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EFFECT OF ALTERNATING MAGNETIC FIELD ON MAGNETIC PROPERTIES, STRUCTURE AND STRESSED STATE OF VESSEL STEEL WELDED JOINTS

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Earlier investigations showed that treatment of welded joints of reactor vessel steel 15Kh2NMFA with alternating magnetic field of commercial frequency significantly improves a complex of mechanical properties under conditions of uniaxial tension that is accompanied by decrease of a level of thermal stresses in a weld zone. Aim of the present work is study of the effect of magnetic treatment on magnetic characteristics, structure, level and distribution of residual stresses in the welded joint. Changes of stress-strain state in different areas of the welded joint were evaluated on data of X-ray diffraction and electron-microscopic examinations. It is shown that effect of alternating magnetic field results in decrease of a level of microstresses in a transition layer and balancing of spectrum of these stresses in all area of heat affect. Correlation of changes of initial magnetic susceptibility and microstresses in the transition layer and formation of expressed magnetic texture in the weld central part is noted. The mechanisms of changes of magnetic properties and structure at magnetic treatment of welded joint, which are related with activation of plastic microdisplacements and defect redistribution, were considered. Given method of magnetic treatment can be observed as magnetic tempering, providing rise of homogeneity of stress-strain state of welded joints. This promotes increase of their resistance to nucleation and propagation of cracks. 10 Ref., 1 Table, 3 Figures.

Keywords: *welded joint, vessel steel, magnetic treatment, structure, internal stresses*

Performance of welded joints in the structure elements can result in development of spatially-inhomogeneous stressed state with formation of zones of local stress concentration. They introduce start of plastic deformation at very small external loads and as a result provoke degradation of service characteristics, in particular, under conditions of static, cyclic and impact loading. Known methods for decreasing the level of residual stresses and development of more uniform their distribution in order to prevent appearance of micro- and macrodiscontinuities stipulate special heat treatment, ultrasonic, pulse or vibration treatment [1].

Earlier it was shown that treatment of welded specimens of steel 15Kh2NMFA in stressed-strain state with alternating magnetic field significantly improves mechanical properties under conditions of uniaxial tension, increase impact toughness, decrease temperature of ductile-brittle transition and level of first-kind stresses in welding zone and in heat-affected zone [2]. Welded joint of vessel steel as a result of magnetic treatment can be characterized with correlated change of magnetic properties, structure and stress fields due to interaction of magnetic and lattice subsystems, that is typical for magnetic-ordered materials [3].

In this connection, aim of the present work lies in study of impact of magnetic effect on structure, magnetic characteristics, level and distribution of microstresses in welded joints of steel 15Kh2NMFA.

Materials and investigation procedures. A plate of 12×50×150 mm^3 with a groove of 8 mm depth and 10 mm width was made of solid billet of vessel steel 15Kh2NMFA. It was used for making a weld with argon-arc non-consumable electrode welding. Welding rate made 6 m/h and number of passes equaled 13. Edges of the plate were fixed in the grips for prevention of shape change in weld cooling. A Table shows composition of steel and filler wire.

Specimens, structural state of which corresponded to different areas of welded joint from central weld part to metal at around 18 mm distance from it, were made from welded joint using spark cutting. Figure 1 shows a scheme of welded joint «tailoring».

Magnetic treatment of the specimens was carried out employing alternating magnetic field of 50 Hz frequency. The specimens were located in a magnetic field direction and were cooled by flowing water

Composition of steel and filler wire, wt.%

Material	C	Si	Mn	S	P	Cr	Cu	Ni	Mo	V
15Kh2NMFA	0.13–0.18	0.17–0.37	0.3–0.6	0.012–0.013	<0.035	1.8–2.3	0.07	1.0–1.5	0.5–0.7	0.1–0.12
Sv-08G2S (d = 1.2 mm)	0.09	0.89	1.89	0.023	0.024	0.032	0.052	0.028	–	–

in order to eliminate additional heating by Foucault currents. Applied mode of magnetic field influence corresponds to mode for treatment of wrought vessel steel providing maximum effect of microhardness change [4].

Measurements of magnetic characteristics were carried out in closed magnetic circuit on a permeameter scheme. Measured values of initial magnetic susceptibility χ in the specimens were used for plotting its distribution on welded joint section. Values of microstresses σ_{II} and dimensions D of coherent-scattering regions (CSR) were determined on reflection curves, taken using difractometer DRON-4.1. Imaging of difractograms of reference (reflected Armco-iron) and investigated specimens were carried out point by point under constant conditions. Reflections (110) and (220) in filtered K_α-radiation of iron anode were taken for analysis. Area of region being radiated, located close to the weld, did not exceed 4 mm^2. Electron microscope examinations of fine structure were carried out for the same regions using EMV-100BR microscope.

Results and discussion. Figure 2 presents distribution of normalized quantities χ/χ_{min} of initial magnetic susceptibility of welded joint. It can be seen that χ/χ_{min} dependence in the initial state reaches the minimum value in HAZ close to the transition layer, at that χ/χ_{min} rises approximately 2 times for material close to weld center and at around 5.5 mm distance from the transition layer to plate edge. Significant change of distribution nature took place as a result of magnetic treatment. Thus, 40 % rise of χ/χ_{min} is observed close to weld-steel boundary, whereas for areas distant from the transition layer there is approximately 50 % decrease of this value in the weld center.

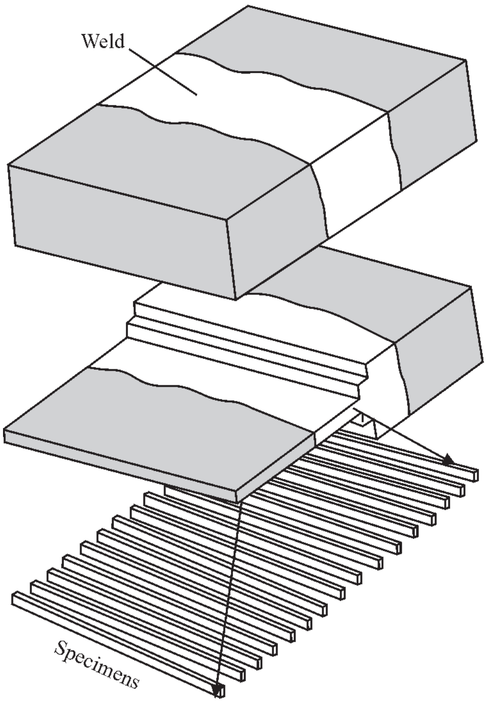

Figure 1. Scheme of manufacture of specimens from welded joint

Let's consider possible reasons of different variations of the initial magnetic susceptibility for different sections of the welded joint. In scopes of existing concepts [5], the initial magnetic susceptibility is determined by reversible small displacements of domain boundaries in the area of weak magnetic fields and depends on distribution of internal stresses, relationships of concentration of different magnetic phases and magnetization orientation in a crystal. Approximately 2 times growth of χ/χ_{min} is observed that corresponds to decrease to the same level of an average amplitude of internal stresses σ_i due to relationship $\chi \sim (\sigma_i\lambda_s)^{-1}$, where λ_s is the magnetostriction constant [5].

The results of X-ray examinations of the relative changes of a lattice period allow making a conclusion on the average value of elastic deformations, and, respectively, microstresses in microvolumes, related with dislocation hardening nature. It was found that σ_{II} and D values in the weld at up to 2 mm distance from the transition layer reduced after magnetic treat-

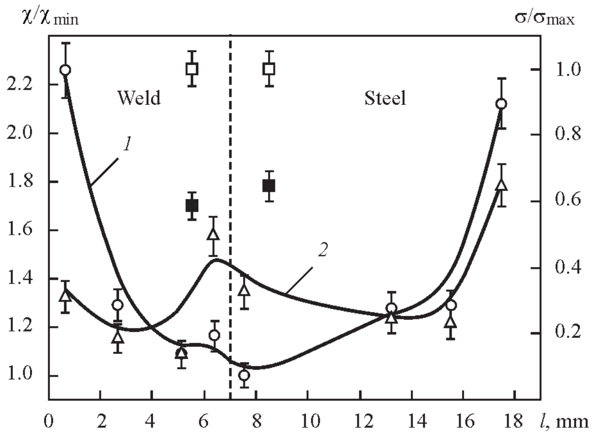

Figure 2. Distribution of given values of initial magnetic susceptibility and microstresses (□, ■) in welded joint: before magnetic treatment (1, □) and after magnetic treatment (2, ■). χ_{min}. σ_{max} are the minimum and maximum values of susceptibility and microstresses, dashed line – weld boundary

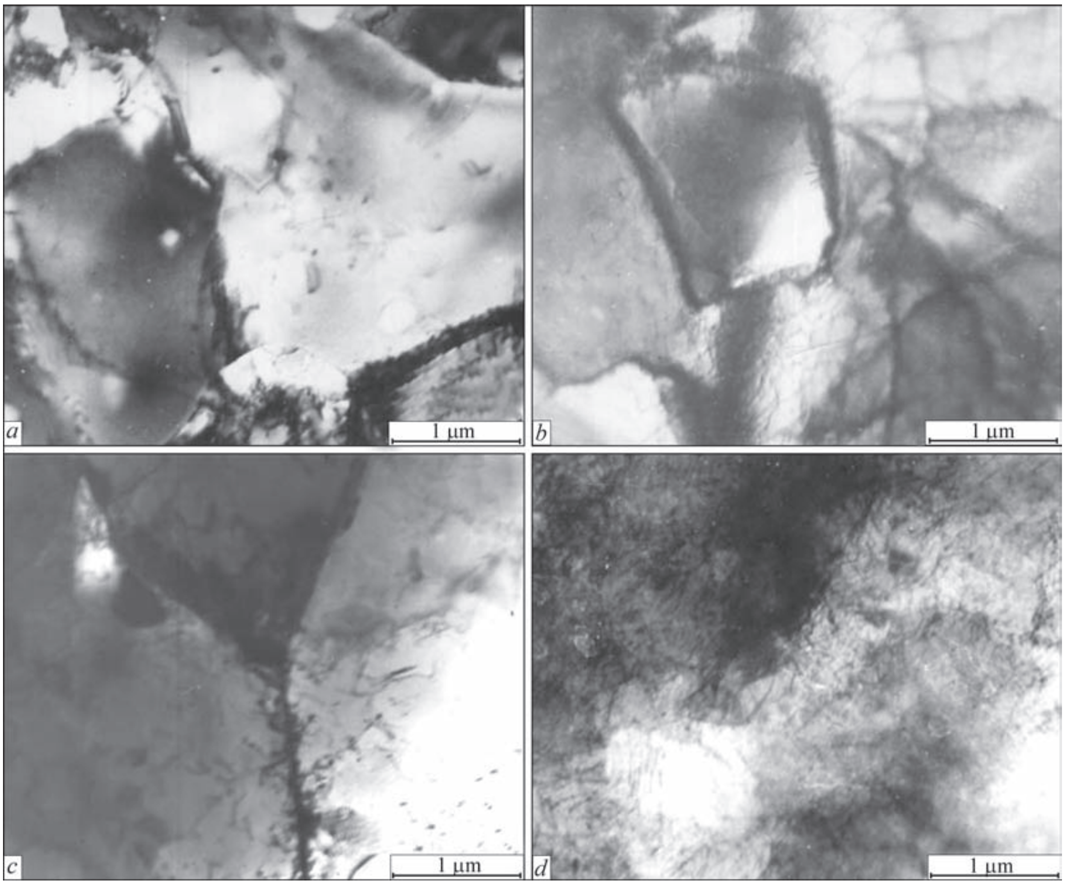

Figure 3. Microstructure of welded joint of steel 15Kh2NMFA before magnetic treatment (*a*, *b*) and after (*c*, *d*): *a* — steel; *b* — weld

ment from 650 to 380 MPa and 0.13 to 0.083 μm, respectively. At the same distance from the transition layer in steel, the second kind stresses make 310 MPa, and CSR dimensions do not exceed upper limit of proper determination of *D* (around 2.5 μm). Magnetic treatment resulted in blocks' division (*D* = 0.25 μm) and drop of stresses to 200 MPa. Thus, microstress changes observed as a result of magnetic treatment in HAZ at qualitative level correspond to the changes of initial magnetic susceptibility.

In the center of welded joint the level of internal stresses in the coarse grains solidified from the melt will be significantly lower and their change at magnetic treatment can not explain dramatic decrease of magnetic susceptibility. It is the most possible case for appearance of the expressed magnetic texture. Fine elongated contours of the areas close to weld boundary from the electron-microscopy images (Figure 3, *a*, *b*) are classified as areas of elastic bending deformations of thermal origin lattice. Density of such formations in the weld makes $4\cdot10^8$ cm^{-2} that indicates high level of inhomogeneity of stressed state.

The result of magnetic treatment is generation of the dislocations in the places of peak elastic stresses and slaking of dislocation walls with formation of chaotic dislocation assembly, similar to tempering structure (Figure 3, *c*, *d*). The same phenomenon is observed in work [6] where microstresses reduced due to vibration treatment and dislocation density rose in a near weld zone of welded steel structure.

Let's study some probable mechanisms of change of dislocation mobility and displacement of spot defects in course of magnetic treatment, making mutually complementary contributions in formation of stress fields. Magneto-elastic stresses inside the domain boundary of steel became close to values of iron $\sigma_m \approx$ ≈ 3 MPa, such a condition corresponds to dislocation movement, which is not fixed by impurity atoms, under effect of elastic deformations inside the domain boundary [7]. Magneto-stimulated depinning (tear) of area of dislocation line with the impurity atoms precedes an elementary act of microplastic deformation. Concentration of impurities in the weld (3–4 wt.%) eliminates the possibility of realization of deformation controlling mechanism, related with overcoming by dislocations of the obstacles in form of the impurity atoms or their accumulations. It is known fact that there is a possibility of appearance of double dislocation kinks at application of external alternating stresses with amplitude below the Peierls stress [8]. It is naturally to assume that microdeformation of material will be controlled by movement of geometry kinks at dislocation edge components. Kink movement along the dislocation under effect of magneto-elastic waves in combination with internal stresses will provoke transverse movement of a dislocation line.

Evaluation of magnetic input in free energy using experimental data (*B* ≈ 0.1, T, H ≈ 40 kA/m) showed that its value is close to magnetic anisotropy due to stable displacement of the pairs of interstitial atoms and vacancies [9]. Directed ordering of the spot defects is apparently the most probable mechanism of induction of magnetic anisotropy [10], which is mainly responsible for significant change of χ value directly in the weld zone.

Effects of mutual influence and self-consistence appear in the process of magnetic treatment in behavior of dislocations and spot defects in HAZ. Superposition of dynamic mechanisms stipulates development of relaxation processes, dissipation of accumulated internal energy, that results in irreversible rebuilding of dislocation structure and setting more uniform stress distribution.

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