INFLUENCE OF SUBSTRUCTURE STRENGTHENING OF LAW-CARBON STEEL ON THE ARCING PROCESS

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Abstract. For the arcs of forward and reverse polarities there found extreme dependences value of electric current on cold drawing with a maximum at 60% strain. In order to explain the nature of the dependencies of value of electric current on cold drawing the equation for estimating electric current was used with the replacement of surface tension coefficient for the surface tension coefficient of the ferrite of low-carbon steel. Taking into account the fact that as cold drawing increases from 17 to 80% the size of cells is reduced by 30%, the value surface tension coefficient of the ferrite was increased approximately by 1.5 times. After substituting surface tension coefficient of the ferrite in the ratio it has been found sufficiently good agreement of value of electric current with the experimental values of the welding current for reductions of up to 60%. Increase of cold drawing over 60% has led to an increase in differences up to 14–22% between value of electric current and the obtained experimental data.

Key words: structure, electric current, cold drawing, cell, ferrite.

1. INTRODUCTION

Stability of the electric arcing process according to the technology using a meltable electrode is determined by the influence of numerous factors [1]. The most significant ones include reaching a certain ratio between the speed of electrode metal melting and its feed into the reaction zone, which stipulates maintaining the size of the inter electrode space. In addition to the above mentioned factors the metal transfer process through the inter electrode space should influence the arcing stability [2]. Indeed, maintaining a certain balance between the input energy and the energy spent for melting the joinable edges, for the development of metallurgical reactions, for filling the welding pool with metal, etc. makes it possible to achieve the conditions of formation of high-quality welded seam in a whole. Taking into account the fact that the metal transfer through inter electrode space is carried out in the form of a gas-droplet mixture, the process of forming a liquid metal drop at the end of the electrode, its size and shape should to some extent influence the characteristics of the electric arc welding. From the analysis of the simultaneous effects of several factors on the formation of droplets, two power components deserve some attention. They are the surface tension of the metal and the gravitational force [3]. Based on this, the process of the liquid metal drop formation except the physical constants of the metal should be determined by the features of the internal structure in the solid state. The study is aimed to evaluate the possible influence of the formed low-carbon steel substructure on the process of electric arcing.

2. METHODOLOGY

Material for the electrode was a wire with the diameter 1 mm made of steel with 0.2% carbon content. Different degrees of substructural strengthening were achieved by varying the heat treatment and cold deformation parameters. To achieve different degrees of plastic deformation the blank diameter was adjusted so that after drawing the final diameter of the wire was 1 mm. The heat treatment was carried out by heating in electric oven SNOL — 1,6.2,5.1/11-ИЗ, to control the temperature the thermocouple chromel — alumel and potentiometer of direct current were used. The initial structural state of steel corresponded to improvement (hardening form the temperatures above Ac_3 and tempering at 650°C, duration 1 h.). It was followed by cold drawing for the values of 17–80%. Metal microstructure was observed under transmission electron microscope УЭМВ — 100 K at the accelerating voltage of 100 kV. Thin foils for diffraction electron microscopic studies were made by the methods of Bohlmann and tweezers in the chlorous-acetic reagent and the Morris reagent [5]. Size of the steel submicroscopic elements was evaluated using a quantitative metallography methodologies described in the work [6]. The defect density of the crystalline structure was measured on a diffractometer ... using a scintillation registration of X-ray reflexes [7]. Survey was carried out in the monochromatic SuK_{α} radiation at room temperature. To remove the cold-hardened metal layer after grinding the samples for X-ray studies were subjected to electrolytic dissolution in the chlorous-acetic electrolyte. Treatment duration was determined on the basis of removal of 1 micron of metal from the grinding surface for 1 min. It was studied the process of electric arcing of forward and reverse polarity with the definition of the welding current value. For studies of the arcing process welding converter... was used. The average value of the welding current was estimated at 10 measurements.

3. FINDINGS

During the welding the formed arc is burning between the electrode and the workpiece. One of the major forces that determine the process of drop formation at the end of the electrode wire are the axial component of the pinch effect and the force of the metal surface tension. Based on the analysis of experimental data [1–3] it can be expected a certain influence on the phenomenon under consideration from the effect of gravitational forces. Although in the case of slight change in the welding current force the influence of gravitational component can be attributed to the category of permanent characteristics [2]. As the metal melts, it concentrates at the end of the electrode in the form of drop under the action of surface tension forces. The drop is growing until the moment of achievement of equality from the action of the gravitational component and surface tension forces. It is followed by separation of the formed drop. Taking into account that as the temperature increases the surface tension force of the metal is reduced, increase of the welding current value should be accompanied by a quite expected increase in the dispersion of the formed drops. The above-mentioned situation is caused by proportional dependence of the electrodynamic force on the current value during welding. On the basis of the balance analysis between the gyrostatic pressure from pinch effect and the surface tension strain, the value of the critical welding current (I_c) at which the molten metal drop is being formed is estimated as follows [3]:

$$I_c = C\sqrt{\sigma \cdot d}, \quad (1)$$

where C — is a constant; σ and d — the surface tension coefficient of metal and the electrode diameter, respectively.

For steels the value C is 32.7 $A/\sqrt{dyne}$. For the estimations of I_c the value σ is taken equal to the surface tension coefficient of the molten iron (1220 *dyne/cm* [3]). After substituting the above mentioned data into (1) the value of the critical welding current for the steel under study was about 360*A*. Comparative analysis with known results showed good agreement [3, 4]. The obtained results of the arcing process research showed that in the conditions of stable arcing of straight polarity (Fig. 1) the welding current value (I_x) is about an order of magnitude lower than the values of the estimated level (360*A*). Although for the arc of reverse polarity the difference is less, but it still exceeds the value I_x for 5–6 times. Taking into account the sensitivity of the metal substructure parameters to the welding modes [4], it can be assumed that either the value *A* is not a constant one and depends on the chemical composition of the steel, or one should use a different characteristic instead of using the coefficient of surface tension of the liquid metal. Indeed, as it follows from the nature of the correlation relationship (Fig. 1) between the degree of cold reduction after the wire drawing and the welding current force in the conditions of stable arcing for explanation of the dependence $I_x=f(\varepsilon)$ one can use equation of the type (1) having replaced the coefficient of the molten metal surface tension by the surface tension coefficient of metal in the solid state.

According to stoichiometry the volume fraction of the ferrite in the mild steel with 0.2% carbon is about 97%. Based on this it is reasonable to replace the value σ in the relation (1) for the surface tension of ferrite (σ_F) of the steel under study. To estimate the surface tension coefficient of ferrite the results of studies [8] will be used. According to these studies the value σ_F is estimated by the relationship:

$$\lambda = \frac{G \cdot b^2}{2\sigma_F}, \quad (2)$$

where G — is a ferrite shear modulus (0.82 *dyne/cm*^{2}); b — Burgers vector equal to $2{,}3 \cdot 10^{-8}$ [8, 9]; λ — distance between chaotically distributed dislocations.

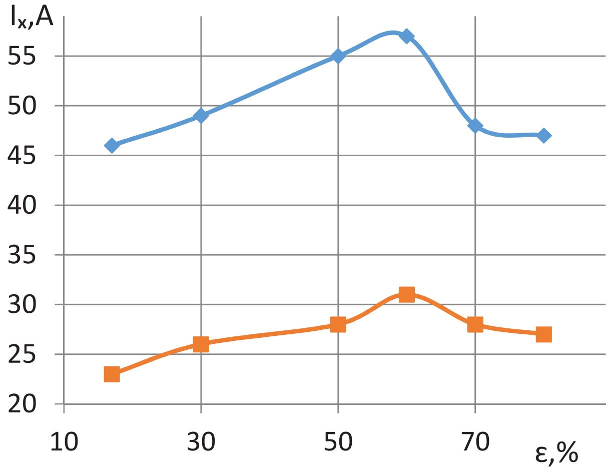


Fig. 1. The influence degree of plastic deformation by drawing on the magnitude of the welding current (I_x) when arcing straight (■) and reverse (♦) polarity

After cold drawing the dislocation cell structure (Fig. 2) with different degrees of perfection is starting to form in mild steel after 20–30% reductions. As compared to the conditions of calculation according to the work [8], when it is assumed existence in the ferrite of almost uniform dislocation distribution, the occurrence of inhomogeneity in their distribution may change the character of dependence according to the work (2). Indeed, decomposition of the uniform distribution of dislocations into the periodic structures leads to a change in the value λ in a fairly wide range of values [9,10]. On this basis, it is difficult to estimate the average value of the distance between dislocations for the case of their inhomogeneous distribution in the metal microvolumes. On the other hand, for the cold-deformed state the cumulative dislocation density and the size of dislocation cell which is being formed are connected by the inverse relationship [10, 11]. On this basis, for the estimations of the surface tension coefficient of the ferrite it was made an attempt to replace the distance between dislocations in the relation (2) by the size of dislocation cell (*D*). After that, the dependence (2) takes the following form:

$$\sigma_F = \frac{G \cdot b^2}{2D}. \quad (3)$$

On the basis of the cold-deformed metal structure studies using the methodologies of quantitative metallography it was discovered the unique dependence of the size of dislocation cell

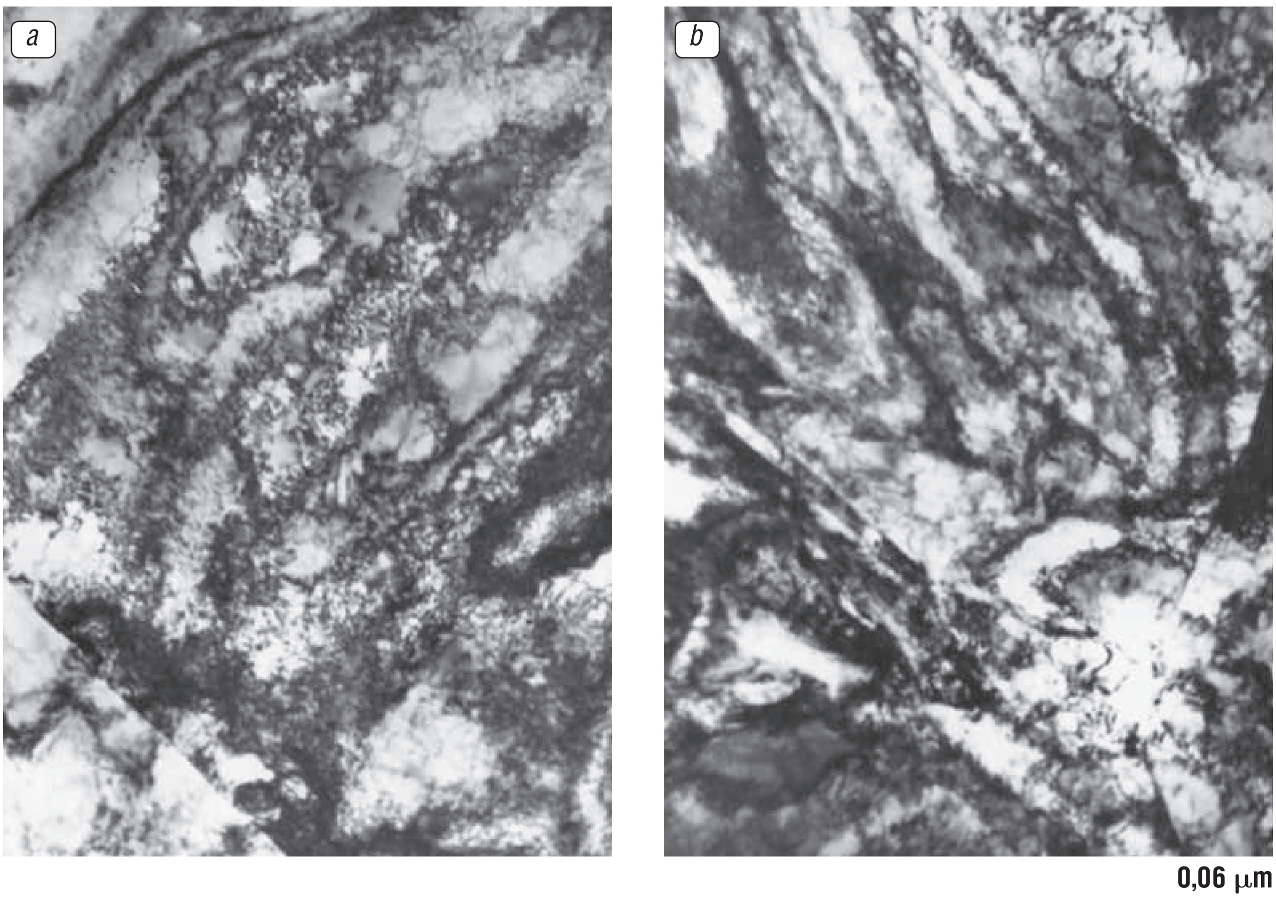


Fig. 2. The structure of steel with 0.2%C after hardening, tempering at 650 C, cold-drawn by 17 (*a*) and 30% (*b*)

which is being formed on the degree of the wire reduction during the cold drawing (Fig. 3*a*). The obtained values D are in fairly good agreement with the known experimental data [9,10].

After substituting the permanent metal characteristics and the size of dislocation cells into (3) values σ_F were calculated. The dependence of s_F reduction value during deformation of the low-carbon steel is shown in the Figure 3*b*. According to the obtained data increase in the degree of cold reduction when drawing is accompanied by increase of the surface tension coefficient of the ferrite. After substituting the calculated values of the ferrite surface tension coefficient into the ratio of the type (1), the evaluation of the value of electric welding current (I_D) has been carried out:

$$I_D = C\sqrt{\sigma_F \cdot d}\ . \qquad (4)$$

It can be assumed that the values I_D should be enough to maintain stable conditions of straight polarity arcing. Results of the welding current calculation according to (4) are compared with the experimental data of (I_x) in the Figure 1. A comparative analysis of the values I_D and I_x (Fig. 4*a*) for the straight polarity arc shows a good agreement between them to the 60% reductions. For reductions exceeding 60%, the observed differences in the dependencies I_D, $I_x \sim f(\varepsilon)$ can be caused by the emergence of qualitative changes in the dislocation cellular structure. Indeed, at a reduction more than for 60–70% the processes of improvement of the formed dislocation cells start to develop in the carbon steels. At high degrees of plastic deformation the progressive increase of the dislocation density is accompanied by intensive cleansing of the cell body from unbound dislocations, changes in the cells form, reduction in the thickness of the sub-boundaries, etc. [9–11]. All of this evidently leads to the distortion of the ratio (3) and, consequently, to the error increase when estimating the surface tension coefficient of the ferrite.

The obtained results for the straight polarity arc are supported by the data for the reverse polarity arc too. At constant sub-structural parameters of cold-deformed steel for the arc of forward and reverse polarity, equidistant nature of the dependencies $I_x = f(\varepsilon)$ (Fig. 1) indicates the value C as a single characteristic that could compensate the disagreement of the calculated values of the welding current for the reversed polarity arc (I_D^*).

Comparative analysis of the absolute values of the welding current (Fig. 1) value indicates that the value C for the arc of reverse polarity should be about 60 $A/\sqrt{dyne}$, against 32.7 $A/\sqrt{dyne}$ for the straight polarity arc. After substituting C=60 $A/\sqrt{dyne}$ into (4) = 60 and performing calculations the change nature I_D^* is represented in the Figure 4*b*. As for the straight polarity arc, good agreement between the calculated and experimental values of the welding current is limited to 60% reduction. For large reductions the disagreement degree is proportional to the level of welding current values. Indeed, for the conditions of straight polarity arcing, when the level of I_x is 20–35*A*, the error in the calculating value I_D is 14%. For the reverse polarity arc with I_x of about 45–57*A*, the value of I_D^* deviation from the experimental values is about 1.5 times higher.

Thus, the conducted studies indicate the existence of a certain influence of the inner structure

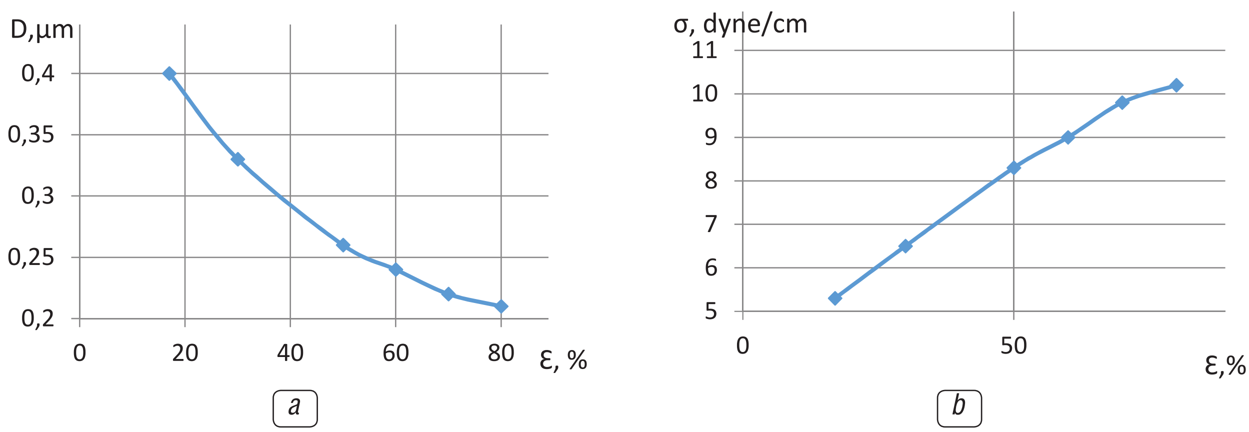
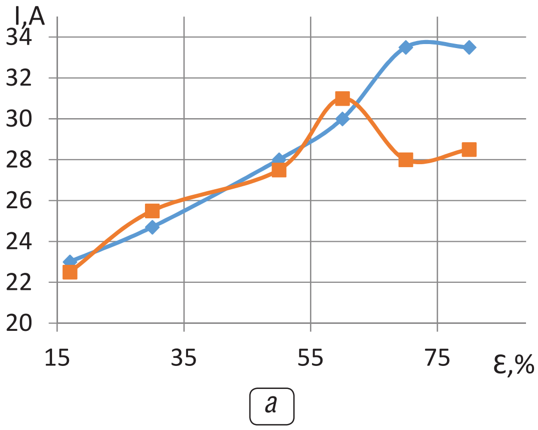


Fig. 3. The dependence of the average size of dislocation cells from the amount of cold drawing (*a*), and calculated value by σ_F by (3) — (*b*)



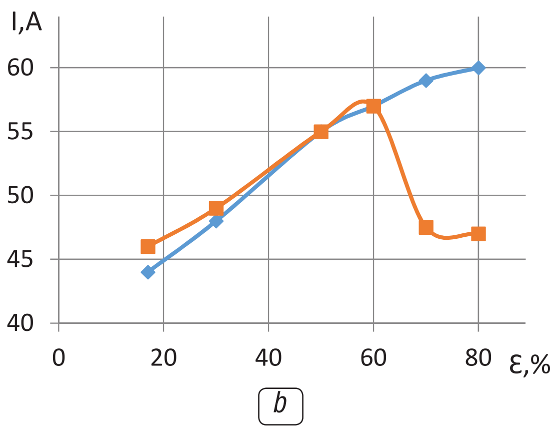


Fig. 4. The influence reduction of drawing on I_D (♦), I_x (■) arcing straight (*a*), and I_D^* (♦), I_x (■) for reverse polarity (*b*)

of the electrode metal in the solid state on the arcing processes. Overall, even with the observed deviations for large reductions, the dependence of the electric current value when burning the arc of different polarity is satisfactorily explained by the parameters of the substructure which is being formed as a result of cold drawing of low-carbon steel.

4. CONCLUSIONS

1. In the conditions of stable arcing of different polarity for the electrode of mild steel the extreme dependence of the welding current on the degree of cold plastic deformation was found.

2. Dispersing the dislocation cellular structure of the low-carbon steel with growth in the reduction degree during drawing is accompanied by increase in the welding current regardless of the polarity of the arc.

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