Graphite flake cast iron surface hardening

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Abstract. The influence of the operating parameters of electric arc heat treatment of the surface layer of graphite flake cast iron type СН-61 on the structure, microhardness of structural components and the size of the hardening zone is studied. It is shown that controlling the arc power, its speed and the degree of overlap of local hardening zones allows purposefully forming modified structural States with properties most suitable for specific operating conditions in the surface working layer of cast iron. Overlapping of local hardening zones allows purposefully forming modified structures with suitable properties for specific operating conditions in the surface working layer of cast iron rolls. According to the research results, regularities of formation of the structure and phase composition and properties of the surface layer of cast iron type СН-61 under the influence of electric arc heat treatment were obtained. Control of parameters of the processing mode (power and speed of the arc, the degree of overlap of local hardening zones) allows you to purposefully form modified structures with suitable properties for specific operating conditions in the surface working layer of cast iron.

1. Introduction

Hardening of the working surface of cast iron rolls with high and industrial frequency currents in order to form a bleached layer with increased wear resistance is used only in their primary production. When repairing the worn surface of the rolls, the hardness of the cooler layer formed during manufacturing is reduced. In this case, the output of the rolling mill is also reduced by reducing the inter-repair cycle and the diameter of the rolls.

To increase the service life of cast-iron rolls, it is promising to use heat treatment for their working surfaces with a concentrated energy flow. Hardening-type structures formed during high-speed heating and cooling have high hardness, wear resistance, and fracture resistance. Moreover, it is advisable to perform treatment after each repair machining using low-cost and high-efficiency methods with low labor intensity that are suitable for use in the conditions of metallurgical production. A method of surface heat treatment with argon shielded plasma (constricted) or conventional electric arc [1–9] is rational in terms of universality, availability, environmental friendliness and economic efficiency for extending the service life of cast rolls. Without changing the parameters of surface roughness, such treatment is easily integrated into the process of preparation and repair of rolls, being a finishing operation, low-cost, quite efficient and makes it possible to extend their service life.

The purpose of the work is to identify the basic laws of structure formation, as well as quantitative ratios of the phase composition, microhardness of structural components, the size of the heat-affected zone formed in roll-foundry iron, with parameters of the mode of surface heat treatment using direct electric arc. It is also necessary to evaluate the range and efficiency of controlling the characteristics of
the heat-treated working layer of the rolls by changing the parameters of the mode and determine the area of rational treatment modes.

2. Material and research methods
The study was carried out on samples cut from hot rolling rolls (CII-61 type graphite flake hypoeutectic mottled cast iron containing 3% of carbon, 0.7% of silicon and 0.5% of manganese), the surface of which was heat-treated by electric arc in a range of mode parameters specified in Table 1.

| Mode number | 1       | 2       | 3       |
|-------------|---------|---------|---------|
| Arc current strength, A | 250     | 250     | 350     |
| Arc speed, m/h | 200     | 200     | 300     |
| Overlapping of local hardening zones during layer formation, % of the zone width | 60      | 30      | 30      |
| Maximum depth of the hardened layer, mm | 0.60    | 0.45    | 0.54    |
| Average depth of the hardened layer, mm | 0.53    | 0.35    | 0.47    |
| Peak-to-peak amplitude of the hardened layer depth, mm | 0.12    | 0.17    | 0.22    |
| Average depth of the ledeburitic interlayer, mm | 0.10    | 0.04    | 0.06    |

The features of structure formation in the heat-affected zone were revealed using optical metallography, electron microscopy, durometry, and X-ray diffraction analysis. Microhardness of the structural components was determined using a Neophot-2 instrument under load of 0.78 N. X-ray diffraction patterns were recorded using a DRON-3.0 diffractometer in cobalt Kα-radiation. In order to obtain a continuous layer on the treated surface of a structure modified as a result of thermal action with increased microhardness of the components, the treatment was performed with sequential overlapping of the local heat-affected zones by 30–60% of their width.

3. Results and discussion
The initial structure of cast iron is presented in Figure 1, c. Microhardness of cementite is 12,700 MPa, and perlite is 3,200 MPa.

It was found that heat treatment with a current of 250 A at arc speed of 200 m/h with the sequential formation of local hardening zones with 30% overlapping ensures the maximum layer depth of 0.45 mm and the minimum of 0.28 mm (the average value of the modified layer depth is 0.35 mm). In this case, the ledeburitic interlayer on the surface has a thickness of ~0.04 mm. The option of local zones overlapping by 60% of their width (mode 1) makes it possible to increase the maximum depth of the hardened layer to 0.60 mm, and the average value is 0.53 mm. The depth of the ledeburitic interlayer varies between 0.096–0.120 mm (the average value is 0.100 mm). It should be noted that this treatment option provides a hardened layer that is more uniform in depth – the difference in depth of different areas of the layer is 0.12 mm, while after treatment in mode 2 (30% overlapping) the difference is 0.17 mm at a lower average depth. Treatment by current of 350 A at the speed of 300 m/h increases the depth of the layer compared to the second mode by almost 1.5 times (up to 0.47 mm), however, the peak-to-peak amplitude of the hardened layer depth in this case is 0.22 mm.

Figure 1 shows microphotographs of the structure of various areas of the heat-strengthened layer obtained by treatment in the first mode. The heat-affected zone manifests itself by the appearance of martensitic areas (Figure 1, d). In the transition zone, these areas border on areas in which perlite cementite experienced only coagulation. When moving towards the surface, the length of the martensite needles increases while at the same time their density decreases; the microhardness of martensite is 7,500 MPa. In the surface layer there are areas of ledeburite with a high degree of dispersion of the components. The areas within which the density of martensite needles is very low...
(1–3 per austenite grain, Figure 1, a) are observed. The main part of the surface layer is represented by a ledeburite eutectic, the components of which are perpendicular to the surface (Figure 1, a, b).

X-ray diffraction analysis of the surface of heat-treated cast iron samples showed that cementite is textured in the studied treatment options. This is evident in the deviation of the intensity of the interference lines of this phase in comparison with its normal (perfectly crystalline) state. Figure 2, a shows that the interference lines (120), (130) and (140), in the formation of which the basal plane and planes close to it in orientation take part, have abnormally high intensity values. The latter fact indicates a directional arrangement of cementite crystals relative to the surface of the sample. Austenite and martensite do not have such a pronounced texture. The presence of cementite texture indicates the oriented growth of its particles, which can be implemented by melting the surface of the samples and subsequent directional crystallization.

The influence of specific treatment modes is manifested in the following. Heat treatment using current of 250 A (mode 2) is characterized by a diffraction pattern, a fragment of which is shown in Figure 2, b. The position of austenite lines indicates a significant content of carbon in its composition (~2 %). With a volume fraction of cementite of 20–25 %, the amount of austenite in this case is about 50 %, and martensite is about 30 %. The state of interference lines of different areas of the heat-treated surface brings us to the conclusion on alternating martensitic areas with different carbon concentrations. Formation of a hardened layer with overlapping of local heat-treated zones by 60 % of their width is accompanied by a decrease in the degree of texturization of cementite and an increase in the volume fraction of austenite to 60–65 % due to a decrease in the amount of martensite. The state of martensite in this case is more stable than after treatment with less overlapping, (Figure 2, c).
Treatment using higher values of arc current and speed leads to an increase in the intensity of interference lines of cementite, the content of martensite also increases (up to 40%), and the fraction of residual austenite decreases accordingly (Figure 2, d).

Figure 2. Areas of X-ray diffraction patterns from the surface of cast iron after surface heat treatment.

The main part of the surface layer is almost completely austenitic and ledeburitic; martensite does not reach the surface. Microhardness of ledeburitic areas is slightly inferior to microhardness of cementite and is commensurate with microhardness of martensitic areas. Massive martensite in the treatment option under consideration is found directly near the surface austenitic and ledeburitic layer; its depth can reach 0.2 mm.

The rest of the heat-affected zone is, in addition to cementite inclusions, a complex structural combination of austenite and martensite, the crystallites of which have a high degree of dispersion.

In general, various treatment options with a certain combination of mode parameters (arc heat input, its speed and degree of successive overlapping of local heat-affected zones) allows for obtaining various combinations of structural components with the corresponding variation of properties.
Thus, a relatively mild mode (arc current is 250 A, treatment speed is 200 m/h) with successive overlapping of hardening zones by 30% of their width allows for obtaining a ledeburitic and austenitic structure with a relatively low (15–20%) martensite content in the surface layer with a thickness of 10–30 µm. An increase in the degree of zones overlapping leads to the formation of a uniform ledeburitic layer with a thickness of up to 60 µm with a martensite content increasing to ~30% on the surface. A further increase in the arc current and speed is accompanied by the formation of an uneven martensitic and ledeburitic layer on the surface.

With an increase in the arc current and the degree of overlapping of local heat-treated zones, the heat input to the treated material increases, while the depth of the heat-affected zone with the modified structure and the hardness of its surface also increase in the studied range of process mode parameters. This is associated with an increase in the duration of stay of near-surface volumes in the temperature range exceeding the transition points, with a corresponding increase in the stability of austenite upon subsequent cooling. In this case, structurally this is manifested by a decrease in the martensite fraction. An increase in the arc speed or a decrease in the degree of zones overlapping at a constant current value leads to a decrease in the specific heat flux through the treated surface and is accompanied by a decrease in the considered indicators.

Thus, changing the treatment mode parameters, primarily the arc power and speed, as well as degree of overlapping of local hardening zones makes it possible to purposively form modified structural states with properties that are the most suitable for particular operating conditions in the surface working layer of cast-iron rolls.

For example, the formation of a structure with a certain amount of residual austenite provides an opportunity for further strain hardening of the working layer under conditions of dynamic frictional contact during operational loading.

4. Conclusions
The analysis of the results of studies revealed the patterns of formation of the structure and phase composition and properties of the CI-61 type cast iron surface layer when exposed to electric-arc heat treatment.

Control of the treatment mode parameters, primarily the arc power and speed, as well as degree of overlapping of local hardening zones makes it possible to purposively form modified structural states with properties that are the most suitable for particular operating conditions in the cast iron surface working layer.

References
[1] Korotkov V A 2019 Russian Eng. Res. 39 (3) 234–6
[2] Safonov E N and Mironova M V 2018 IOP Conf. Series: Materials Sci. and Eng. 411 (1), 012069
[3] Korotkov V A 2015 J. of Frict. and Wear 36 (2) 149–52
[4] Korotkov V A and Zlokazov M V 2014 J. of Frict. and Wear 35 (2) 133–6
[5] Korotkov V A, Ananyev S A and Shekurov A V 2014 Welding Int. 28 (2) 140–2
[6] Safonov E N and Zhuravlev V I 1998 Welding Int. 12 (4) 326–8
[7] Balanovsky A E 2015 Strengthening Techn. and Coatings 12 18–30
[8] Korotkov V A 2016 Metal Science and Heat Treatment 58 (7-8) 449–54
[9] Safonov E N 2005 Metal Science and Heat Treatment 47 (9–10) 434–9