2. Investigation of the stability of melting and electrode metal transfer in consumable electrode arc welding using power sources with different dynamic characteristics [Electronic resource] / Yu N. Saraev [et al.] // Welding International. – 2017. – Vol. 31, no. 10. – P. 784–790.

3. Complex for investigation of arc welding processes [Electronic resource] / Yu N. Saraev [et al.] // The Paton Welding Journal. – 2018. – Vol. 2018, no. 8. – P. 13–21

4. Ślązak B. Analysis of instantaneous values of current and voltage parameters in the evaluation of process stability of shielded electrode welding [Electronic resource] / Benedykt Ślązak // Welding International. – 2015. – Vol. 30, no. 1. – P. 33–37.

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CRACKING RESISTANCE OF MOLYBDENUM-RHENIUM ALLOY FOR ARMATURES OF THERMOELECTRIC CONVERTERS (TC)

Industrial thermoelectric converters (TC) of the immersion type work in conditions of a large gradient of shock measured temperatures, mechanical, chemical and, in some cases, radiation influence of an aggressive environment [1].

The structural element of the TC is the protective fitting, which has high requirements: a) ensuring the specified accuracy of temperature measurement in a certain interval with minimal inertia in relation to the heat flow; b) mechanical strength at thermal shocks; c) exclusion of direct contact of thermoelectrodes with the controlled environment (hermeticity and gas tightness); d) lack of influence of the armature material on the electrodes; e) sufficient operating resource; g) acceptable technological processing [2].

Molybdenum is used as an armature material for high-temperature TCs operating in environments up to 2000^0C. Unlike the rest of the refractory metals, it has a number of positive properties that are acceptable for ensuring the workability of the structure: high melting point and modulus of elasticity, low coefficient of thermal expansion, high indicators of thermal resistance and thermal conductivity, small cross-section of thermal neutron capture. However, in the process of operation, the material of the armature is recrystallized, starting from the contact surface with the environment. Further grain growth into the depth of the armature wall depends on the intensity of thermal shocks and the metallurgical purity of molybdenum [3].

The combined effect of thermo-mechanical stresses and structural unevenness contribute to the manifestation of molybdenum's typical disadvantages - a tendency to crack formation and brittleness.

The main technological measures to improve the mechanical properties of reinforcement are riveting (rolling) and recrystallization heat treatment, as well as alloying, mainly to ensure technological and operational plasticity.

The promising alloy Mo+Re (3.5%) was studied for the resistance to crack formation in the material after rolling, as well as after heat treatment by annealing ($T^0_{annealing}$ = 1200...2000^0C; step 200^0C; holding time $t_{annealing}$ = 1h) under mechanical loading at a constant speed (v= $69\cdot10^{-5}$ m/s) at the temperature of the external environment ($T^0_{testing}$= -50...200^0C). The tests were carried out on samples measuring 48·8·2mm along the rolling line along the longer side with a 4·0.2 mm notch; the IMASH-20-75 installation.

J(Jc) is the integral and stress intensity factor KQ(KQc), which were calculated according to GOST-25.506-85 methods, [4] (Fig. 1, 2).

The results of the research show that in the temperature range (-50...+20^0C) the fracture energy is spent only on the nucleation of the crack with the subsequent one-moment decay of the sample, and at temperatures higher than +20^0C part of the energy is spent on the growth of the crack, which

is typically manifested on samples that have received annealing $T^0_{annealing} = 1600^0C$. it is also noted that at $T^0_{testing} = 200^0C$, the fracture is accompanied by significant plastic deformation of the crack tip. The latter violates the requirements of the theory of linear fracture mechanics for the correct determination of the K_Q coefficient according to the deformation diagram (P_{max}/P_Q=1.61).

In general, according to the criteria J(J_c, J_{c1}) and K_Q(K_{Qc}), it is possible to testify: a) for the material after rolling, as well as annealed at temperatures of 1200...1600^{0}C at a test temperature of +200C, the value of Jc - the integral is statistically significant at the same level of 440...460 kN/m, and at higher annealing temperatures (1800...2000^{0}C) it sharply decreases.

The same regularities are inherent in the values of the K_{Qc} - coefficient.

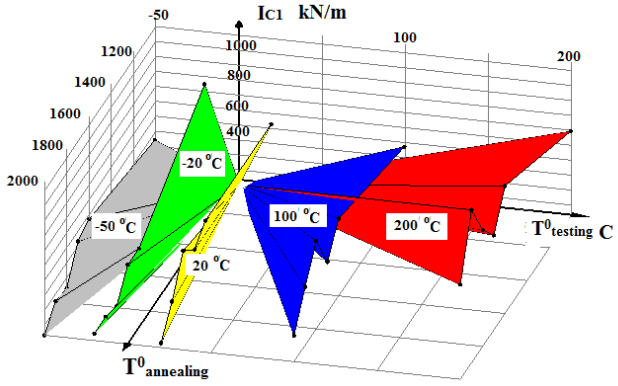

Fig. 1 – The response surface of the change in the value J_{c1} – the integral of the evaluation of crack resistance due to the combined effect of temperature factors: annealing temperature ($T^0_{annealing}$) and test temperature ($T^0_{testing}$)

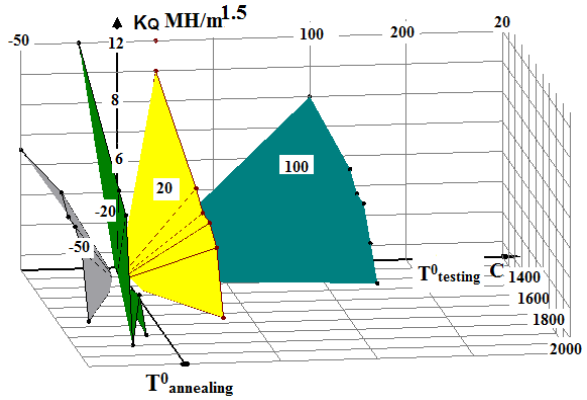

Fig. 2 – The response surface of the change in the value of K_Q – the stress intensity factor due to the combined effect of temperature factors: annealing temperature ($T^0_{annealing}$) and test temperature ($T^0_{testing}$)

The mechanical properties change as follows: with an increase in the annealing temperature, the strength decreases, and the plasticity remains within acceptable limits of 10...14%; b) at a test temperature of 100^{0}C, the material annealed at 1600^{0}C with high mechanical properties has the maximum resistance to destruction, and the worst values of Jc - the integral correspond to the material annealed at 2000^{0}C; c) at a test temperature of 200^{0}C, the best indicators of Jc - the integral and the K_Q- coefficient correspond to the samples annealed at 1200^{0}C and 1800^{0}C. And for samples that have undergone annealing at 1400^{0}C and 2000^{0}C, the crack resistance is of the same order as that of the material after rolling; d) in the region of negative temperatures, in all variants of sample preparation (mechanical and thermal), the fracture is brittle with insignificant indicators of Jc - the integral and the K_Q - coefficient; mechanical properties deteriorate with increasing annealing temperature. Acceptable for such external temperature conditions is an alloy after mechanical processing (rolling), as well as one that had annealing no higher than 1200...1400^{0}C; e) annealing of 2000^{0}C is unacceptable for the entire investigated temperature range $T^0_{testing}$ = -50...200^{0}C, and the choice of annealing temperature is correlated with the operating conditions of the armature according to the indicators of crack resistance and mechanical properties.

References

1. F. R. Caldwell. Thermocouple Materials National Bureau of Standards. Monograph 40 Issued March 1, 1962. Reprinted with corrections, February 1969. P43.

2. Kurytnyk I.P., Biloborodchenko V.I., Bolshakov M.V. Modern technologies for the manufacture of thermocouples. TC-6. "Instruments and devices for control and regulation of technological processes". M.: 1990.-40 p.

3. Savitsky E.M., Burhanov G.S. Metallurgy of alloys of refractory and rare metals. Science, 1971, 354p.

4. Kovalevsky V.N., Sagarda E.V., Zhuk A.E., Senchenko H.M. experimental definition and numerical calculation of the fracture viscosity criterion (J – integral). Bulletin of BNTU, No. 2, 2005. P. 34-37.