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ELECTROSLAG TECHNOLOGIES FOR REPAIR OF THROUGH-THICKNESS CRACKS IN THICK PARTS

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ABSTRACT

Results of investigations are presented, which were performed in order to develop a highly-productive technology for repair of through-thickness cracks in thick parts in their operation site. The aim of the work is to study and establish the main principles of a high-efficient technology of repairing defects of the type of through-thickness cracks in thick parts in their operation site by the method of consumable nozzle multipass electroslag welding. The main tasks of the study were selection of principal diagram of electroslag welding, development of a procedure for calculation of geometrical parameters of edge preparation, that the most fully meet the conditions for formation of sound metal of the welded joint in a wide gap, development of basic principles of the technique of making welds and creation of routing technology of repair. Performed studies were the base for development of decision taking algorithms and general principles of the technology for repair of large-sized parts of unique equipment in its operation site, using the proposed method. Technological recommendations for repair of through-thickness cracks in such parts are based on the following postulates, elaborated proceeding from the features of the proposed method: domain of rational values of welding specific energy, providing sound weld formation, techniques allowing hot crack prevention in the weld central parts, conditions of minimizing the welding stresses when welding rigid joints, conditions of controlling the weld chemical composition that provide reduction of the fraction of base metal participation in weld formation, and lowering of harmful impurities level in it, and recommendations on selection of electrode and auxiliary materials, etc. Technological recommendations were successfully tried out in six cement works at repair of through-thickness cracks in rotary kiln tires.

KEY WORDS: multipass electroslag welding, consumable nozzle, through-thickness cracks, repair, specific heat input, hot cracks, welding voltages, decision taking algorithm, technology recommendations

Restoration of worn-out or fractured parts of machines is an environmentally friendly and resource-saving production [1]. The main task of repair production is the effective restoration of reliability of machines as a result of the most optimum use of residual life of their parts.

In the cost of repaired machines, the share of spare parts amounts to about 70 % [2]. Since the cost of parts restoration amounts to 50–60 % of the cost of their manufacture, an increase in the volumes of parts restoration is a real way to reduce the cost of repairing machines and units. 5–6 times reduction in the number of operations during restoration as compared to manufacturing and 20–30 times shortening in the cost of materials provides the prime cost of parts restoration, making 40–80 % of the cost of new ones. The production practice shows that scientifically substantiated technology and organization of defective parts restoration allow providing the service life of restored parts, which is close to the service life of new ones, equal to it, and in some cases even exceeds it [1–3].

Repair technologies with the use of welding processes are fundamentally different from those used in serial production of welded structures, mainly in the difficulty of creating universal technological recommendations. This is caused by the fact that defects to be eliminated, as a rule, differ significantly in nature, shape and sizes and it leads to the formation of non-standard large welding gaps, as well as atypical shape of edges preparation as a result of removal of defective metal. Therefore, each case of repair requires the development or specification of certain modes of welding, especially the technique of its realization. Before offering the technology of repair, it is necessary to carefully analyze the causes of failure of a part, evaluate technological characteristics of the whole part and especially the fatigue strength [1–3].

When correcting most unique parts, the specific conditions for repair works include: large cross-sections of parts, wide gaps, high rigidity of assembly, impossibility of dismantling of a repaired part as well as mechanical and high-temperature treatment, high carbon content and harmful impurities in cast steels of type 35L, etc. In addition, the repair of fractured parts of the equipment that is included into the production line with a continuous mode of operation should be carried out promptly to minimize losses of an enterprise from underproduction, which is also an urgent task. This requires the maximum possible structurization of tasks and creation of an algorithm for taking grounded technological decisions [4].

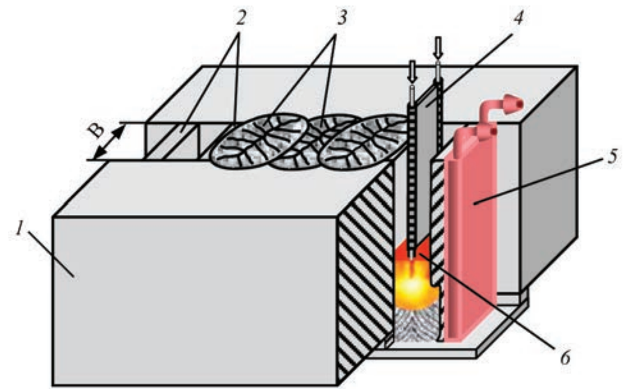

Figure 1. Scheme of the method of CNMEW of massive products with a large intersection of joining elements: *1* — welded part; *2* — forming partitions; *3* — welds; *4* — consumable nozzle; *5* — forming device cooled with water; *6* — slag pool; *B* — welding gap

The aim of the work is the research and development of basic principles of highly-efficient technological process of restoration of defects of the type of through-thickness cracks in parts of large thickness at the site of their operation applying the method of consumable nozzle multipass electroslag welding (CNMEW).

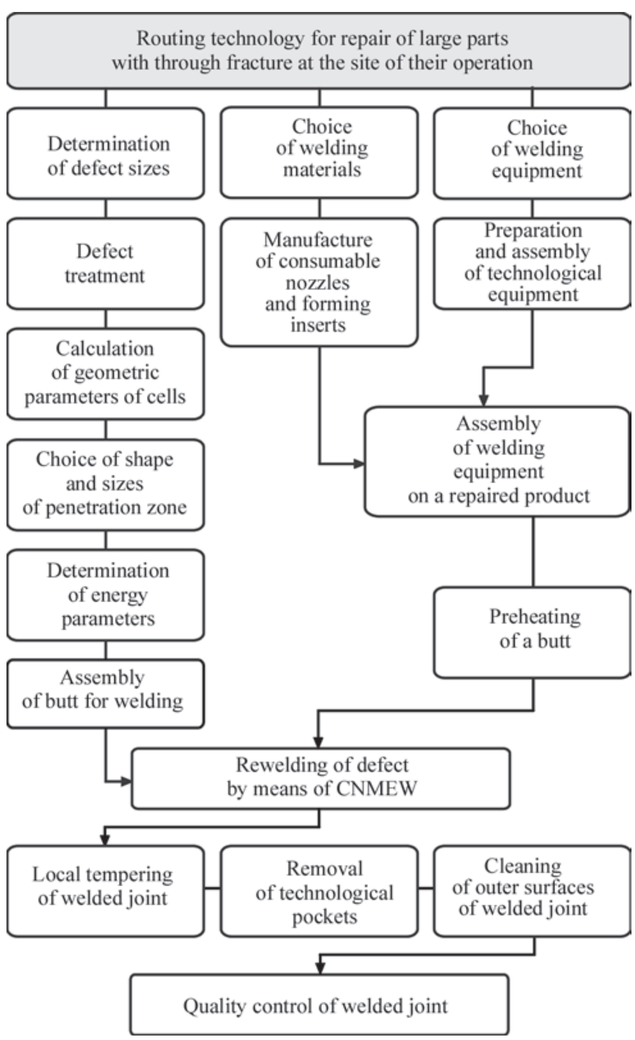

Figure 2. Algorithm for taking decisions during repair of through-thickness cracks in large steel parts of units at the site of their operation

The main tasks of the work are the choice of principal diagram of ESW, development of procedure for calculation of geometric parameters of edges preparation that most completely corresponds to the conditions for the formation of a sound welded joint metal in a wide gap, development of basic postulates of the technique of welds producing, as well as creation of routing repair technologies.

The known methods of repair of through-thickness cracks in parts of large thickness at the site of their operation using methods of welding differ in a low efficiency, hard working conditions of performers and do not always guarantee the satisfactory quality of welded joints [5, 6].

Analysis of the technical level of existing repair methods [6, 7] showed that restoration of large parts with defects of the type of through-thickness cracks is reasonable from technical and economical point of view, applying CNMEW method for joining the metal of large thickness (Figure 1) [8].

Based on the results of the carried out investigations, the algorithm for taking decisions (Figure 2) and general principles of the technology for repair of large parts of the unique equipment at the site of its operation using the proposed CNMEW method were elaborated.

Technological recommendations for repair of through-thickness cracks in such parts at the site of their operation are based on the following postulates elaborated in relation to the features of the proposed method. The main of them are:

- procedure of calculation of geometric parameters of cells and forming inserts depending on the width of a gap (60–120 mm), formed after removal of metal in the area of a crack and over the thickness of a part being repaired [9];
- domain of rational values of specific welding energy, providing a sound weld formation [10];
- technological techniques that provide prevention of hot cracks in the central parts of the welds [11];
- conditions for minimizing welding stresses during welding of rigid joints [12];
- conditions for regulating chemical composition of the weld, providing a decrease in the share of the base metal participation in the formation of a weld and a decrease in the level of harmful impurities in it [10];
- recommendations for choosing electrode and auxiliary materials, etc.

For successful realization of the technology of repairing through-thickness cracks on the site of defective

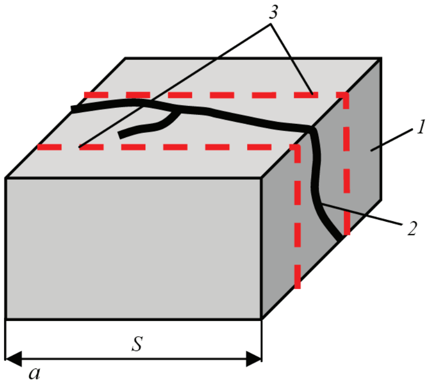

Figure 3. Scheme of layout (*a*) and removal of defective metal in the area of a through-thickness crack (*b*): *1* — part subjected to repair; *2* — through-thickness crack; *3* — plane of a cut; *B* — welding gap

parts operation using the proposed CNMEW method, it is necessary to carry out the following operations:

● determine sizes of the area of laying a through-thickness crack using visual inspection and with the help of a portable device for ultrasonic flaw detection, for example, UD2-12;

● remove a defective area with a crack by making two through parallel cuts of a product using oxyfuel cutting or by an oxygen lance (Figure 3, *a*). The distance between the planes of a cut is chosen in such a way as to cover the entire area of laying and branching of a crack;

● having measured the value of the formed gap *B* (Figure 3, *b*), choose the desired width of welded cells S_c from the domain of their technological ratios [9]. Determine the thickness of the forming inserts S_n from the expression $S_p = 0.04B + 34$, where *B* is the welding gap, mm;

● determine the required number of cells for rewelding of the formed opening from the expression

$$n = \frac{S - S_c}{S_c + S_p} + 1, \tag{1}$$

where *S* is the thickness of a welded butt (fractured part), mm; S_c is the width of the cell, mm; S_p is the thickness of the insert, mm;

● determine the distance between the axes of rewelded cells (step) *t* (Figure 4, *a*) from the expression [9]:

$$t = 2k\sqrt{\left[1 - \frac{B^2}{B^2 + 4h(B+h)}\right]\left(\frac{S_c}{2} + 0.577h + 13\right)^2}, \tag{2}$$

where $k = 0.85$–0.95; *B* is the gap; *h* is the depth of the base metal penetration.

● set the input and output technological pockets;

● make the layout of the butt in the places of mounting inserts *4* (Figure 4, *a*), which form an assembly to perform the first (central) pass. Install the water-cooled devices *3* to the outer surfaces of the inserts;

● choose the required penetration depth of the base metal and in accordance with the proposed procedure [10] determine the value of the specific heat energy of the process and expected sizes of welds in the cross-section;

● produce consumable nozzles *5* (Figure 4, *a*) and assemble the welding apparatuses of type AShP113M over the butt [13];

● calculate the time of rewelding a crack at a successive fulfilment of passes by a one welding apparatus from the expression:

$$t_w = \frac{H}{V_w} n + (n-1)t_p, \tag{3}$$

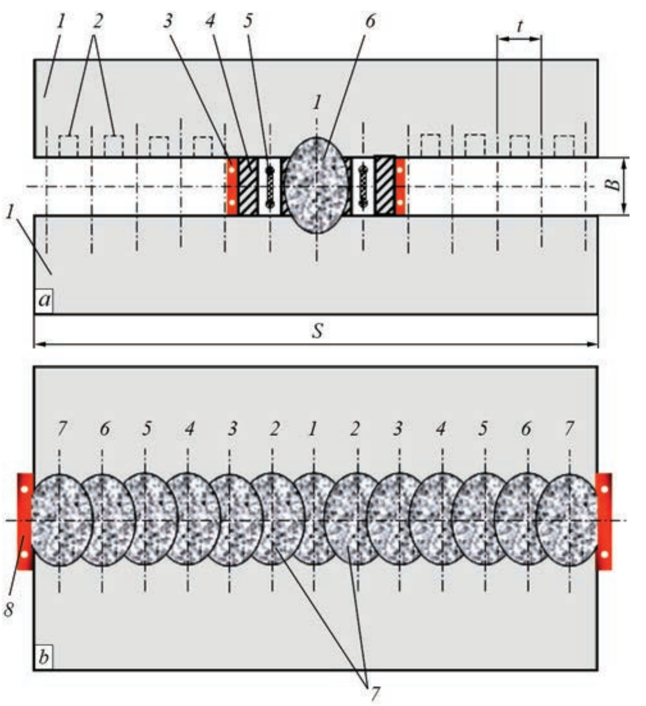

Figure 4. Scheme of butt layout, rewelding of central cell (*a*) and performance of adjacent passes by CNMEW (*b*): *1* — welded regions of defective part; *2* — places for mounting of forming inserts; *3*, *8* — water cooling device; *4* — insert; *5* — consumable nozzle; *6* — central weld; *7* — adjacent welds; *S* — thickness of part (length of through-thickness crack); *B* — gap; *t* — step of cells

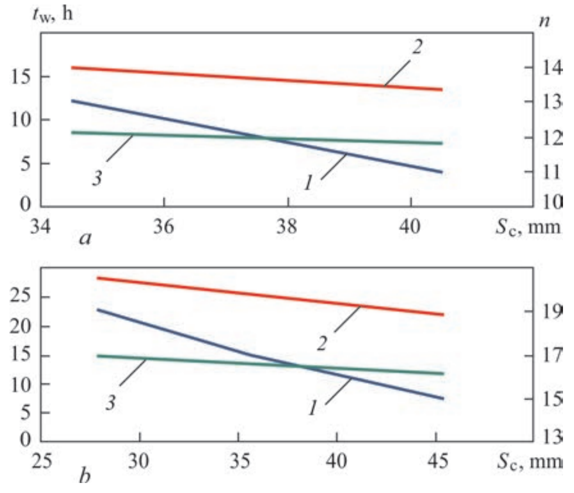

Figure 5. Change in the number of rewelded cells in the opening n and time of opening rewelding t_w, depending on the width of cells S_c: *a* — weldable intersection — 900×355 mm; *b* — 1200×475 mm; *1* — number of cells; *2* — rewelding of a cell successively one-by-one; *3* — welding simultaneously of two cells at a time

where *H* is the butt height (weld length), mm; v_w is the welding speed, m/h; *n* is the number of cells for opening rewelding; t_p is the pause time between the end of the preliminary rewelding and the start of the rewelding of the subsequent cell; *h* (depending on the level of mechanization of assembly and adjusting works this time is t_p = 0.25–0.4 h).

● determine the machine time of welding the butt by CNMEW using simultaneously two welding apparatuses by the formula

$$t_{w2} = \frac{H}{V_w}\left(\frac{n-1}{2}+1\right)+\left(\frac{n-1}{2}\right)t_p, \qquad (4)$$

● carry out a preheating of the assembly metal of the first pass to a temperature of 150–200 °C and perform rewelding of the central cell 6 (Figure 4, *a*);

● after rewelding of the central cell, perform other passes in pairs in the direction from the middle of the butt (central weld) to its edges (Figure 4, *b*);

● after welding of the entire butt is completed, remove the technological pockets, disassemble the welding equipment, mount a portable electric kiln on the welded joint and perform a local high tempering (for steel 35L) in the conditions: temperature of 620–650 °C with an exposure of 6–8 h and cooling together with the kiln to a temperature of 30–80 °C;

● carry out cleaning of outer surfaces of the welded joint with the help of a manual grinding tool;

● perform testing of the quality of the welded joint with the help of a portable device for ultrasonic flaw detection.

In each particular case of repair fulfilment, the necessary number of passes, sizes of welds and time of butt rewedling will be determined depending on the sizes of the cross-section of a repaired part and a degree of branching of a through-thickness crack [14]. The time spent on rewelding of a crack depends on its extension, value of branching, welding gap, number of passes to fill the edges opening, as well as a step between the centers of the holes, formed by the forming inserts.

A number of holes in the opening grows with a decrease in the set hole width and forming inserts. Figure 5 shows a change in the required number of forming holes depending on their width, designed for rewelding cracks in parts with the thickness of 900 and 1200 mm. It also shows diagrams of changing time of rewelding the butt in CNMEW successively of one hole at a time, as well as respectively in rewelding of the opening of two holes simultaneously.

From Figure 5 it follows that in terms of preserving the optimal efficiency of repair works:

a) width of the cells of edge opening should be 40–45 mm;

b) during rewelding of the opening of two cells simultaneously, the total time for welding a butt is almost twice reduced.

For example, for CNMEW of the butt with the cross-section 1000 (thickness) ×420 (length) mm with a gap of 70 mm, the width of the rewelded opening cells will be 43 mm, and for the forming inserts it will be 37 mm. To reweld such opening, it will be necessary to perform 13 passes, producing welds of an elliptical shape with the size of 105×130 mm (thickness and width of the weld, respectively). The machine time of one butt welding by means of a one apparatus will amount to 22–23 h, and simultaneously by two apparatuses it will be 12–13 h.

Technological recommendations were successfully tested on six cement works during repair of through-thickness cracks in the tires of rotating kilns [10, 14, 15]. Cross-sections of the restored (repaired) tires are: 900×355; 900×420; 900×475 and 1200×475 mm.

CONCLUSIONS

1. Based on the performed investigations, the principles of technology and technique of repairing through-thickness cracks in parts of a large thickness at the operation site of large-sized equipment applying the method of CNMEW, algorithm of taking decisions, special technological equipment and adaptation were developed.

2. The application of the developed technology allowed 1.5–3.0 times reducing the total time of restoration works as compared to two-arc automatic submerged welding. As compared to electric arc methods of welding, the use of CNMEW for repairing

through-thickness cracks excludes the formation of defects in the form of lacks of penetration, hot cracks, pores, slag inclusions, etc., which is confirmed by high service properties of restored parts.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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