MECHANICAL PROPERTIES OF JOINTS OF HEAT-RESISTANT 10Kh12M, 10Kh9MFBA GRADE STEELS, MADE BY ELECTRON BEAM WELDING

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In the course of development of works on the technology of electron beam welding of special steels the investigations of properties of the joints of heat-resistant 10Kh12M, 10Kh9MFBA grade steels of δ_m = = 30 mm thickness, made by single- and multipass electron beam welding using horizontal electron beam at the speed of v_w = 3 mm/s without preheating, were carried out. The results of mechanical tests on rupture and impact toughness and also nature of fracture after electron beam welding and after it with the next tempering are given. It was established that toughness and ductility of welded joints of both heat-resistant steels after the first main pass and after the second one in electron beam welding with the next tempering are preserved almost at the same level. The fracture of welded specimens of both alloys, oriented across the weld metal, occurs along the base metal far from the weld, beyond the heat affected zone. The fracture surface is dull. The formed relief has characteristic features of plastic fracture. As a result of tempering the strength of welded joints of both alloys decreases not considerably, and toughness with ductility increase. The third of the passes in electron beam welding results in formation of defects in a form of middle cracks and brittle low-ductile structures in weld structure and near-weld zone. 7 Ref., 2 Tables, 3 Figures.

Keywords: *electron beam welding, heat-resistant steels, welded joints, welding speed, preheating, tempering, strength, toughness, elongation, reduction in area, number of passes*

One of the decisive factors influencing the rate of increment of tensile stresses during weld crystallization and resistance of weld metal to formation of longitudinal hot cracks in the middle of a weld is energy input of welding. As is shown in work [1], the electron beam welding (EBW) of heat-resistant steels of martensite-ferrite class of grades 10Kh12M and 10Kh9MFBA of δ_m = = 30 mm thickness without preheating should be performed at the speed of $v_w \leq 3$ mm/s which corresponds to the energy input of 2.56 kJ/mm. At the increase of EBW speed along the weld axis on the line of abutting crystallites growing in the direction meeting each other from the opposite sides of cast zone boundaries, the longitudinal crystallization cracks («middle» cracks) of 2–15 mm height and 0.05–0.2 mm width appear. Besides, with increase of width of a weld and also at the presence of local extensions with increment of tensile stresses on it during crystallization of a weld, the probability of formation of middle cracks grows considerably [2–7]. To prevent the formation of cracks it is necessary to provide formation of narrower welds with a uniform width along the depth of penetration.

In this work the mechanical properties and nature of fracture of welded joints of heat-resistant 10Kh12M and 10Kh9MFBA steels, made by single- and multipass EBW without preheating were investigated.

The control of quality and strength properties of welded joints of heat-resistant steels 10Kh12M and 10Kh9MFBA after EBW at the speed of $v_w \leq$ ≤ 3 mm/s can be performed by mechanical tests in accordance with the GOST 6996–66. To determine static and dynamic characteristics of welded joints the given standard establishes the shapes and sizes of specimens and sequence of mechanical tests.

The specimens of welded joints of heat-resistant steels 10Kh12M and 10Kh9MFBA were tested in their initial state and after tempering. The result of tempering is influenced by temperature and heating rate, holding time and cooling rate. The heat temperature was selected coming from the conditions of recovery of ductility and toughness of near-weld zone of heat-resistant steels with martensite structure and weld reaching the values close to the base metal. With the growth of tempering temperature the hardness and tensile strength of steel are decreased whereas toughness and ductility are increased. The time of holding depends on thickness of specimen, initial structure and chemical composition of the steel. Thus, the optimal conditions of tem-

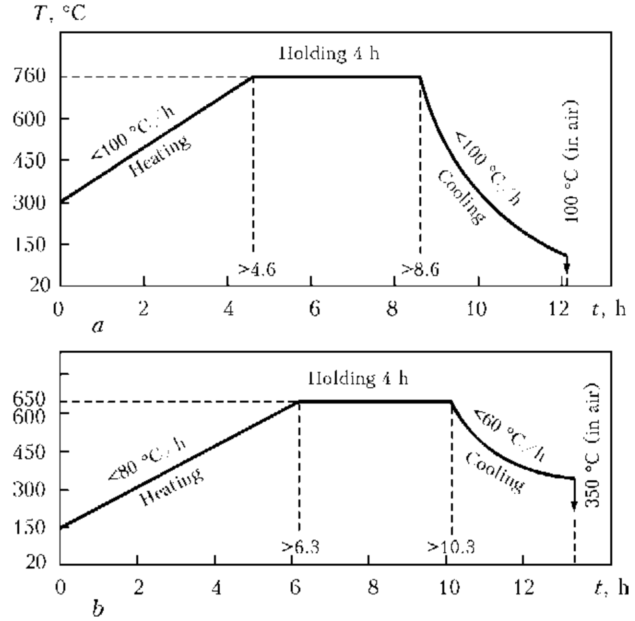

Figure 1. Diagram of tempering of welded specimens of heat-resistant steels 10Kh9MFBA (*a*) and 10Kh12M (*b*) (*t* — duration of tempering)

pering of heat-resistant steels 10Kh12M and 10Kh9MFBA for obtaining the required mechanical parameters of welded joints can not be the same. As is seen from Figure 1, the diagrams of tempering of test alloy welded specimens are differed by their temperature, heating and cooling rates.

The rupture tests of welded joints of heat-resistant steels 10Kh12M and 10Kh9MFBA were carried out on the cylindrical specimens of dumbbell type with the diameter of test part d_0 = 6 mm after EBW and after EBW with the next tempering at the following conditions: U_{acc} = 60 kV, I_b = 128 mA, v_w = 3 mm/s, $-\Delta I_f$ = 15 mA, d_{circle} = 1.5 mm, $l_{w.d}$ = 200 mm. The specimens for tests were cut out at the half of the penetration depth of billets of δ_m = 30 mm thickness in welding using horizontal electron beam and movement of electron beam gun in the horizontal plane. As is seen from Figure 2 the specimens of both alloys after EBW and EBW with next tempering oriented across the weld metal are fractured along the base metal far from the weld beyond the heat affected zone (HAZ): for the specimens after EBW — at the distance of 9–10 mm from the weld axis, for the specimens after EBW with next tempering — at the distance of 6–6.5 mm from the weld axis. The formed relief in the place of fracture has a «pit» nature and has the typical features of plastic fracture: the surface of fracture is located in an inclined position (approximately at the angle of 45°) relatively to the direction of normal stresses, the fracture surface is dull, the edges of fractured area are considerably deformed. As a result of rupture tests, except of σ_t value other parameters of welded joint: $\sigma_{0.2}$, δ, ψ were also determined.

To control the dynamic characteristics of welded joints and make a correct selection of welding technology, the tests on impact bending of weld metal of some areas of a near-weld zone were carried out (on notched specimens). The tests were carried out using specimens of 10 × × 10 mm section with a semicircular notch profile for weld metal and V-shape notch profile for the

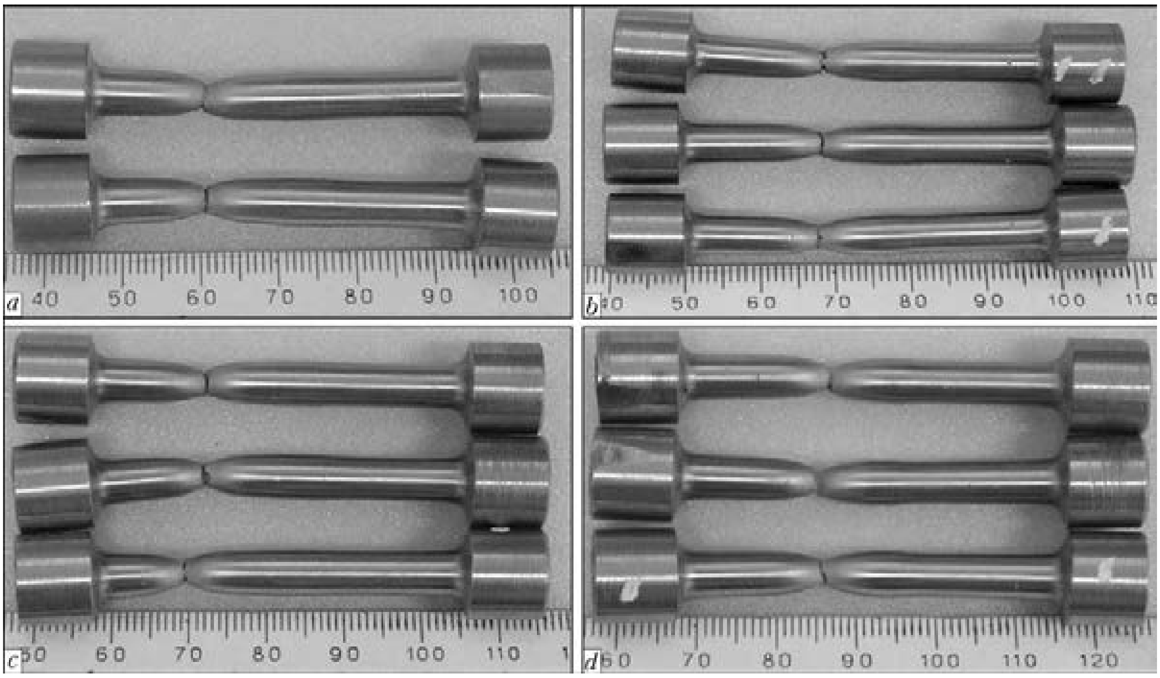

Figure 2. Specimens after mechanical rupture tests of welded joints of heat-resistant steels 10Kh12M (*a*, *b*) and 10Kh9MFBA (*c*, *d*) after EBW (*a*, *c*), EBW and next tempering (*b*, *d*)

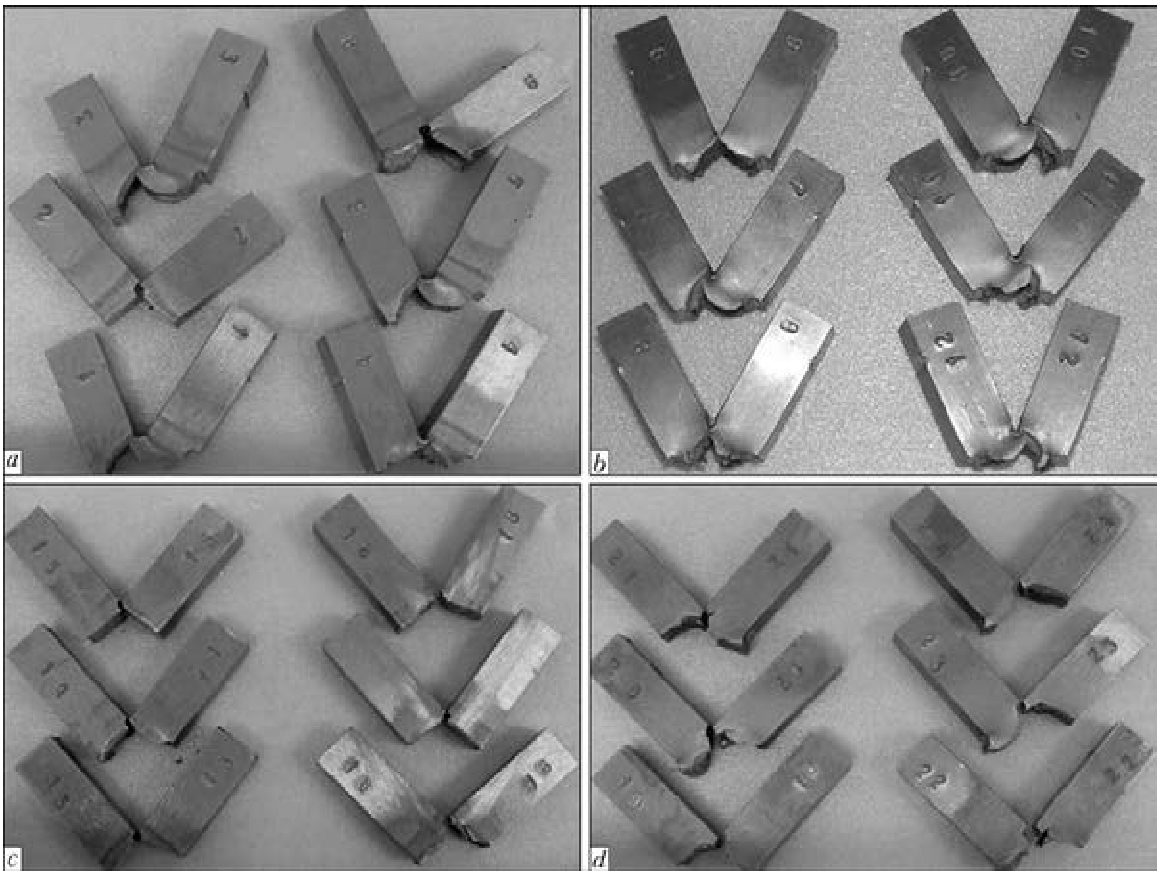

Figure 3. Specimens after mechanical tests on impact toughness of welded joints of heat-resistant steel 10Kh12M (*a*, *b*) and steel 10Kh9MFBA (*c*, *d*): *a* — after EBW (*1–3* — bending along the weld axis; *4–6* — bending along the fusion line); *b* — after EBW and next tempering (*7–9* — bending along the weld axis; *10–12* — bending along the fusion line); *c* — after EBW (*13–15* — bending along the weld axis; *16–18* — bending along the fusion line); *d* — after EBW and next tempering (*19–21* — bending along the weld axis; *22–24* — bending along the fusion line)

fusion line with the base metal. As is seen in Figure 3, *a*, *b*, all the specimens of heat-resistant steel 10Kh12M after EBW and after EBW with next tempering are bent in the process of impact toughness test mainly without the complete fracture; at incomplete fracture the formed relief has a «pit» nature and features of plastic fracture. The specimens after mechanical impact toughness tests of welded joints of heat-resistant steel 10Kh9MFBA (Figure 3, *c*, *d*) after EBW and after EBW with next tempering are bent with the complete fracture, the fracture surface is dull, the formed relief has features of plastic fracture.

The obtained data of mechanical properties of welded joints of heat-resistant steels 10Kh12M and 10Kh9MFBA after EBW and after EBW with next tempering are given in Table 1. As a result of tempering the strength of welded joints (σ_t, $\sigma_{0.2}$) is decreased, whereas toughness and ductility (*KCU*, *KCV*, ψ) are increased. The influence of tempering on mechanical properties of welded joints of heat-resistant steel 10Kh9MFBA has a stronger effect than that which can be predetermined by a larger amount of alloyed elements.

The ductility of test specimens, evaluated by the values of reduction in area, for heat-resistant steel 10Kh12M amounts to 68 % and for steel 10Kh9MFBA it is 73 %.

To optimize the repair technology of EBW of heat-resistant steels, removing the inner defects of welded joints and evaluate changes in shape and sizes of penetration zone and also strength characteristics, the investigations were carried

Table 1. Mechanical properties of welded joints of heat-resistant steels 10Kh12M (numerator) and 10Kh9MFBA (denominator)

State of metal	σ_t, MPa	$\sigma_{0.2}$, MPa	ψ, %	*KCU*, J/cm^2 (weld)	*KCV*, J/cm^2 (fusion line)
After welding	739/721.9	584.6/653	67/71	121.6/216.8	101.3/183.2
After welding and heat treatment (tempering at 650 °C, 4 h)	730/677.8	564/536.4	68/73	163.0/302.6	151.2/296.6

Table 2. Mechanical properties of welded joints of heat-resistant steels 10Kh12M (numerator) and 10Kh9MFBA (denominator) at the temperature of +20 °C depending on number of passes in EBW

Number of passes in EBW	σ_t, MPa	$\sigma_{0.2}$, MPa	ψ, %	*KCV*, J/cm^2 (fusion line)
Two passes + tempering	728.4/660.0	562.4/524.6	66/71.5	188.3/222.0
Three passes + tempering	718.0/664.0	552.0/522.4	70/70.6	10.2*/37.2**

*On the specimen of steel 10Kh12M with three passes the defect in a form of a middle crack is present.

**On the specimen of steel 10Kh9MFBA with three passes the brittle fracture is present.

out on influence of double and triple remeltings of the same weld. The preparation and tests of specimens with welded joints were carried out according to the procedure described above. To prevent influence of concurrent heating on the formation of face and reverse weld beads, the holding in time was performed before the second and the third passes for cooling down the specimen to room temperature. To provide the accurate movement of welding electron beam along the weld axis the position of specimen and welding program were preserved unchanged. It was found that such succession in producing of double and triple remeltings of the same weld does not influence the change in shape and sizes of penetration zone, and width of face and reverse beads remains almost unchanged. The fracture of specimens of dumbbell type of both steels after double and triple remeltings of the same weld with next tempering occurs on the base metal far from the weld, beyond the HAZ. The formed relief at the place of fracture has characteristic features of plastic fracture.

The obtained data of mechanical properties of welded joints on heat-resistant steels 10Kh12M and 10Kh9MFBA at the test temperature of +20 °C depending on the number of passes using welding electron beam with next tempering are given in Table 2. As is seen from the Table, toughness and ductility of welded joints (*KCV*, ψ) of both steels after the second pass and next tempering are preserved at the level of toughness and ductility of welded joints after the first pass (see Table 1). It should be noted that specimens after mechanical tests on impact toughness of welded joints after the second pass with next tempering of heat-resistant steel 10Kh12M are bent with the complete fracture along the fusion line, and heat resistant-steels 10Kh9MFBA are bent with the fracture along the fusion line, but specimens remain integral.

As is seen from Table 2 the mechanical properties of welded joints of heat-resistant steels 10Kh12M and 10Kh9MFBA are sharply deteriorated after the third pass with next tempering. The impact toughness of specimens of heat-resistant steel 10Kh12M is $KCV = 10.2$ J/cm^2, which is predetermined by the formation of defect in the form of a middle crack. The value of impact toughness of specimens of heat-resistant steel 10Kh9MFBA amounted to $KCV = 37.2$ J/cm^2 and was connected with the formation of brittle structures along the fusion line.

Thus, in EBW of heat-resistant steels 10Kh12M and 10Kh9MFBA only one pass after the first basic welding is admitted, as far as it does not lead to deterioration of mechanical properties of welded joints. The toughness and ductility of welded joints of both heat-resistant steels after the second pass in EBW and next tempering are preserved at the level of toughness and ductility of welded joints after the first basic pass.

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Received 13.06.2013