

1. Over the past period from the beginning of XXI century, the scope of ESW application in manufacture and repair of products of greater than 100 mm thickness has markedly decreased both in Ukraine and abroad. Nonetheless, a stable growth of the scope of its application for joining 30 to 100 mm thick metal is noted over the recent years.

2. A range of new welding equipment was designed, featuring a high reliability of ESW performance, and ensuring continuous monitoring and certification of the main mode parameters. New technologies have been developed, which allowed widening the range of products, manufactured with ESW and ESS application. Recently, the methods of ESW with tubular consumable nozzle (diaphragms, stiffeners, reinforcement and other elements of construction columns, bridges) became the most widely accepted, as well as methods of ESS with electrode strip and consumable nozzle (deposition of protective coatings, reconditioning worn parts of machines, etc.).

3. The following is expected in the next 5 to 10 years: widening of the scopes of ESW with wire electrode, as well as with tubular consumable nozzle in a narrow gap in fabrication of large-sized structures (primarily, construction) from metal with lower sensitivity to HAZ overheating in the shop and site conditions; producing large cast-welded, rolled-welded and forge-welded billets for heavy engineering with up to 4000×6000 mm cross-sectional dimensions, which can be realized by the technology of consumable nozzle ESW, applied with success at PJSC «NKMZ»; expansion of the fields of application of the process of ESS with strip electrode for deposition of anticorrosion coatings of a large area for pressure vessels and separators, tanks, valves, pumps, compressors, steam generators, pipes, operated in oil, gas, power, chemical and other industries; increase of the scope of application of the technologies of reconditioning repair of metal structures and rapidly wearing parts of machines, based on application of ESW with wire electrodes, multipass ESW and new methods of ESS.

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