The influence of plasma power with a liquid electrode on the microhardness of gray cast iron

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Abstract. The effect of a plasma jet in an installation with an electrolytic cathode on the structure and properties of gray iron has been investigated. The dependences of the sizes of the zone of plasma treatment influence, the average diameter of dendrites and microhardness on the plasma power in the range of 2 to 6 kW have been determined. It has been established that as the plasma jet power increases, the volume of the reflow zone and the size of the grains of its structure increase, while the microhardness of the treated cast iron decreases.

1. Introduction

Concentrated energy flow is an effective tool for modifying the properties of traditional materials. [1 – 3]. Low-temperature plasma sources are especially widely used as such a tool [4 – 8]. The least studied are the processes occurring when a plasma substance is subjected to electrical discharges using liquids. At the same time, this method is of particular interest, since the use of various liquid media provides ample opportunities in regulating the chemical composition, structure and properties of modified materials [9 – 12].

In recent years, as a result of the joint efforts of researchers and engineers, a number of new plasmatrons has been developed, using an electric discharge between solid and liquid electrodes [13, 14]. The practical application of these plasmatrons in the production field is delayed due to the insufficient knowledge of the processes occurring in materials under the influence of plasma. The modification of the surface layers of the material by plasma treatment with preservation of the original properties of the massive core is of particular interest for engineering. In particular, cheap gray cast iron widely used in mechanical engineering, does not often meet the requirements of modern production, under surface-loaded working conditions [15, 16], therefore, the study of the influence of plasma parameters on its mechanical properties in order to modify them is of practical interest.

2. Materials and methods

Gray cast iron with a mass concentration of the elements C = 3.4%; Si = 1.9%; Mn = 0.8%, P < 0.2% and S < 0.15% was used as a research material. Samples of this cast iron were treated with a plasma jet of electric discharge between a solid metal electrode and an electrolyte. To obtain a plasma jet, a uniquely designed device with a discharge chamber in the shape of a truncated hollow cylinder with a dielectric tube was used [13]. The treatment was carried out with a plasma jet velocity of 10 mm / s, and the jet spot diameter on the cast iron surface was 6–8 mm. The power of the plasma jet varied.
from 2 to 6 kW. When the plasma treatment modes are used, two zones are formed in the surface layer of cast iron: a reflow zone and a heat-affected zone.

To determine the hardness of the samples the "Durimet" device was used. The microhardness was measured in layers, 30 μm from the surface to the depth of the treatment zone, according to the results of 5 measurements with a load of 0.5 N.

3. Results and discussion
The phase and structural transformations in the surface layers of cast iron when exposed to plasma are determined by thermal and hydrodynamic processes that accompany the material's absorption of the discharge energy. The main physical processing parameters that determine the thermal field in the material are the specific power of the flow and the time of plasma exposure.

When the plasma treatment modes are used, two zones are formed in the surface layer of cast iron: a reflow zone and a heat-affected zone (Figure 1). When processed with a concentrated flow of energy, it is absorbed by a small volume of material, its remaining massive part is still relatively cold. In this connection, ultrafast cooling of the treated zones occurs. In other words, the cast iron is hardened: in the zone of reflow from the liquid state, and in the zone of thermal influence from the solid state. This leads to a quantitative and qualitative difference in the microstructure and properties of these zones. Therefore, the study was carried out separately, by zones.

In the equilibrium state, graphite cast irons consist of a metal base and graphite inclusions. Prior to plasma treatment, the initial structure of the iron under investigation is a lamellar perlite with lamellar graphite inclusions.

After plasma treatment there are no graphite inclusions in the reflow zone. This happens because graphite under the influence of plasma is completely dissolved in the liquid metal and then does not have time to stand out in the form of inclusions due to the ultrafast cooling. The metal in the reflow zone has a dendritic structure (Figure 2).

The reflow zone is a highly crushed structure, which consists of small dendrites grown during the crystallization of the molten metal, surrounded by finely-dispersed ledeburite. In this case, the average size of the dendrites depends on the power of the plasma jet (Figure 3). A noticeable increase in the size of dendrites occurs in the power interval from 2 to 4 kW, a further increase in power practically does not affect the average diameter of the dendrites.

A proportional change in the size of the dendrites from the power of the plasma jet in the range of 2–4 kW is accompanied by a similar change in the area of the reflow zone (Figure 3). However, with a further increase of the power of the plasma jet, the dimensions of the reflow zone increase significantly: the area of the reflow zone at the power of 6 kW reaches 30 mm², that is, more than 2 times compared to the dimensions of the reflow zone at 4 kW.

The increase of the power of the plasma jet and of the area of the reflow zone is accompanied by the increase of its depth (Figure 4).
Figure 3. The dependence of the average diameter (d) of dendrites and the area of the reflow zone (S) on the power of the plasma jet.

Plasma treatment of cast iron significantly increases the hardness of the surface layers of gray cast iron. If the microhardness of the initial samples of cast iron was only 200 HV, then after exposure to plasma, the microhardness of the reflow zone reaches 1100 HV. Although the microhardness drops to 700 HV when the plasma jet power is increased to 6 kW (Figure 4), it is still more than three times higher than the original value.

Figure 4. The dependence of the microhardness (HV) and the depth of the reflow zone (h) of the cast iron on the power of the plasma jet.

Such large values of the hardness of the plasma-treated zone compared to the initial state of the cast iron are explained by the processes of its hardening. The high cooling rates of the reflow zone are due to the influence of the nearby cold layers of the bulk material. As a result of the transformations of a solid solution of carbon based on iron at high cooling rates in the reflow zone, a metastable structure of martensite, a supersaturated solid solution of carbon in α-iron, appears.

As shown above (Figures 3 and 4), as the plasma jet power increases, the volume of the reflow zone increases. The thermal energy accumulated in this zone reduces its cooling rate as it is not exposed to the plasma anymore. This leads to the increase in the size of martensitic needles, respectively, the hardness of the cast iron having been treated decreases.

In the heat-affected zone of the plasma, which is outside the reflow one, the structure is also changed. The structure corresponds to the hardened state of the iron-carbon alloy and is due to the processes occurring in the solid state. In the area where during the processing the temperature rises above the critical point, perlite is transformed into austenite. With further rapid cooling, γ-iron is converted to α-iron without the release of excess carbon from the solid solution. The deeper from the surface these processes occur, the slower the rate of the heating and cooling is. This causes the growth of the austenitic grains, and as a result, large martensite needles after the hardening.
4. Conclusion

Thus, the effectiveness of a plasmatron with an electrolytic cathode for modifying the mechanical properties of gray cast iron is shown. The change of the power of the plasma jet from 2 to 6 kW increases the average size of the dendrites of the reflow zone from 1.2 to 1.5 μm and reduces its microhardness from 1200 to 700 HV. The plasma jet forms the reflow and heat-affected zones in the gray iron, where the hardening processes take place from the liquid and solid states, respectively. This causes the difference of these zones, both in structure and microhardness. As the plasma power increases, the volumes of these zones increase, which leads to a decrease in the rate of being cooled by nearby cold layers of the massive metal. In this case, the structure becomes more stable and less strained, which is reflected in the microhardness of the treated surface layers. The quantitative analysis of the structure gave the additional clarity to the understanding of the mechanism of formation of the strained, which is reflected in the microhardness of the treated surface layers. The quantitative analysis of the structure gave the additional clarity to the understanding of the mechanism of formation of the metastable state of the hardened zone, and made it possible to evaluate the role of the structure during the plasma processing in improving the physicomechanical properties of iron-carbon alloys.

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