alloy since its compressive strength is incomparably higher than its tensile strength. For this reason since it provides no information about the stresses, the stress intensity cannot be a strength criterion for the hard alloy. The calculations and experiments demonstrate that the axial tensile stresses on the cylindrical surface in the zone of the welded joint is such a criterion.

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EFFECT OF ELECTRON TRANSFER ON THE COLD RESISTANCE OF THE NEAR-SEAM ZONE IN ELECTRIC ARC WELDING

Ya. S. Semenov, M. N. Sivtsev, and A. A. Argunova

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Electron transfer can be used to produce atomic fluxes and concentration shifts in alloys and, hence, to study the mobility and diffusion coefficients of atoms [1, 2]. It is also interesting technologically. Electron transfer has been shown to be responsible for damage in metal strips in integrated circuits. On the other hand, it has been used successfully to remove interstitial impurities from metals [3]. Accordingly, we developed [4] a procedure for treating the near-seam zone (NSZ) by the current of the electric welding arc, which lowered the cold brittleness temperature but did not determine why this happened.

In this work we study the microstructure of the near-seam zone and use Mössbauer spectroscopy to study the electron transfer parameters. The following procedure has been developed for Mössbauer studies of electron transfer. A dc current, regulated with an external variable resistance R, is passed through a specimen absorber. The electric current and the voltage applied are determined by instruments built into the power supply.

When a high electric current flows through it the specimen is heated by Joule heating, which cannot be disregarded when determining the electron transfer. In this case the absorber must be placed in a cryostat to keep the specimen at a constant temperature.

Using the scheme described above, we studied the electron-transfer parameters of steels St.3 and 14Cr2MgMoB. These steels are used extensively in the national economy of northeast Russia and lend themselves well to welding. Steel St.3 is customarily used in GOST (All-Union State Standard) welding tests. They can thus serve as a standard experimental material.

Foils for the specimens were prepared by the generally accepted method. Wires to carry the current were welded to the specimen. Mössbauer spectra were obtained on an electrodynamic spectrometer with a Co^{57} γ-ray source.

Figure 1 shows the resonance spectra of St.3 and 14Cr2MgMoB steels with a different current (horizontal axis shows the channel numbers and the vertical axis, the relative intensities: a) shows the Mössbauer spectra of St.3 steel in the initial state and during passage of a current of density 70 mA/mm^2). The resonance spectrum of St. 3 steel in the initial state consists of the sum of the separable partial spectra of ferrite and martensite. With the passage of electronic current the resonance lines become narrower and the martensite spectrum is virtually inseparable. The resonance spectra of 14Cr2MgMoB steel are shown

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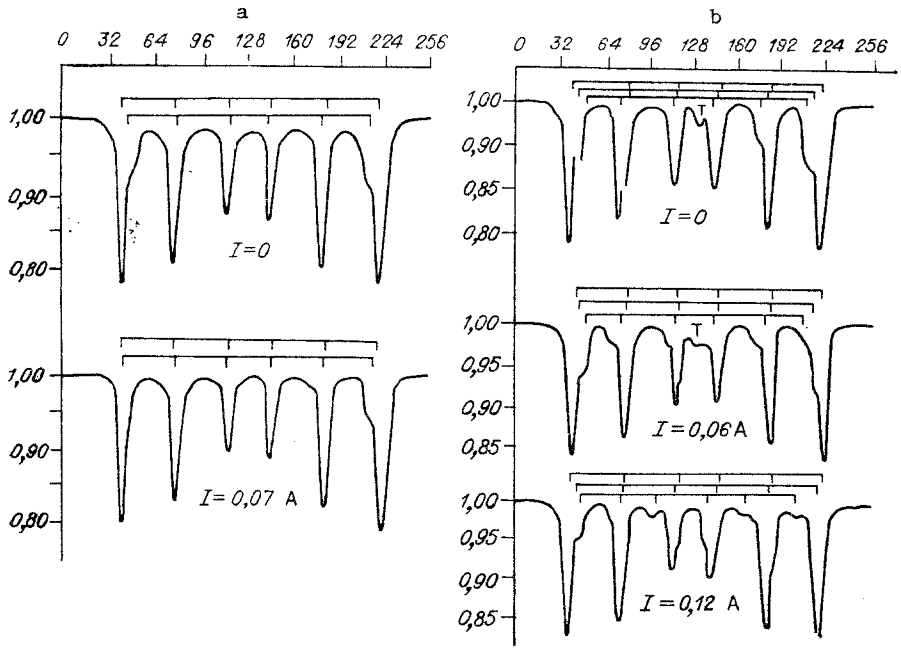

Fig. 1

TABLE 1

Material	I, A	H_{eff}, kOe	$(\delta_i - \delta_0)$, mm/sec	$\Delta\Gamma$
St.3	0	333,36 321,09	—0,025	0,770
	0,07	335,25 325,86	—0,075	
14Cr2MgMoB	0	333,36 321,09 301,99	0,075 0,275	
	0,06	339,03 323,92 296,20	0,15 0,05 0,025	0,706
	0,12	342,81 326,75 311,34	0,05 0,075 0,025	1,412

in Fig. 1b. The initial resonance spectrum of 14Cr2MgMoB steel consists of three separable sextets, corresponding to the ferrite, martensite, and chromium-containing subsystems and a slight amount of paramagnetic residual austenite. With increasing electric current the resonance lines become narrower and the paramagnetic phase vanishes.

It is well known [5, 6] that the narrowing of the resonance lines of the spectrum corresponds to the motion of atoms in the specimen. The experimental spectra obtained when an electric current was passed through St.3 and 14Cr2MgMoB specimens reveal narrowing of the resonance lines, which can be identified with electron transfer. We determined the electron-transfer coefficients by calculating the parameters of the experimental spectra by the method of [7] on a personal computer.

Table 1 shows the results of calculations of the effective magnetic field, isomeric shift, and variation of the average resonance line width. The results show that an increase in the effective magnetic field of the subsystems, a positive isomeric shift relative to α-Fe, and a change in the line width $\Delta\Gamma$. As noted in [5], atoms of the interstitial solid solution, i.e., carbon, can be the most mobile. Electron transfer is effected by a direct force field $F = -eZ^* \operatorname{grad} U$ and the "electron wind" generated by the interaction of impurity atoms with conduction electrons. "Washing" of carbon atoms out of the respective subsystems by such forces increases H_{eff} and changes the isomeric shift and width of the Mössbauer line $\Delta\Gamma$.

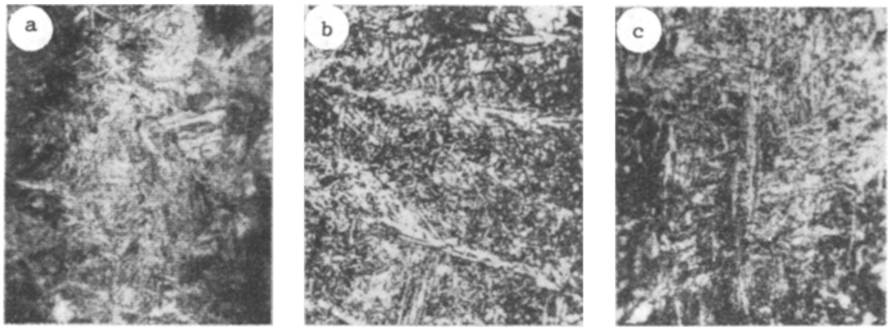

Fig. 2

TABLE 2

Zone of measurements	Specimen (14Cr2MgMoB)	
	1	2
	HV, kg/mm^2	
Base metal ($I = I_W$)	201	191
TEZ	237	234
NSZ	340	328
Seam	221	212
NSZ	340	297
TEZ	259	248
Base metal ($I = 0$)	224	234

An estimate of the diffusion coefficients of the carbon atoms from the parameters of the experimental spectra in accordance with [6] gives the following values: $D = 8.3 \cdot 10^{-5}$ cm^2/sec at $I = 0.07$ A for St.3 steel and $D = 6.3 \cdot 10^{-5}$ and $1.52 \cdot 10^{-4}$ cm^2/sec at $I = 0.06$ and 0.12 A for 14Cr2MgMoB steel. This means that the electron-transfer-induced diffusion of carbon atoms should change the microstructure in the zone where electric current passes during electric-arc welding. For this reason we analyzed the microstructure of various zones of the welded joint and made a fractographic analysis of surface breaks of Charpy impact specimens, at various test temperatures. A metallographic analysis was made on a Neophot-21 optical microscope at various magnifications (×500, ×1000) and the fractographic analysis was done on a Comebax scanning electron microscope.

The microstructure of the welded seam of 14Cr2MgMoB steel has a columnar direction, as indicated by the distribution of the hypoeutectoid ferrite, which precipitates out primarily along grain boundaries as a result of the decomposition of austenite. The bainite component is located between regions of ferrite (Fig. 2b).

The melting point of the metal is the temperature limit of the coarse-grained region on the seam side and about 1200°C, on the base metal side. The high temperature causes growth of austenite grains and the formation of a large-acicular or coarse-grained structure, depending on the chemical composition of the metal and the welding conditions and method. A study of the microstructure of the thermal effect zone (TEZ) and the zone of electric current flow at the same distance from the boundary of the fusion showed that while the troostite-martensite structure is the same the size of the former austenite grain does differ (Fig. 2a, c).

The flow of an electric current substantially increases the diffusion coefficient of carbon atoms in the direction of the electric field. Diffusing, the carbon atoms settle on grain subboundaries, fragmenting the grains. The welding current, therefore, substantially reduces the grain size (Fig. 2c) in accordance with the Hall—Petch relation, raising the yield stress, and at low temperatures it lowers the cold brittleness threshold [9], which accords with the results of [4].

Microhardness measurements in zones of the welded joint were made on a PMT-3 microhardness meter. The averaged results of the measurements are given in Table 2, from which we see that the base metal in the zone of electric-current flow has a low microhardness; this is attributable to the carbon depletion of the troostite-martensite structure since, as is known

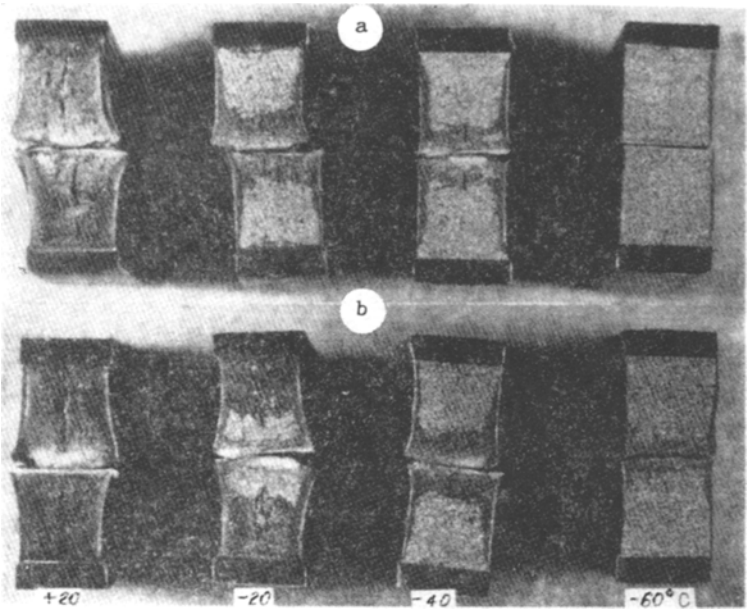

Fig. 3

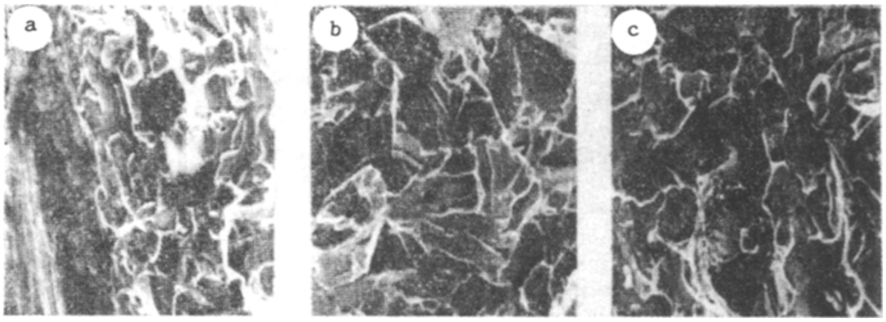

Fig. 4

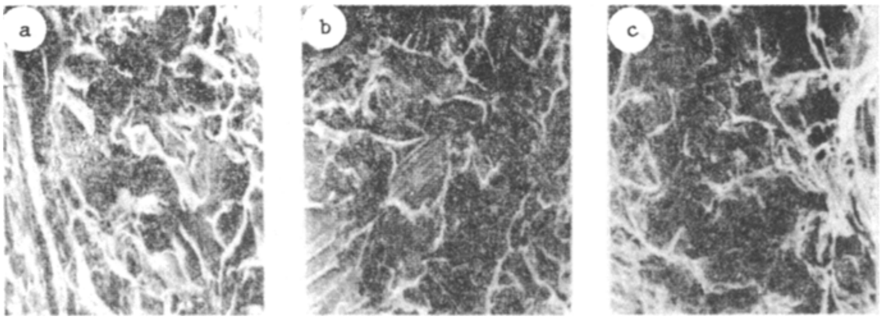

Fig. 5

[10], low-alloy steels with a low carbon content also have a lower microhardness. The decrease in microhardness is clearly visible from the macrostructure of the breaks in the Charpy impact specimens (Fig. 3a) breaks of specimens without treatment with electric current and b) with treatment). The macrostructure of breaks usually does not give a complete picture of the fracture; accordingly, we made a fractographic analysis of breaks in specimens at various temperatures. We studied the surface of breaks in specimens tested at +20°C and −60°C. The specimens were taken in pairs (with and without electric-current treatment).

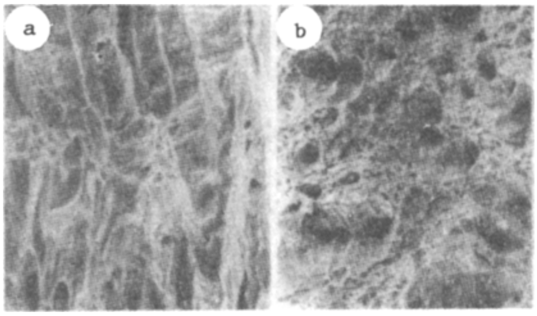

Fig. 6

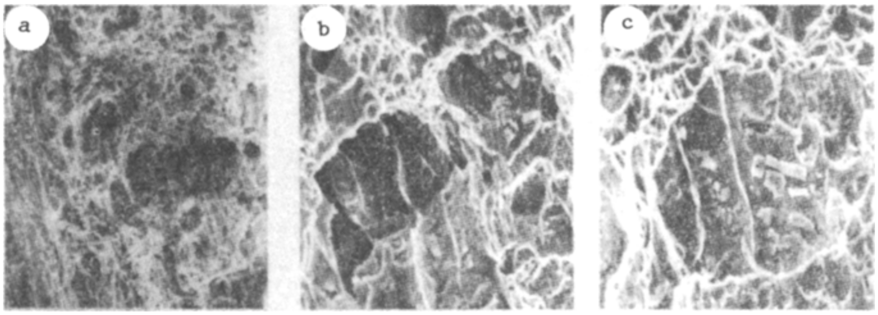

Fig. 7

We consider the fractograms of a specimen which had not been treated with electric current and was broken at −60°C. Brittle fracture begins right from the surface of the notch, if the displacement zone is not taken into account (Fig. 4a). The surface length of the break is 7.55 mm. The largest cleavage facets are 3.21 mm from the notch (Fig. 4b), indicating an accelerated crack development at this place in the break. The transition from the brittle zone to the ductile zone occurs 7.22 mm from the notch and has a length of 0.33 mm (Fig. 4c).

Fractograms of various zones of a specimen treated with an electric current, taken at −60°C, are given in Fig. 5, where zones of crack displacement (a), brittle fracture (b), and ductile fracture (c) can be distinguished. In comparison with the previous specimen, the crack displacement zone is larger and the brittle fracture zone is smaller. A ductile fracture zone (1.25 mm) is clearly distinguishable. This indicates that the specimen not treated with electric current has a lower energy capacity than does the treated specimen, which means that it also has a higher cold-brittleness temperature.

A visual inspection of the surface of the breaks in specimens with and without electric-current treatment, obtained at +20°C, reveals the ductile nature of the fracture with pronounced compression along the sides and with a cracking zone along the middle. From the fractograms of both specimens we an almost completely ductile type of fracture with some characteristic features, such as fatigue striations (Fig. 6a), a sequence of accumulations of large pits in an environment of small pits (Figs. 6b, 7a), and so forth. The stratification faces have the nature of brittle fracture (Fig. 7b, c). The explanation for this is that the electron transfer of carbon atoms to grain boundaries and subboundaries leads to the formation of a brittle, carbon-saturated phase at those boundaries.

In summary, we can conclude that the electron transfer in the near-seam zone of a welded joint has a favorable effect on its cold resistance. The cold-brittleness temperature is lowered because the former austenite grains are fragmented, the average microhardness drops, and the concentration shifts of carbon atoms decreases.

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