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APPLICATION OF ELECTROSLAG WELDING IN CONSTRUCTION

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The paper presents the results of experimental studies and engineering developments, which were the base for creating a technology and technique of performance of electroslag welding with consumable nozzle of reinforcing elements of building columns of a high-rise building. Experience of application of the developed technology in construction of a high-rise building is described. New machines and special technological fixture at performance of welding operations under assembly conditions was demonstrated. 15 Ref., 7 Figures.

Keywords: *building columns, girths, reinforcing elements, electroslag welding, consumable nozzle, special technological fixture, assembly conditions, efficiency of welding operations*

One of the specific features of application of welding processes in construction is strict compliance of the terms of welding operations performance with the terms of construction and mounting work. Special requirements are made of welding technologies to ensure simultaneous performance of this work, namely high process efficiency, mobility, higher reliability of welding equipment and its insensitivity to unfavourable (field) conditions of operation, low labour consumption, minimum time consumed by assembly-preparatory operations.

In recent years, a significant growth in the construction of high-rise administrative buildings necessitated application of rolled metal of increased thickness (60 mm and greater) by design institutes for manufacturing all-welded bearing columns. At present the girths of building columns and reinforcing elements of their opening frames are joined by coated-electrode manual or mechanized welding with solid or flux-cored wire, i.e. the methods, which are characterized by high labour consumption and low efficiency for the above thicknesses that significantly prolongs the terms of construction and mounting work.

At the initial stage of construction of basement flooring at erection of high-rise «Community Center» experimental building (Kiev) it became necessary to significantly increase the welding operations efficiency. It was proposed to replace coated-electrode arc welding by electroslag welding, as the most productive method of joining metals of unlimited thickness [1] that was the objective of this work.

Electroslag welding (ESW) was applied for the first time in the USSR at construction of blast furnace jackets, mounting of metal structures of industrial buildings, large-capacity converters, processing apparatuses for alumina plants, massive water conduits, etc. [1].

Also known is the experience of successful application of ESW in the USA and Japan in fabrication of massive building structures for administrative buildings [2–6]. ESW was applied for making longitudinal butt joints of T- and I-beams in fabrication of heavy building columns [3], as well as joining corner columns with support plates and diagonal braces [5]. Here, the method of consumable-nozzle ESW (CNESW) became the most widely accepted for fabrication of all-welded columns for steel frames of 52–59-storey buildings due to the possibility to weld elements of different thickness from 44 to 73 mm [7]. At present CNESW is widely applied in these countries for joining inner diaphragms 40–150 mm thick to girths of building columns of a rectangular profile [8, 9] at their fabrication under production conditions.

According to Production Project the design of the building columns of 54-storey «Community Center» experimental building under construction resembles the shape of the Maltese cross in its cross-section (Figure 1). It was necessary to weld reinforcing elements *2* (90 mm thickness, 800–1450 mm length) to the opening frames located between the end faces of girths *1* with the purpose of subsequent erection of basement flooring on their base. Column girths were made from new structural steel 06GB-390 (TU U 27.1-05416923-085–2006) 50 mm thick, and reinforcing elements of their opening frames were from steel 09G2S-15 (GOST 19281–89). A feature of steel 06GB is its good weldability, high delayed and cold cracking resistance, compared to the known grades of low-carbon steels of this strength class [10].

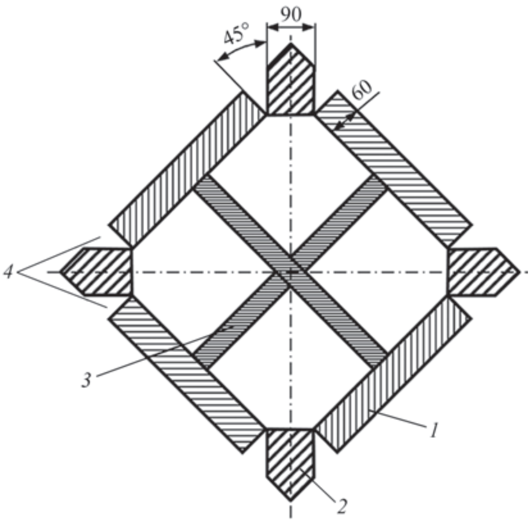

Figure 1. Scheme of butt assembly for welding the reinforcing elements of girths of a building column of Maltese cross type: *1* — cross-section of column girth; *2* — column reinforcing element; *3* — stiffener; *4* — butt welded joint

According to project documentation, a V-shaped groove was specified in the points of welding the reinforcing elements to building column girths, which is designed for performance of multipass electric arc welding in the vertical position (of the order of 300 passes). For application of single-pass CNESW it was necessary to develop a special technology and technique of joining the reinforcing elements to the column.

In connection with the non-standard groove shape, adverse working conditions in the underground space (high humidity, abrasive and cement dust), as well as complexity of formation of the reverse side of the butt joint, the following problems had to be solved to reach the defined goal:

- develop the technology and technique of ESW performance, ensuring guaranteed fusion of filler metal with base metal, sound formation of weld metal and absence of defects;
- develop and manufacture portable welding machines of higher reliability, where the control systems are protected from possible penetration of moisture and dust, that is characteristic for operation in site conditions. Machine design should provide their fast mounting on the item, as well as dismantling;
- develop special devices for quick mounting of welding machines on building columns;
- develop technological fixture, ensuring sound formation of outer and reverse sides of the electroslag weld, as well as devices for its fast mounting and dismantling, particularly in difficult-of-access sections.

To solve the defined tasks we have conducted design work and experimental studies. CNESW parameters were optimized on full-scale samples, made from the above-mentioned steels, using a DC power source. Sv-08G2S electrode wire and AN-8U welding flux were used as welding consumables. Welding speed was 1.6–2 m/h to reduce the heat input.

Transverse templates were cut out of the welded samples to determine the mechanical properties and chemical composition of welded joints. Microhardness measurements were performed by contact-resonance hardness meter TKR-35. Transverse macrosection of welded joints, scheme and results of hardness measurements are shown in Figure 2, from which one can see that hardness distribution in the studied sections is characteristic for ES welds of analogous steels, not subjected to subsequent heat treatment. Here, considering the sequential performance of adjacent welds, as well as close location of welded-up grooves, one can see from Figure 2, *b* that the heat, evolved when making the second weld, produced partial auto-heat treatment of metal of the previous weld and part of the heat-affected zone (HAZ).

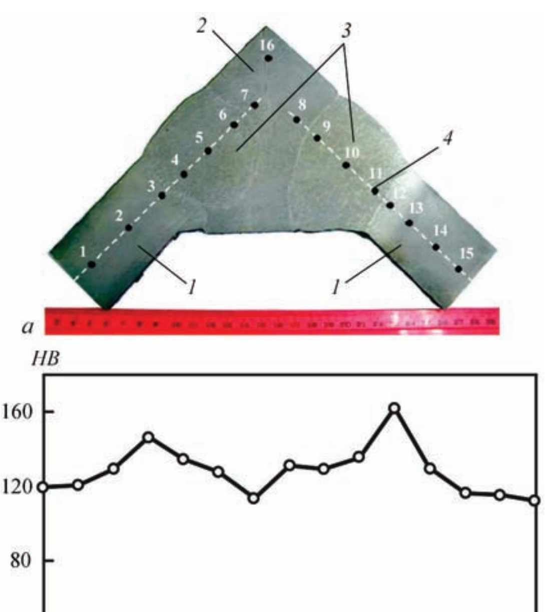

Figure 2. Transverse macrosection, scheme (*a*) and results of measurement of welded joint metal hardness (*b*): *1* — column girths; *2* — reinforcing element; *3* — electroslag welds; *4* — measurement points

Visual inspection of welded samples after CNESW of V-shaped butt joints is indicative of satisfactory formation of weld surface. Welds are tight, without slag inclusions, pores, lacks-of-fusion or cracks.

Figure 3 shows the results of determination of chemical composition of metal of a column girth, reinforcing element, welding wire and weld, from which it follows that the weld metal composition differs only slightly from that of the steels being welded, and low content of carbon and increased content of manganese in the weld metal ensure a high level of technological strength of the welded joint.

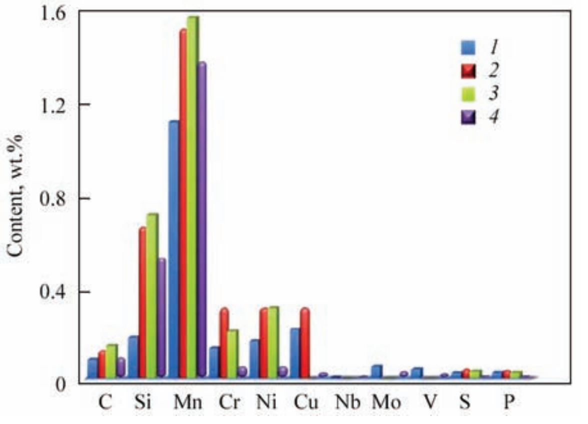

Figure 3. Chemical composition of the metal of girths reinforcing elements, electrode wire and weld: *1* — 06GB; *2* — 09G2S steel; *3* — Sv-08G2S; *4* — weld

Values of mechanical strength of welded joint metal were determined from the side of column girth. Tensile tests of samples showed that ultimate strength value σ_t for metal along the fusion line and in the HAZ at 5 mm distance from the fusion line is equal to σ_t = 466–480 MPa, that is indicative of a sufficient level of welded joint strength at ESW of steels 06GB and 09G2S. Values of impact toughness after testing at the temperature of 20 °C in the as-welded condition for metal along the fusion line and in the HAZ

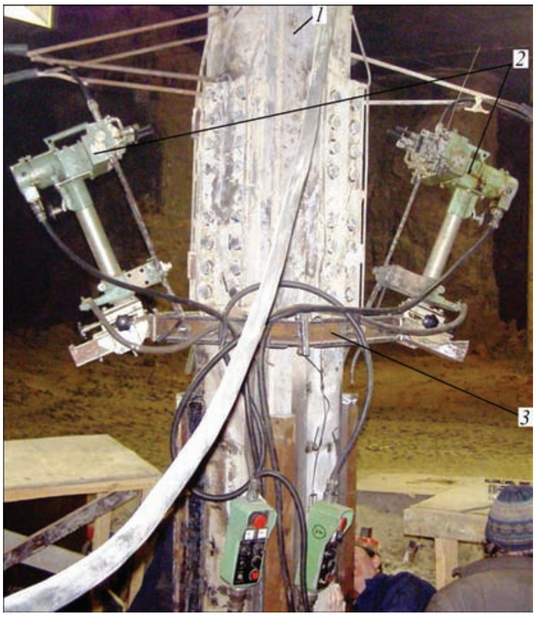

Figure 4. Fastening A-1304 machines on a building column: *1* — column; *2* — welding machines; *3* — quick-detachable frame

at 5 mm distance from the fusion line are equal to *KCU* = 108–155 J/cm^2.

Analysis of the given results of CNESW of butt joints, earlier to be joined by electric arc welding, as well as positive experience of operation at above zero ambient temperatures of welded structures, not sub-

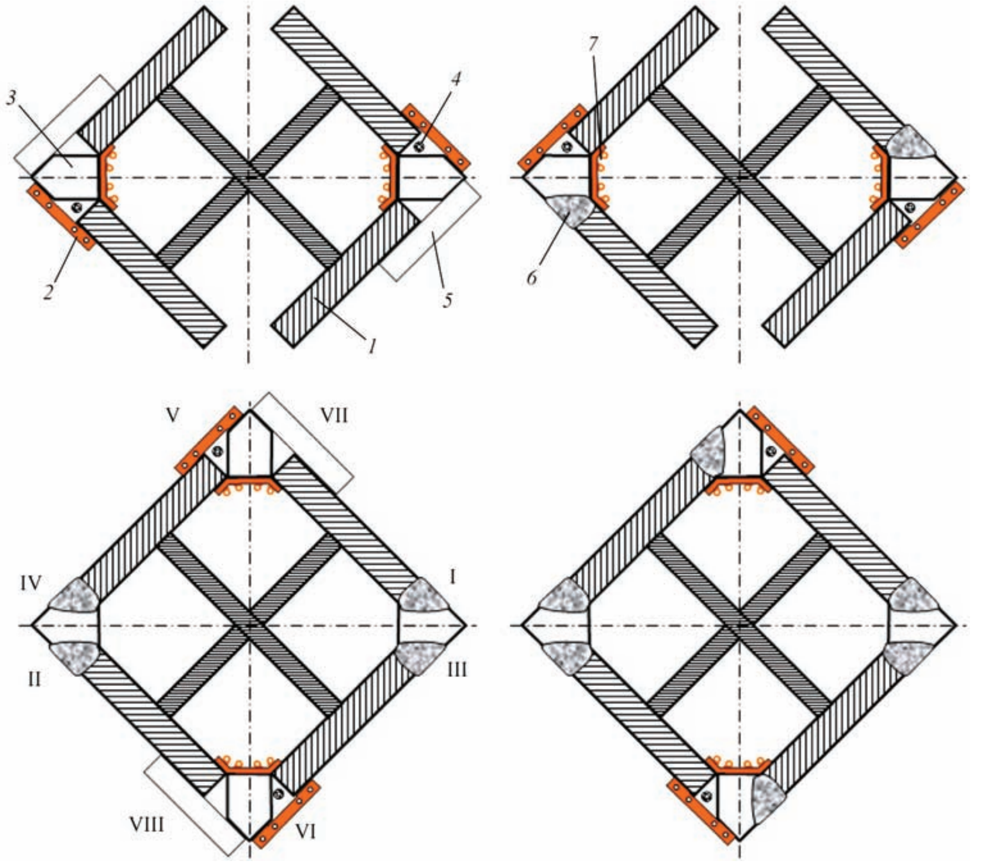

Figure 5. Sequence of assembly and consumable-nozzle electroslag welding of reinforcements of building column opening frames: *1* — column girth; *2* — water-cooled coverplate; *3* — reinforcing element; *4* — consumable nozzle; *5* — technological tab; *6* — weld; *7* — forming coverplate on the reverse side of butt joint; I—VIII is the weld stacking sequence

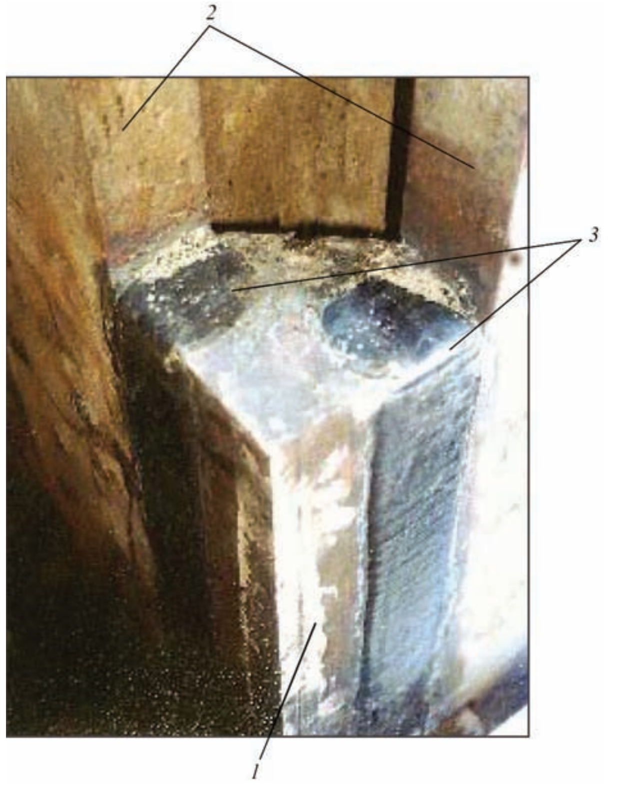

Figure 6. Appearance of electroslag welds after welding-up the shrinkage cavity on their linear part: *1* — reinforcing element; *2* — building column girths; *3* — welds

jected to postweld heat treatment [11], are indicative of technical possibility and rationality of its application for welding the reinforcing elements of opening frames of columns of Maltese cross type.

Considering the short construction time, at the first stage it was proposed to adapt for CNESW batch-produced A-1304UKhLCh welding machines for their application under specific conditions of construction work performance in underground premises. A special quick-detachable frame (Figure 4) was developed and manufactured for fastening the machines on the columns. It allows quickly mounting and dismantling the systems after welding the butt joints.

Reliable containment of the slag and metal pools in the gap is provided by copper water-cooled devices from the outer and reverse sides of the welded butt joint [1]. Nonstandard shape and dimensions of the groove, as well as difficult access for servicing the reverse side of the butt joint (Figure 1), required application of forming devices of a special design. Customized technological fixture was developed and manufactured to ensure sound fusion of filler metal with base metal and satisfactory weld formation, namely water-cooled forming devices and fixtures for their quick fastening on the item being welded [12, 13].

In order to lower the level of residual welding stresses, welding of eight butt joints on each column was performed with simultaneous application of two welding machines and with specific stacking order of welds at higher welding speeds (Figure 5).

Figure 7. Fragment of consumable-nozzle electroslag welding of reinforcements of opening frames of building columns using AShP 113M2 machines (*a*) and appearance of welds (*b*)

Considering the prohibition for oxy-fuel cutting application at construction of the above building, as well as to reduce the welding time and save welding consumables, a technological measure was implemented, resulting in maximum reduction of the size of the crop parts of welds by welding-up the shrinkage cavity on the welded butt joint linear part (Figure 6).

After transfer of the developed technology to Ukritarm Company (Kiev) and training its personnel in the technique of CNESW performance, the latter performed welding of reinforcing elements of opening frames on eight columns (64 butt joints) in construction of the flooring of the first basement storey. However, during performance of the above work, some problems were encountered in operation of A-1304 machines. A large weight of the machines greatly increased the labor consumption and time for assembly-preparatory operations. The electric components of the machines failed periodically, because of the high humidity and dustiness of the locations of welding operations performance. To solve the above problems, PWI developed portable AShP 113M2 machines for CNESW with two electrode wires in site, which is devoid of the above drawbacks [14]. Two pilot-production AShP 113M2 machines were manufactured and transferred to the customer for welding operations performance in the object under construction. New machines were used to successfully weld more than 1500 butt joints (more than 1250 run. m of welds) in construction of eight basement storeys (Figure 7) [15][*]. Ultrasonic testing of welded joints did not reveal any defects in the form of cracks, pores, lacks-of-fusion, etc.

Conclusions

1. Technology and technique for performance of CNESW of reinforcing elements of building columns opening frames were developed, which provide guaranteed fusion of filler metal with base metal, sound formation of weld metal and absence of any defects. Labour consumption of assembly-preparatory and welding operations was essentially reduced, process efficiency was increased by more than 20 times, compared to coated-electrode manual welding, and production standards were improved.

2. Application of new portable AShP 113M2 machines ensured their trouble-free operation under the conditions of high humidity and presence of cement dust during the entire cycle of welding operations.

3. Application of developed special technological fixture ensured reliable containment of slag and metal pools in the welding gap, also in difficult-of-access sections, and allowed an essential reduction of labour consumption of assembly-preparatory operations.

4. New technology and equipment can be recommended for welding in site of massive building columns, thick-walled tanks and other metal structures, operating at positive ambient temperatures.

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