Improving the properties of wheeled steel during thermal repair

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Abstract. The purpose: to increase durability and life of railway wheels and to reduce the cost of purchasing new ones by restoring the mechanical properties of the metal rim and improving its structure. Methods: study using a multiple electron microscope and local X-ray spectral analysis of wheeled steel after induction thermocyclic processing at a high-frequency facility and in a state of delivery. Results: The structure resulting from induction thermocyclic processing - sorbit leads to the formation of compressive stresses, which has a positive effect on the efficiency of the surface of the wheel. As a result, the reliability of the wheel on accidental failures (cranks, chippings, etc.) is improved and, as a result, the safety of the operation of rolling stock is improved. Practical importance: the rational use of induction wheel heating technology will improve the efficiency of the use of rolling stock by significantly reducing the number of purchases of new wheel pairs.

1. Introduction
During the operation, wheeled pairs of wagons wear out on the surface of the wheel [1]. When they are repaired on wheel machines restore the geometry of the profile of the surface of the skating, and the question of restoring the mechanical properties of the metal rim of the wheel is not raised. The hardness of the metal on the section of the rim is descending. The metal rim layer cut when restoring the geometry of the profile not only reduces the diameter of the wheel, but also determines the decrease in its hardness and, accordingly, durability. Restoring the mechanical properties of the metal rim to the level of new wheels and improving its structure will increase the durability and life of the wheels and reduce the cost of purchasing new ones. The cost of the metal of the new wheels, which have passed all stages of metallurgical redistribution, is much higher than the cost of the metal rim with mechanical properties restored during repair.

The problem lies in not using the capabilities of the thermocyclic wheel processing technology when repairing them to restore the mechanical properties of the metal rim and improve its structure.

2. Setting a task
Study of the structural state of the metal rim of the whole-rolled wheel before and after induction thermocyclic treatment
3. Research materials and methods

To assess the structural state of the rim metal, studies were conducted on the wheeled steel brand 2 (GOST 10791) after induction thermocyclic processing on a high-frequency current installation and in a state of delivery.

Comparative analysis used the method of resby electron microscopy (REM) and local X-ray spectral analysis (LSRA) using a raster electron microscope – X-ray analyzer Kaebax. The study was conducted on the surface of micro-sanders and fractures of samples after the shock bend test.

4. Study results

Figure 1 shows the microstructure of wheeled steel (a – after induction thermocyclic processing, b – in a state of delivery). The image is obtained by the detection of secondary electrons.

![Microstructure of wheeled steel](image)

**Figure 1.** Microstructure of wheel steel: a – steel after induction thermocyclic processing; b – steel in a state of delivery.

After induction thermocyclic processing, the structure of wheeled steel becomes more dispersal and homogeneous. Multiple polymorphic $\alpha \rightarrow \gamma \rightarrow \alpha$ transformation leads to the formation of a dispersal structure with a high degree of homogeneity due to multiple phase recrystallization. Characteristically, the absence of fragments of excess ferrit in the structure of steel, which indicates the high homogeneity of the structure and its high efficiency [2-5]. It should also be noted that short induction heating prevents decarbonization of steel, which is very important for durability/ At the same time, induction heat treatment only affects the surface layers of steel.

The chemical composition of wheeled steel, defined by the spectral method, is represented in Table 1.

| Chemical element | Element content, % |
|------------------|--------------------|
| C                | 0,602              |
| Si               | 0,311              |
| Mn               | 0,738              |
| P                | 0,011              |
| S                | 0,012              |
| Cr               | 0,045              |
| Ni               | 0,062              |
| Mo               | 0,014              |
| Cu               | 0,132              |
| Ti               | 0,008              |
| V                | 0,004              |
| Sn               | 0,002              |
| As               | 0,004              |

A number of impurities with a concentration of about a few tenths of a percent - Cr, Ni, Mo, Cu were detected. Similar impurities are often found in steel and usually get into it together with scrape during smelting. In addition, traces of Ti, V, Sn, As were detected. The last two impurities are undesirable because they reduce the properties of steel, but in this case their content is small.
A qualitative microprobe analysis of the metal matrix (sensitivity of 0.01-0.02%) at a depth of 10 mm. Results are shown in figure 2, where the range of the X-ray spectrum is divided into 4 sections in accordance with the scope of the used crystals-analysers (PC2, TAP, LIF, PET). Detected C, Fe, Si, Mn, Cr, Cu, Ni. This analysis showed that there is no liquation in the area under consideration.

Figure 2. Quality analysis of wheeled steel.

Quantitative linear x-ray spectral analysis was performed from the metal surface to a depth of 3 mm (figure 3 – steel after induction thermocyclic processing, figure 4 – steel in the delivery state). The carbon distribution is uniform, which indicates that decarburization does not occur during induction thermocyclic processing.

Figure 3. Distribution of elements in wheeled steel after induction thermocyclic processing. Quantitative analysis
Quantitatively, the result is considered good if the sum of the concentrations deviates from 100% by no more than 2%. As can be seen from table 2, in this case, the deviations are lower.

**Table 2.** The composition of steel according to quantitative linear analysis.

| Chemical element | Steel after induction thermocyclic processing | Steel in the delivery state | Average |
|------------------|--------------------------------------------|-----------------------------|---------|
| C                | 0,82                                       | 0,81                        | 0,81    |
| Fe               | 98,04                                      | 97,51                       | 97,77   |
| Mn               | 0,86                                       | 0,85                        | 0,85    |
| Si               | 0,38                                       | 0,33                        | 0,35    |
| Cr               | 0,07                                       | 0,06                        | 0,06    |
| Number           | 100,17                                     | 99,56                       | 99,84   |

Quantitative analysis of residual ferrite (10 points) and sorbitol (10 points) was also performed. The carbon content was not analyzed in this case (table 3).

**Table 3.** The contents of the elements according to the analysis of ferrite and sorbit.

| Chemical element | Steel after induction thermocyclic processing | Steel in the delivery state | Average |
|------------------|--------------------------------------------|-----------------------------|---------|
| Fe               | 98,25                                      | 96,57                       | 97,41   |
| Mn               | 0,78                                       | 0,81                        | 0,80    |
| Si               | 0,33                                       | 0,31                        | 0,32    |
| Cr               | 0,05                                       | 0,05                        | 0,05    |
| Ni               | 0,05                                       | 0,04                        | 0,05    |
| Cu               | 0,15                                       | 0,14                        | 0,15    |
| Number           | 99,61                                      | 97,83                       | 98,78   |

From the data table 3 it follows that the difference in iron content is statistically significant for ferrite and sorbitol. This is due to the fact that the carbon content of sorbitol (more precisely, cementite) is increased, due to which the iron content is reduced. No other differences were found in the composition of ferrite and sorbitol.

Digital images describing the carbon distribution were obtained (Fig. 5, a – steel after induction thermocyclic processing, b – steel in the delivery state) in the riding surface area at a distance of 1 mm from the surface. The images correspond to a section of the sample measuring 82x82 mm. They show that in the...
case of induction thermocyclic processing, the carbon distribution is more uniform, and the structure is more dispersed.

![Figure 5](image1.png)

**Figure 5.** Distribution of carbon in wheeled steel in the ski area: a – steel after induction thermocyclic processing; b – in a state of delivery

Fractographic studies have shown (Fig. 6, 7) that the fractures of samples of wheel steel both in the delivery state and after induction thermocyclic processing are fragile, have facets of transcrystalline cleavage with a characteristic brook pattern and separate elements of the quasicole. There were no significant differences between them. Also, the values of impact strength are almost the same – 3.5 and 3.7 kgf / cm².

![Figure 6](image2.png)

**Figure 6.** Microfractograms of wheeled steel in the crest area after induction thermocyclic processing. Increase x300. Rastral electron microscope: a – at a distance from the surface of 1 mm; b – 5 mm

![Figure 7](image3.png)

**Figure 7.** Microfractograms of wheeled steel in the crest area in a state of delivery. Increase x300. Rastral electron microscope: a – at a distance from the surface of 1 mm; b – 5 mm

Figure 8 shows the microstructure of the wheel steel in the delivery state. It follows from this figure that there are no significant differences in depth in the microstructure.

Figure 9 shows the evolution of the wheel steel microstructure as it moves away from the surface after induction thermocyclic processing. A drastic change in the microstructure is manifested to a depth of up to 2
mm. In this range, the structure is a dispersed spheroidized sorbitol. The fine-grained structure combined with the increased hardness gives the wheel steel an optimal set of mechanical properties within the permissible hardness. The change in structure occurs most completely on the surface of the wheel. This is explained by the specifics of induction heating of HDPE. The most complete change in the structure occurs in areas that have undergone complete austenitization during heating.

![Microstructure of the wheeled steel in the crest area](image)

**Figure 8.** The microstructure of the wheeled steel in the crest area is delivered depending on the distance from the surface. Increase x1000. Rastral electron microscope.
Figure 9. The microstructure of the wheeled steel in the crest area after induction thermocyclic processing, depending on the distance from the surface. Increase x1000. A raw electron microscope

Visual evaluation of the structure is subjective and has low accuracy. Therefore, the automatic image analyzer "Quantimet 520" was used to calculate the parameters that characterize the structure grinding, which were taken as the average size of residual ferrite inclusions with an area of more than 8 microns, as well as the area occupied by them. Limiting the minimum particle size allowed us to get rid of "noise" and select the most informative part of the size distribution. The results are shown in Fig. 10, 11. According to the data obtained, the depth at which the structure is crushed during induction thermocyclic processing reaches 3-5 mm.

Figure 10. Changing the total area of ferrit particles in wheeled steel in the ski surface area.
5. Conclusion
Rational use of the technology of induction heating of wheels during repairs [1, 6, 7] will increase the efficiency of the use of rolling stock by significantly reducing the number of purchases of new wheel pairs. The resulting induction thermocyclic processing structure – sorbitol (quasi-eutectoid) is non-equilibrium, since it is formed during accelerated cooling. Compressive stresses that occur during the formation of sorbitol have a positive effect on the performance of the wheel surface. As a result, the reliability of the wheel operation due to accidental failures (dents, chips, etc.) increases and, as a result, the safety of the rolling stock operation increases.

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