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EFFECT OF REHEATING IN MULTIPASS SUBMERGED-ARC WELDING ON DELAYED FRACTURE RESISTANCE OF ROTOR STEEL WELDED JOINTS

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The change in relayed fracture resistance, depending on preheating temperature and thermal effect during deposition of new beads was experimentally studied, using the Implant method, in the case of 0.25C–2CrNiMoV rotor steel joints, produced by submerged-arc welding. The nature of the change in hardness in the cross-section of quenching steel with a deposited bead was investigated, which illustrates formation of quenching and tempering areas under the influence of reheating in welding. Using critical stresses as a quantitative index, causing delayed fracture, it was shown that after reheating in welding, the cracking resistance can increase by about 1.5–2.5 times or more. Under the conditions of welding without preheating, one-time and two-time cycles of heating in welding increase the cracking resistance up to the level obtained during welding with preheating up to 150–200 °C. 9 Ref., 4 Figures.

Keywords: *heat-resistant rotor steel, submerged-arc welding, quenching, reheating in welding, Implant, delayed fracture resistance*

One of the advantages of automatic submerged-arc welding is its high efficiency, which allows producing metal joints of larger cross-section at smaller number of passes. Higher efficiency is achieved due to greater thermal power of the welding arc. However, welding in the modes with a higher heat input leads to higher welding stresses [1] that can have a negative effect on welded joint performance. Moreover, welding stresses are a factor, provoking development of delayed fracture in quenching steel welded joints. In its turn, excess heating leads to undesirable structural changes, increase of grain size in the HAZ that also adversely affects the service properties, increases the probability of delayed fracture and reheating cracks [2–5]. In order to lower the level of residual stresses, the heat input into the joint zone should be limited, as well as the preheating temperature [1, 2]. For the case of welded joints of power engineering steels of great thicknesses, including rotor structures, narrow-gap submerged-arc multipass welding is used. A rational technological scheme also envisages limitation of the heat input in order to obtain the optimum cross-section of the deposited beads that ensures sound formation of the welded joint and lowering of the level of residual stresses [5].

Thus, in many cases multipass welding with limitation of welding mode parameters is preferable that has a positive effect both on lowering of the stress-strain state, and on formation of a uniform structure and resulting properties. The cold cracking problem is solved by application of preheating and concurrent heating in welding. As shown in [6], in the case of coated-electrode multipass manual arc welding, reheating, by influencing the structural and hydrogen factors, allows a considerable increase of delayed fracture resistance of metal in earlier deposited layers. This enables a certain lowering of preheating temperature, making the welding process more cost-effective. It is of interest to check the possibility of obtaining such an effect under the conditions of automatic submerged-arc welding.

The objective of this work is evaluation of the effect of reheating in submerged-arc welding on cold cracking resistance of quenching steel.

Investigations were performed with application of rotor steel of 0.25C–2Cr–NiMoV type. Cold cracking tests were conducted by the Implant method [3], using 8 mm diameter samples with a spiral stress raiser in the test part. Minimum (critical) stress σ_{cr}, above which delayed fracture developed, was the cracking

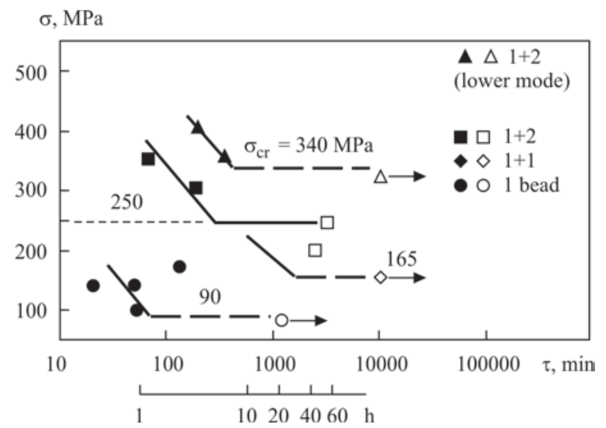

Figure 1. Influence of reheating in automatic submerged-arc welding (without preheating) on delayed fracture susceptibility of test joints of rotor steel of 0.25C–2CrNiMoV type (dark and light signs mean there is fracture or no fracture, respectively). $[H]_{dif}$ = = 5.23 cm^3/100 g Me

resistance characteristic. Automatic welding of Implant samples with a backing plate (from steel 20), and deposition of process beads were performed with wire of 0.14C–Cr–2NiMo alloying system using agglomerated flux UV422TT of basic type (basicity according to Bonishevsky of 2.5 for wt.%). Temperature measurement in the sample HAZ was conducted using a thermocouple passed through a hole in the plate end face and welded to the sample by a capacitor-type machine [6, Figure 1]. Vickers hardness was measured with 50 N load on the indenter. Alcohol method was used to determine the concentration of diffusible hydrogen $[H_{dif}]$ in the deposited metal (5.23 cm^3/100 g Me) [7]. Metal samples were obtained by bead deposition on the surface of steel with a drilled-out hole — at arc shifting to the hole zone the drooping metal fell on the detachable copper mould, in which the «pencil» sample formed for analysis. Metal reheating in the area of the earlier deposited bead was created by deposition of one new bead in the center of the first (1 + 1 scheme), or of two partially overlapping beads, deposited with wire shifting from the zenith of the first bead by approximately 1/4 of its width (1 + 2 scheme). At deposition the following mode was used as the basic one: I_w = 320–340 A, U = 35 V, V_w = 19 m/h; where additionally specified, deposition of just the new layer beads at lower current I_w = 250–280 A, was performed, voltage and speed remaining the same as in the base mode. In the experiments, deposition of each of the subsequent beads was conducted after cooling of metal with the previous deposit to the temperature of 100 °C and lower; loading of the tested joints was performed after their cooling to room temperature (the joints were cooled to 100 °C in calm air, after that — in accelerated mode with air blowing). Unlike the recommended by GOST 26388–84 loading temperature of 150–100 °C, the selected approach is explained by the fact that, as was experimentally established [8], in the range of 120–100 °C the joints of steels with martensitic and martensitic-bainitic structure (similar to the tested one) manifested instability as regards delayed fracture resistance, and in the 100–80 °C range, they showed a rather high fracture susceptibility. Assuming that such a high sensitivity to factors, causing delayed fracture, and unstable behaviour of the loaded welded joints at their cooling from 150 to 100 °C, can influence the accuracy of the results of the conducted comparative studies, it was decided to load the joints at room temperature. At evaluation of the effect of reheating on cracking resistance, the welding operations were conducted without preheating.

The experimentally found nature of the change of delayed fracture resistance of initially quenched metal in the HAZ after repeated heating cycles (Figure 1) is in agreement with the results of similar experiments in manual arc welding [6]. From the changes of critical stresses it follows that deposition of two subsequent beads is quite efficient (1 + 2 scheme): cracking resistance, compared to one-bead welding increased by approximately 2.5 times; one-time heating yields an intermediate result — σ_{cr} increased 1.6 times. An even greater effect was achieved after reheating at deposition of the second and third beads at current lowering (scheme 1 + 2 in the graph, «decreased mode»).

Change of cracking resistance is related to a certain degree to geometry of bead cross-section, temperature distribution and degree of tempering of the quenched region in the HAZ at the initial bead. In welding in the commonly used modes, the deposited beads have a shape elongated across the width, and close to an elliptical one. As shown by the results of studying bead cross-sections in automatic submerged-arc bead deposition on the steel surface (experiments were performed with application of steel Kh10CrMoVNb91), change of the heat input due to the change of current stronger affects the increase of bead width and penetration depth, deposit height changes only slightly: for instance, at q/v increase from 14 to 20 kJ/cm, the width, depth of penetration and height of the bead increased by 6.5; 1.8 and 1.0 mm, respectively. At deposition of the second bead in an unchanged welding mode a large part of the area of quenched metal in the HAZ at the first bead is again subjected to quenching, that can be seen in the scheme in Figure 2 (in this case, the second bead is made with a small shifting from the zenith of the first one; abbreviations denote: HAZ1, HAZ2 — regions of quenched metal, formed as a result of heating when making the first and second beads, delineated by boundary lines B1 and B2; FL1, FL2 are the respective fusion lines). In the two

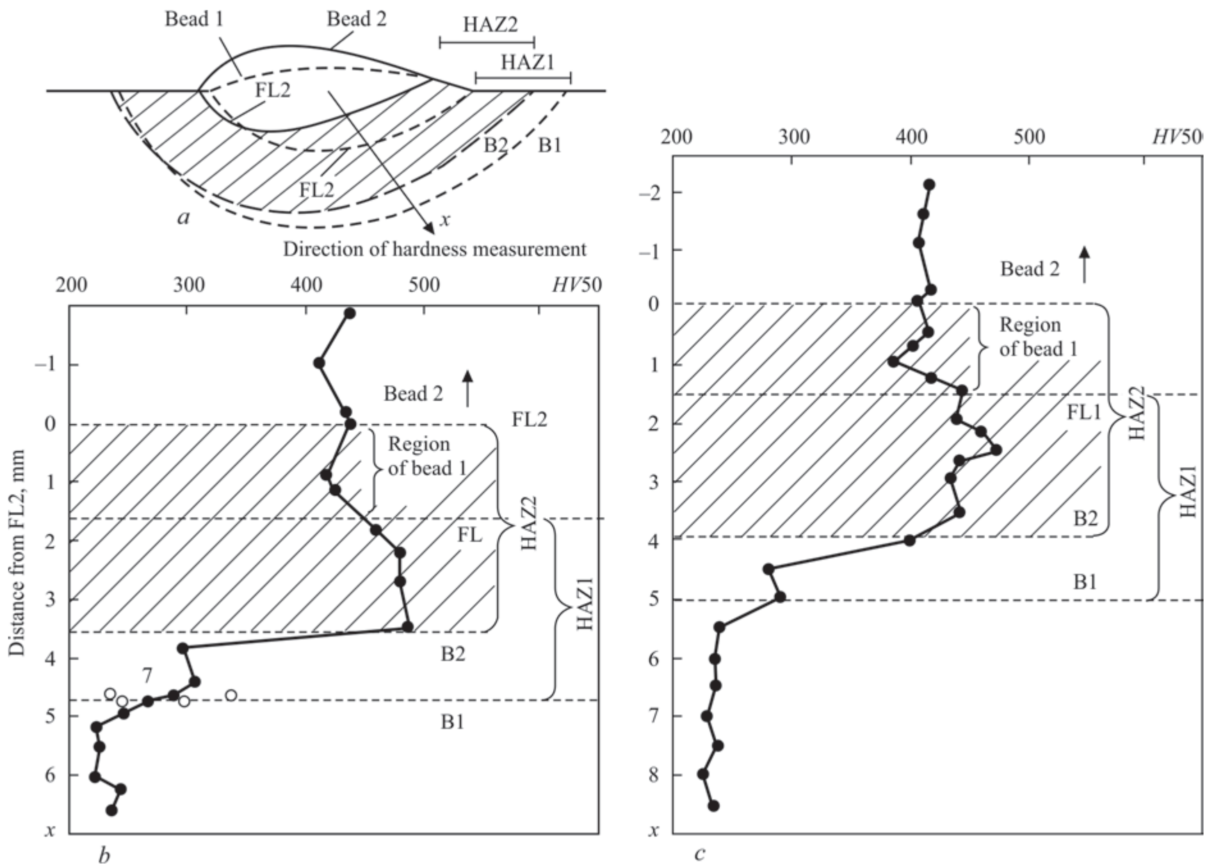

Figure 2. Change of hardness in different zones of metal cross-section with deposition of two beads: *a* — scheme of deposition of the second bead and direction of hardness measurement; *b* — distribution of hardness values corresponding to scheme (*a*) at bead deposition in the mode with heat input q/v = 13 kJ/cm (I_w = 200 A, U_a = 43 V, V_w = 19 m/h); *c* is the hardness profile at bead deposition in higher modes — q/v = 16.23 kJ/cm (I_w = 250 A, U_a = 43 V, V_w = 19 m/h)

schemes of hardness variation, one can see that deposition of new beads at smaller (*b*) and greater (*c*) heat input led to hardness decrease only in HAZ1 regions about 1.0 mm wide at HAZ1 total width approximately equal to 3.0 and 3.5 mm, respectively, for the considered variants. It is natural that deposition of just one bead gives a smaller tempering effect, compared to deposition of two beads, when additional metal in HAZ1 is subjected to two-time tempering heating (similar results at manual arc welding were obtained in work [6]). In its turn, deposition of two new beads at lower current creates the conditions for the impact of tempering temperatures on a larger area of initially quenched metal in HAZ1, due to lowering of penetration depth. This resulted in increase of delayed fracture resistance, compared to the variant of one-bead welding, approximately 3.5 times, and, compared to 1 + 2 scheme, performed in the basic mode — approximately 1.5 times. A similar effect should be anticipated when making new layers of deposited beads, where repeated quenching of the initial quenched metal (in HAZ1) will be eliminated when moving away from it, at the impact of just the tempering range temperatures (Figure 3).

Figure 4 gives a comparison of critical stresses, obtained in welding without preheating and with preheating up to temperature t_{pr} 250 °C. These data show that in welding without preheating, the two-time thermal impact on the quenched metal in the region of

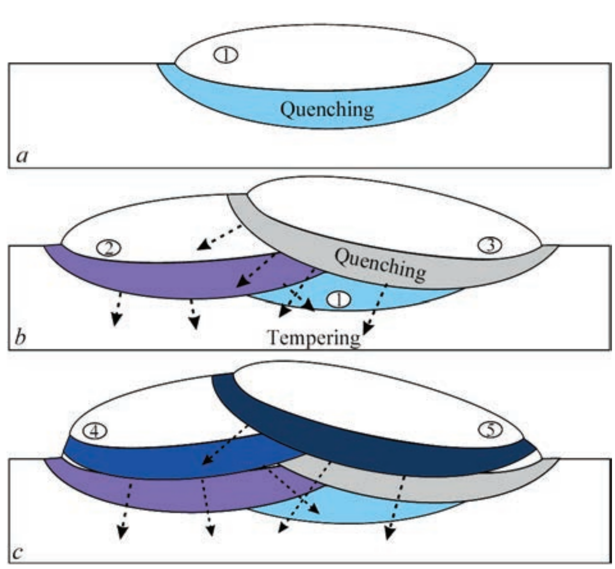

Figure 3. Schematic of bead deposition, formation of quenching regions (filled areas) and superposition of tempering range temperatures (shown by arrows); *a* — initial bead; *b*, *c* — deposition of two layers of two beads each

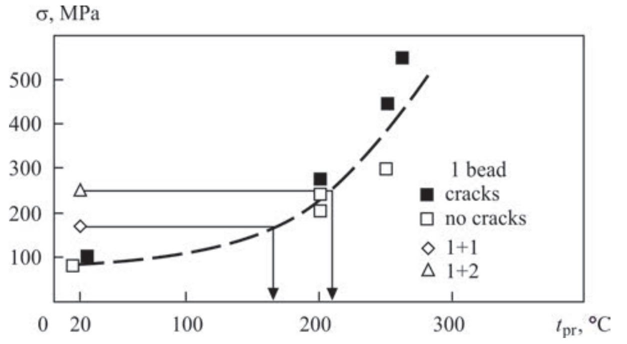

Figure 4. Influence of preheating temperature and welding conditions on delayed fracture resistance of test joints of 0.25C–2CrNiMoV type steel (20 °C — welding without preheating)

the first pass (1 + 2 scheme) allowed achieving cracking resistance, equivalent to welding with preheating approximately to 200 °C. One-time reheating (1 + 1 scheme) also gave considerable positive effect, close to welding with preheating approximately to the level of 150 °C. The above results, as well as the data of [6], lead to the assumption that a greater number of subsequent tempering cycles in multipass submerged-arc welding without preheating should provide an even greater effect, comparable with welding with preheating up to a higher temperature. At the same time, as shown in [9], in the case of welded joints of heat-resistant steel 10CrMo9–10, preheating in submerged-arc welding promotes lowering of the concentration of diffusible hydrogen in the joint zone. In this connection, increase of delayed fracture resistance at repeated cycles of heating in welding, can be regarded as the result of the impact on the structural and, to a certain degree — on the hydrogen factors.

Thus, obtained results show that under the conditions of multipass submerged-arc welding of quenching steels, reheating in welding essentially increases the delayed fracture resistance of welded joints, that was illustrated by increase of critical stresses, causing cracking, by approximately 1.5–2.5 times and more, depending on the number of heating cycles. It can be assumed that allowing for the positive effect of repeated cycles of thermal impact, multipass welding can be performed at lower preheating temperature without the risk of deterioration of technological strength of the produced joints.

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