doi.org/10.15407/tpwj2017.02.04

EFFECT OF WELDING MODES ON MECHANICAL PROPERTIES, STRUCTURE AND BRITTLE FRACTURE SUSCEPTIBILITY OF WELDED JOINTS OF STEEL 15Kh1M1FL MADE WITHOUT PREHEATING

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Structure and properties of metal of HAZ high-temperature area and weld were investigated in 15Kh1M1FL steel welding at higher modes using transverse hill method without preheating. Comparison of the received results with research data of welding process at moderate modes (160–170 A) determined that rise of current to 200–210 A results in increase of susceptibility to brittle fracture of HAZ high-temperature area and weld metal. The reason for this is high hardness caused by presence of martensite constituent in a bainite structure. 3 Ref., 1 Table, 5 Figures.

K e y w o r d s : *steel, welding, preheating, bainite, martensite, brittleness, properties, structure*

Formation of structure and properties in the different zones of welded joint is determined by thickness of welded metal being and its composition as well as parameters of technological process, i.e. effect of welding thermal cycle on metal [1].

Earlier carried investigations [2] showed that a method of transverse hill welding of steel 15Kh1M1FL at moderate modes without preheating and heat treatment provides for high indices of mechanical properties of the welded joints. At the same time from practical point of view it is reasonable to study an effect of higher modes on structure and mechanical properties, which is described in the paper.

The experiments were carried out on plates of 250×200×110 mm size, cast in a plant and subjected to heat treatment after casting. The latter includes homogenization at 1010–1030 °C; normalization at 970–1000 °C and high tempering at 720–740 °C temperature.

Sampling of metal, welded-up by transverse hill method using TML-3U electrodes of 4 mm diameter without preheating and concurrent heating at 200–210 A current, was mechanically carried out in the middle part of the plates in a section of 250 mm for performance of welds. No post weld heat treatment was applied.

The specimens for mechanical tests and structural examinations were made from the templates cut out in transverse direction in the upper, middle and bottom parts of the weld (Figure 1). Macro- and microstructure, and grain size, determined on GOST 5639–82 and on random linear intercept method [2], were examined. Hardness (*HV*5) was measured and characteristics of strength, ductility, impact toughness

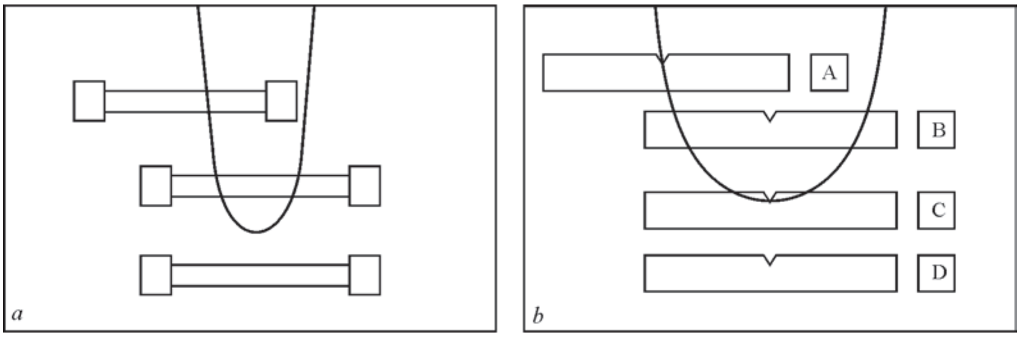

Figure 1. Scheme of specimen cut out from welded joint of steel 15Kh1M1FL: *a* — specimens for tensile testing; *b* — specimens for impact bending testing (A–D — illustration of cut place)

Indices of *HV*5 hardness of metal of HAZ high-temperature area of welded joint of steel 15Kh1M1FL in sections at different levels from weld surface

Variant number	Welding current *I*, A	Distance from weld surface, mm		
		10	25	40
		Hardness *HV*5		
1	160–170	277–278	276–278	281–287
2	200–210	360–368	388–405	365–366
3	In accordance with typical technology	–	355–358	–

KCV at –20; 0; 20 and 100 °C temperature were determined. Received test results were compared with the data of earlier investigations carried after welding on 160–170 A current [2].

Microanalysis determined that the weld height makes 65 mm, width is 55 mm and heat affected zone has 3–4 mm width. No macrodefects were found in the weld. Figure 2 shows a diagram of hardness change.

For comparison the Table provides for the hardness data in HAZ high-temperature area and weld metal in correlation with base metal after transverse hill welding (THW) at different current values as well as after welding using typical technology.

It should be noted that hardness in the near-weld zone and weld metal at all cross section levels of the joint made by welding at higher modes significantly exceeds that in these zones in the joints welded-up at moderate modes (Table, variant 1). At the same time, the levels of hardness of welded joints made by THW and typical technology are close (see Table).

Based on the results of tensile specimen testing it was determined that increase of the welding modes results in decrease of strength and ductility of HAZ metal in relation to weld metal (Figure 3, *a*). At that strength of HAZ metal is somewhat higher and ductility is lower than that in the base metal. The weld metal is characterized by the highest indices of strength and ductility (Figure 3, *b*, *c*). If welding variants are compared then strength and ductility characteristics are higher for the second variant, however, level of full strength of the welded joint is lower. Strength and ductility of HAZ metal is somewhat lower for the second variant that can be referred to rise of hardness and structure inhomogeneity.

Metallographic examinations determined that structure of HAZ high-temperature area, i.e. overheated metal and partially melted grains, is inhomogeneous. The microstructure consists of bainite of different morphology. Together with upper bainite there are areas of lower bainite with sufficiently obvious orientation of carbide phase (Figure 4, *b*). These areas are located in a transfer area of base metal–weld fusion zone. The areas of high-temperature inhomo-

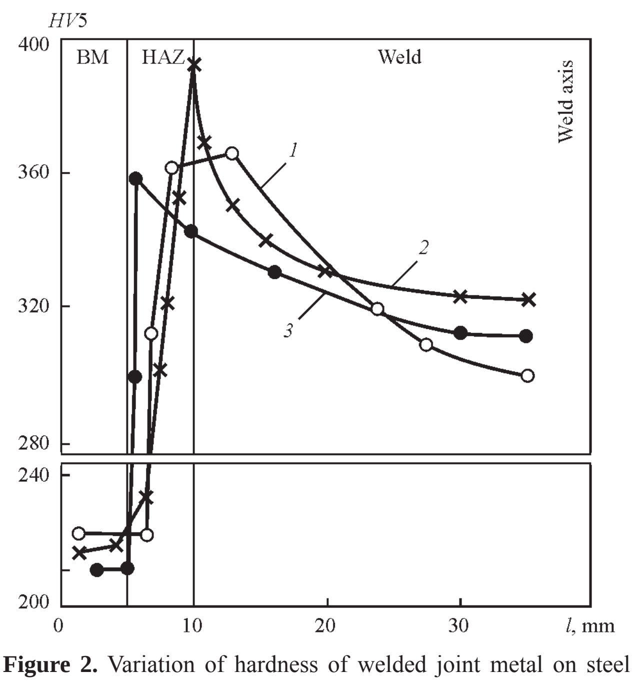

Figure 2. Variation of hardness of welded joint metal on steel 15Kh1M1FL made without preheating, at the following levels from weld axis: *1* — 10; *2* — 35; *3* — 40 mm. Welding current 200–210 A

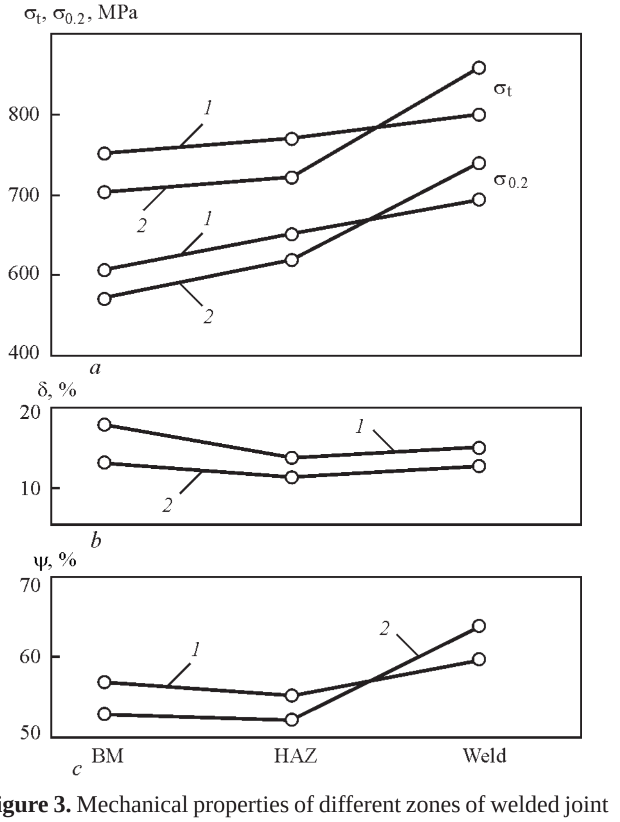

Figure 3. Mechanical properties of different zones of welded joint of steel 15Kh1M1FL: *1* —160–170 A, *2* — 200–210 A

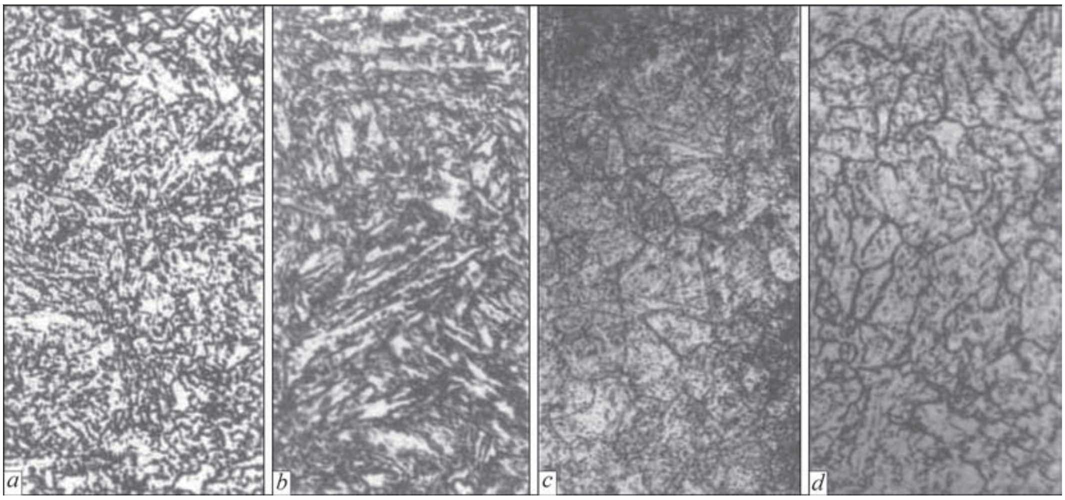

Figure 4. Microstructure of welded joint of steel 15Kh1M1FL made by THW at higher modes (I_w = 200–210 A): *a* — weld metal (×500); *b* — fusion boundary (×500); *c* — grain in HAZ metal in area of overheating (×100); *d* — grain in HAZ metal in a distance from overheating area (×500)

geneity have insignificant sizes and discrete location along conditional transition line.

The grains of granular bainite areas in HAZ metal and weld metal are fine (austenite grain $\breve{D}_{cond}$ = = 0.0138–0.0083 mm, correspond to number 9–10 of GOST 5639–82 scale). At that it should be noted that a value of grain in such areas in welding at moderate modes corresponds to number 7–8 ($\breve{D}_{cond}$ = = 0.0192 mm).

Austenite grain (Figure 4, *c*) in areas with acicular bainite is coarser ($\breve{D}_{cond}$ — 0.053 mm), however, lies in the ranges of acceptable norms and corresponds to number 9–10 of GOST 5639 scale.

Figure 5 shows the diagram of change of impact toughness in testing of sharp notch specimen (Charpy type), at which the results received in welding at higher modes are compared with the data of earlier carried out investigations (see Table, variant 1, moderate mode). As can be seen from the diagram, *KCV* of HAZ metal of the welded joints, made at higher modes, in testing at –20–20 °C temperature interval, is 30–50 J/cm^2 lower (Figure 5, curves *1* and *2*).

Tendency to *KCV* decrease is observed in weld metal testing (Figure 5, curves *3* and *4*). Increase of test temperature levels difference in the indices. No significant difference in *KCV* indices in upper, middle and bottom parts of the welded joint was found, including for the specimens with transverse orientation of fusion zone. Thus, it shows sufficient level of metal homogeneity in different places with various orientation of fusion zone.

The following conclusion can be done based on received experimental results. It is known [3] that homogenization of austenite before its transformation is not finished in HAZ during welding with high rates of heating and further cooling of steels containing active carbide-forming elements (Cr, Mo, V etc.), which is typical for welding processes. The process of complete dissolution of carbides is not provided. Indicated factors decrease austenite stability properties. Under such conditions a transformation process is shifted in the bainite area. An important factor, effecting kinetics of homogenization process, is metal initial structural state.

Cast steel 15Kh1M1FL, used in given experiment, is characterized by coarse different-grain structure (see Figure 4, *c*) with significant dendrite and chemical inhomogeneity.

Welding of this steel with THW without preheating at moderate modes, as was set by us earlier [2], provides for formation of structure of upper bainite characterized by sufficiently high viscoplastic properties. Increase of welding modes (rise of heating rate) and cyclicity of heating (in multilayer weld deposi-

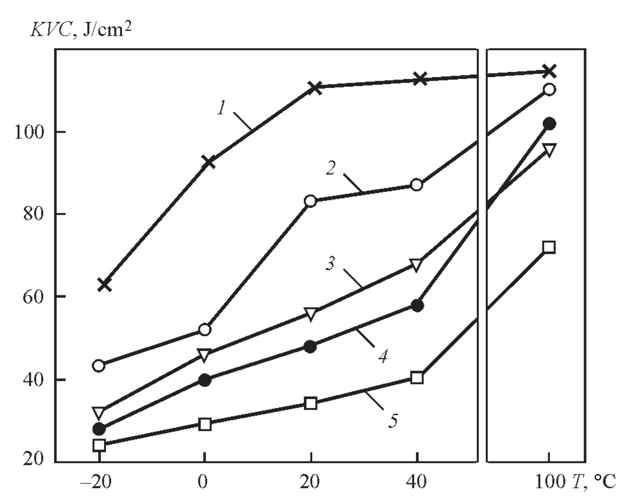

Figure 5. Impact toughness *KCV* of zones of welded joint of steel 15Kh1M1FL made by THW without current preheating: *1* —160–180 A, HAZ (A, C); *2* —200–210 A, HAZ (A, C); *3* —160–180 A, weld (B); *4* —200–210 A, weld (B); *5* — base metal (D) (see Figure 1)

tion) moves HAZ metal sections in the different time temperature conditions that results in formation of austenite with different level of homogeneity. As a result inhomogeneous structure is formed in cooling. Areas of acicular bainite (Figure 4, *b*) are formed together with granular bainite. Apparently, the transformation process in the grown austenite grain with higher homogenization completeness is shifted to the interval of lower temperatures, and formed acicular structure is a product of austenite decay in the area of «lower bainite–martensite» temperatures. At that, rise of hardness is observed in this zone (see Figure 2).

Thus, higher modes at THW without preheating of thick-walled cast structures of steel 15Kh1M1FL have negative effect on brittle fracture resistance of metal of HAZ high-temperature area. The main reason is, most probably, formation of inhomogeneous morphology of bainite, where acicular structure, being identified as lower bainite, is present together with upper bainite of granular shape. At that, metal of indicated zones have increased hardness typical for bainite-martensite structure.

Grains grown in HAZ are not a direct reason for embrittlement of this zone and influence indirectly. It is known fact [3] that grain growth in steels with the active carbide-forming elements is a sign of increased homogenization level of austenite and, respectively, results in rise of its stability, and, hence, shift of transformation temperature to martensite area.

Conclusions

1. Bainite of different morphology, i.e. granular and acicular, is formed in welding of cast steel 15Kh1M1FL using transverse hill method without preheating at higher modes in high-temperature area of HAZ. The reason of formation of such structure is initial different-grain austenite with various level of homogenization and transformation resistance.

2. Welding at higher modes results in growth of hardness values in HAZ metal and reduction of impact toughness in –20–20 °C temperature interval that is a sign of increase of brittle fracture susceptibility.

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Received 04.08.2016