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Surface hardening of structural steel by cathode spot of welding arc

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Abstract. The structure, phase composition, and morphology of the surface layers of structural 1020, 1050, 1060 steels of the steel modified by the cathode spot of the welding arc are studied with the help of electron and optical microscopy. It is shown that the treatment of the cathode spot of the arc leads to grain refinement in the surface layer and causes its hardening. As a result of this treatment, partial or complete amorphization of the surface layer is possible.

1. Introduction

It is known that the erosion of oxide films on electrodes under the influence of nonstationary spots of the arc was studied in detail both theoretically and experimentally [1-3]. Under certain conditions, cathode spots of the arc with a power density on the surface up to 108-1010 W/m² can be an effective instrument for cleaning the surface of metals from contamination and improvement of the surface properties of structural materials [4-5]. This work is a continuation of the work [6,7] and is devoted to the study of the zone of thermal influence of a modified layer of structural steel treated with a welding arc on the reverse polarity. The morphology, phase composition, and microstructure of the thermal effect zone were studied to determine the functional characteristics of the surface of the treated material.

2. Materials and methods of the experiment

Samples of structural steel AISI 1020, 1050, 1060 with the dimensions of 60×10×5 mm were processed. Influence of the cathode spot on the metal surface was considered in detail in [6,7]. Pre-treatment of AISI 1020 steel formed the structure of ferrite and pearlite. Pre-heat treatment of steel AISI 1050, 1060 led to the formation of a polycrystalline structure, represented mainly by grains of pearlite plate morphology. In small amounts in steel, there are ferrite grains free of the carbide inclusions phase (hereinafter – the grains of structurally free ferrite) and the ferrite grain, in the bulk and along the boundaries which are particles of cementite of globular shape (hereinafter – grain “pseudopelade”). The dislocation substructure in the form of randomly distributed dislocations is observed in the ferrite layers of perlite [7]. The grains of ferrite and “pseudopelade” contain the dislocation substructure in the form of grids and randomly located dislocations [7]. Close to the borders and junctions of grain boundaries



of ferrite there is a fragmented structure. It was shown that contamination evaporates from the metal surface under the influence of cathode spots (Figure 1), and structural-phase transformations occur in the underlying layer of steel under the influence of heat flux in the zone of the spot. Constant current of the arc is $I = 250$ A, arc burning voltage is 25 V with atmospheric pressure in the air. Arc burning time was regulated within the limits of $(0.4-900) \cdot 10^{-3}$ s. The interelectrode distance L is 3 mm. Initiation of the arc was carried out by a high-voltage impulse. Samples for studying the properties of the modified surface were cut for metallographic studies, for comparison, the original untreated surface was studied. The phase composition and structure of the surface layers were studied with the help of a Shimadzu XRD 6000 diffractometer in $Cu_{K\alpha}$ -radiation. The microstructure of the modified layer was studied on a metallographic microscope with a power up to $\times 1000$ on transverse sections after etching with a 4% solution of HNO_3 in ethyl alcohol. The microhardness of the structural components was determined by means of a PMT microhardness tester by pressing a diamond pyramid with a load of 0.1 N. Images of the surface of the section with a higher spatial resolution and local microanalysis were studied with a help of scanning electron microscope JEOL JIB-Z4500, equipped with an attachment for energy-dispersive analysis.

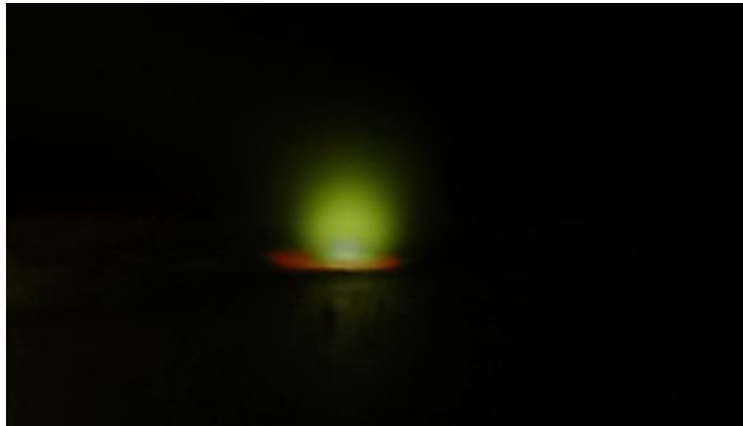


Figure 1. Cathode spot of the welding arc as a concentrated heat source [7].

However, in our experiments, such cases when spots of the first type were emitted by spots of the second type (their lifetime did not exceed 17-20 μs) were observed. Studies of the microstructure of the surface layer of steel cathodes and measurements of microhardness have shown that in the case of cathode spots of the first type, cathode surface fusion does not occur. Structural changes occur in the surface layer of the steel cathode, and these changes lead to the formation of a thin layer with a structure of finely dispersed martensite. Layers with a martensite structure are characterized by a small depth (Figure 2, 3, 4a). As the carbon content in the steel cathode increases, microhardness of the hardened layer increases. A high degree of dispersion is due to the achievement of a high degree of tetragonality of martensite, dislocation density and grinding of the rods and plates of martensite. The microstructure of the surface cathode layer is similar to the quenching structures obtained by laser, electron beam and plasma hardening of metals.

Cathode spots of II type that appear on the cleaned and prepared surface (due to the influence of the spots of I type) leave traces of deep melting (Figure 5). Figure 4b shows the distribution of microhardness over the depth of the cathode after interaction with cathode spots of the II type.

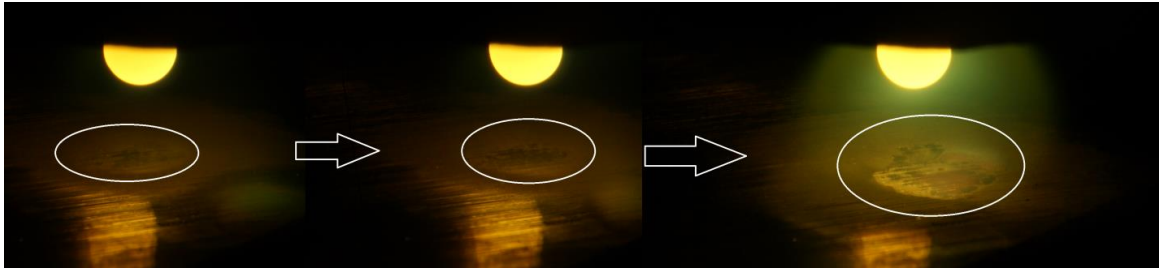


Figure 2. Dynamics of changes on the metal surface after treatment with cathode spots of the 1st type.

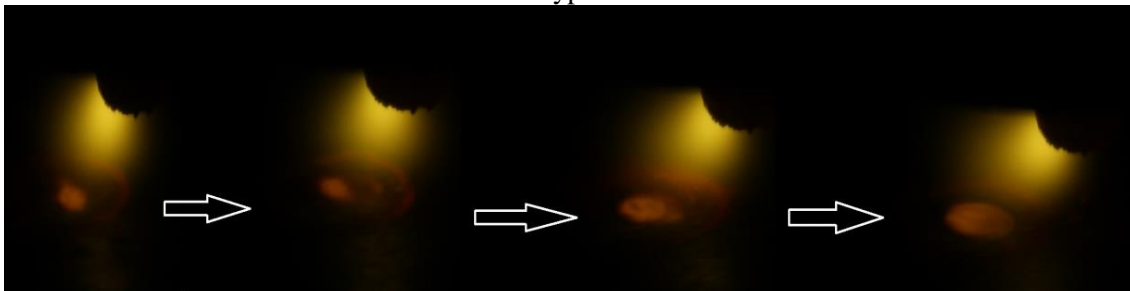


Figure 3. The dynamics of the cathode spot of the 2nd type on the surface of the metal.

The hardened layer of cathode is characterized by three zones: a quenching zone from the liquid phase, a quenching zone from the solid phase (martensite structure), a transition zone from the base metal of the cathode (troostite-sorbitol structure). When the surface is melted, the depth of the hardened layer is greater than that without the surface melting. The melting process of the zone of the surface layer under the cathode spot is accompanied by its saturation by the atoms of the vaporized metal, nitrogen and oxygen, and also by the carbon molecules from the surrounding vapor-gas mixture. In the center of the trace, fritted by the cathode spot, compressive stresses, which transform into stretching ones on the boundary with the unmelted surface of the cathode [7], are recorded.

On the transverse surface of the steel sample, various structural zones are clearly visible, formed as a result of high-speed heating and step-by-step cooling of the material. The first zone, directly adjacent to the surface, is formed from an iron-carbon melt in the form of ultrafine crystallites based on the matrix of α -Fe. In this zone there are transformations of the “liquid–solid” type. High-speed cooling of the steel resulted in hardening of the surface layer. A martensitic structure is formed in the volume of crystallization cells. The size of crystal grains of martensite in most cases was limited to the cell size of crystallization; the transverse dimensions of the martensite crystals changed in the range of 70–110 nm. On the borders and in the joints of the boundaries of cell crystallization in samples of AISI 1060 structural steel, revealed particles of rounded shape. These particles are graphite. The size of the graphite particles changes in the range of 100–165 nm. Martensite crystals and graphite particles are assigned to the nanoscale level. To the nanoscale level, there are also interlayers of austenite particles of cementite (cementite “smoothback” steel) detected along the borders and in obamanistas martensite. The revealed heterogeneity of the structural-phase state of the surface layer of steel after heating with cathode spots is obviously due to the features of the structure of the initial state, namely, the presence of grains enriched with carbon (pearlite grains) and grains with a minimum carbon content (ferrite grains).

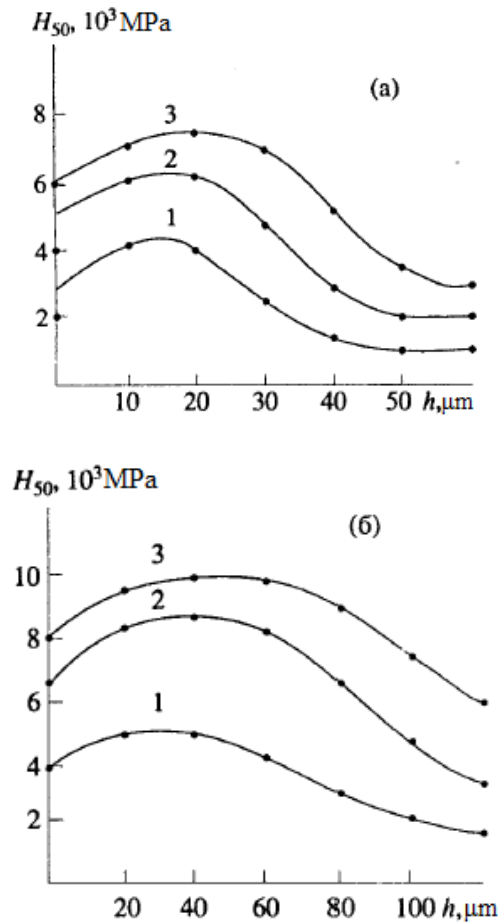


Figure 4. Distribution of microhardness along the depth of steel cathodes after interaction with cathode spots of I type (a) and II type (b): 1 - Steel 1020; 2 - Steel 1050; 3 - Steel 1060.

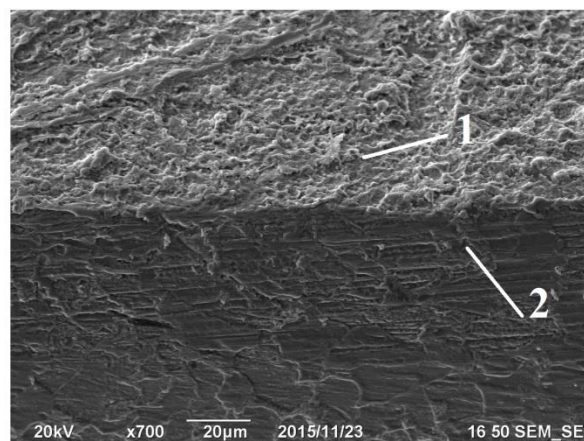


Figure 5. An electronic photo of the surface after exposure to cathode spots II (1) and the surface layer of modification (2).

In the next zone of strong thermal influence (zone II), the temperature does not rise to the melting point of the material, and transformations occur in the “solid–solid” system. The thickness of this zone depends on the speed of the cathode spot and the thermal properties of the processed material. The third

zone is characterized by a mixed structure formed below the temperature of AC1. By X-ray diffraction analysis it was found that in the modified layer in the upper part of the heat-affected zone in the matrix α -Fe there is a small amount of ultradispersed particles of austenite and martensite (by ~0.7%) of ~40-70 nm in size. The presence of martensite and residual austenite indicates the occurrence of polymorphic steel in this layer $\alpha \Rightarrow \gamma \Rightarrow \alpha$ -transformation. In zone II, a multiphase morphologically diverse structure is formed, which is formed in the temperature range of AC3-AC1 of the coexistence of three phases – β -phase, γ -phase and iron carbide. The main phase of this layer is the β -phase. The predominant morphological form of the β -phase is grains, in which martensitic transformation took place with the formation of packet martensite crystals and plate martensite crystals. On the micro electron diffraction patterns obtained with a martensitic structure, there are almost always reflexes of the γ -phases (residual austenite), pointing to the incompleteness $\alpha \Rightarrow \gamma \Rightarrow \alpha$ -turning in the small number of detected grains of structurally free ferrite, which was identified in the structure of steel before its treatment. Therefore, the martensitic structure was formed in the grains of pearlite and “pseudopelade”, i.e. enriched in carbon. In the studied layer of zone II during the processing of steel AISI 1060, pearlite grains are detected, in the volume of which various stages of thermal destruction of cementite plates are fixed. In this case, martensite crystals, interlayers and/or islands of residual austenite and cementite particles of lamellar or globular form are present in the grain volume. The thermal transformation bean “pseudopelade” in some cases leads to the formation of the structure of grain-subgrain type. The size of the grain-subgrain structure varies widely 200-550 nm. In the junctions and along grain boundaries there are particles of cementite of globular morphology; particle size change in the range of 15-25 nm. The volume of these grains and subgrains are present in the crystals of the packet martensite, the transverse dimensions of which vary in the range of 30-50 nm.

3. Conclusion

Conducted investigations made it possible to determine that as a result of the influence of cathode spots of the I and II types with the metal surface in the surface layer of structural steel AISI 1020, 1050, 1060, quenching structures with very high hardness are formed. The formation of a heterogeneous structure of the surface layer is connected, on the one hand, at ultra-high speeds of heating and cooling (little time of homogenization), realized in the processing of steel cathode spots and, on the other hand, the heterogeneous structure-phase state of steel before treatment (grain pearlite and “pseudopelade”, grains of structurally free ferrite). Herewith, cathode spots of I type harden the surface layer without melting the surface, and cathode spots of the II type - with melting the surface. It was determined that the main factor that affects the phase composition and structure of the hardened layer is the cooling rate of the material after the cathode spot stops influencing. The formation of a polycrystalline structure with an ultra-small grain size (0.9-1.7 μm), in the volume of which a nanoscale martensitic structure was found in the layer located on the boundary of the melt bath.

References

- [1] Cobain George, Harris L, Ecker G, Farrell J, Greenwood A, Kimblin S 1982 *Vacuum arcs* (Moscow: Mir) p 432
- [2] Rakhiv V I, Lyubimov G A 1978 *Cathode Spot of a Vacuum Arc. Phys* **125(4)** 665-703
- [3] Kesaev I G 1968 *Cathode Processes of Electric Arc* (Moscow: Nauka) p 244
- [4] Takeda K 2000 *Surf.Coat.Technol* **131(1-3)** 234-238
- [5] Yuya Kubo et al. 2005 *Surface and Coating Technology* **200(1-4)** 1168-1172
- [6] Balanovskii A E 2016 *High Temperature* **54(5)** 627-631
- [7] Balanovskii A E 2018 *TVT* **56(1)** 3–13