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Comparative Analysis of Wheelsets Tyres, Hardened Using a Laser or Plasma Heat Source


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ABSTRACT

Lateral wear of the locomotive wheel flange is one of the main types of wear that occurs during rolling stock operation. An important characteristic of a rail wheel rim is its wear resistance, which directly depends on the carbon content in steel. The carbon content in wheel steel of group 2 in the amount of 0,55–0,65 is due to the fact that at its lower concentration, the proportion of grain boundary ferrite increases, which leads to a decrease in the contact strength of wheels, and a higher one leads to a tendency to brittle fracture. The increased carbon content makes it possible to harden the surface of steel. Plasma and laser hardening technologies can be used to reduce tyre flange wear and increase the service life of locomotive wheelsets.

The objective of this work is to determine advantages and disadvantages of technologies for laser and plasma hardening of working surfaces of tyres of wheelsets of railway rolling stock.

The comparative analysis related to microstructure and microhardness of wheelsets tyres of the 2TE25KM diesel locomotive which are made of wheel steel of group 2 according to GOST 398-2010 state standard and hardened respectively by plasma and laser hardening.

The tasks set were solved using theoretical and experimental research methods. The preparation and study of hardened samples was carried out using the equipment of the testing laboratory of LLC Scientific and Technical Association «IRE-Polus».

A study referred to hardened zones in various areas and sections of the tyre. Tribological tests concerned wear resistance of specimens hardened with a high-power fiber laser. The main advantages and disadvantages of laser and plasma hardening processes are revealed.

The conducted studies allow making a conclusion that the use of laser hardening technology for hardening wheelsets tyres, as an alternative to the plasma hardening process, is highly promising.

<u>Keywords:</u> railway transport, laser hardening, plasma hardening, wheelset, wheel steel.

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Текст статьи на русском языке публикуется в первой части данного выпуска.

INTRODUCTION

The introduction of fundamentally new technologies for laser hardening of medium-carbon and high-carbon steels using industrial fiber lasers and special optical heads that allow processing a tyre in one pass with a hardening zone width of up to 40 mm is currently an important direction in development of technology. The laser hardening process has a number of advantages over other types of processing. When exposed to laser radiation on the surface of the workpiece, compressive stresses are formed that positively affect the overall stress state of the product [1]. Formation of high compressive stresses in the hardened surface layer and reduction of tensile stresses in the transition zone is an important factor in improving the performance of products operating under contact and alternating loads [2]. Laser hardening ensures uniformity of structure and microhardness over the entire depth of the hardened zone.

A significant positive effect is achieved with the creep resistance of the metal. It is due to the fact that because of the finely dispersed structure, the plastic flow of steel occurring in the presence of sharp temperature gradients is prevented [3; 4]. Due to the finely dispersed structure of the hardened layer, the workpiece combines optimal values of plasticity, hardness and strength, which leads to an increase in its tribotechnical characteristics [5]. The laser heat treatment results in an increase in the contact fatigue strength of the workpiece, as well as in an increase in its wear resistance by several times [6].

The equipment for laser processing of flanges of wheelsets tyres is practically not used at Russian maintenance and repair enterprises. Until recently, there has been only one laser hardening site on Gorky Railway using Kometa-2 complex [7]. Plasma technology for hardening locomotive wheelsets tyres is the most common. At the enterprises repairing and maintaining locomotives of JSC Russian Railways, about 90 installations have been introduced, though many of them (at least 20) are not used for various reasons [8].

The authors of [9] showed that high residual tensile stresses are formed in the zone of plasma hardening of the flanges. When they occur in the surface layers, summation with external tensile or alternating stresses arising during operation of wheelsets is possible [10]. The described effect can lead to the occurrence of defects of contact fatigue origin and cause the formation of cracks and fatigue spalling (flaking), which can directly or indirectly affect train traffic safety [11; 12].

The experimental data obtained using plasma technology showed that during plasma treatment it is necessary to ensure the uniformity of the hardened layer both along the width of the hardened zone and along the circumference of the flanges [2]. Based on the presented data, it can also be concluded that in the process of plasma hardening, a significant overheating of the surface layer of the workpiece can occur. With laser processing, this effect is not observed.

The *objective* of the work is to conduct *a comparative analysis* of formation of the microstructure, microhardness and wear of 2TE25KM diesel locomotive wheel tyres, made of wheel steel of group 2[1] and hardened with plasma and laser hardening.

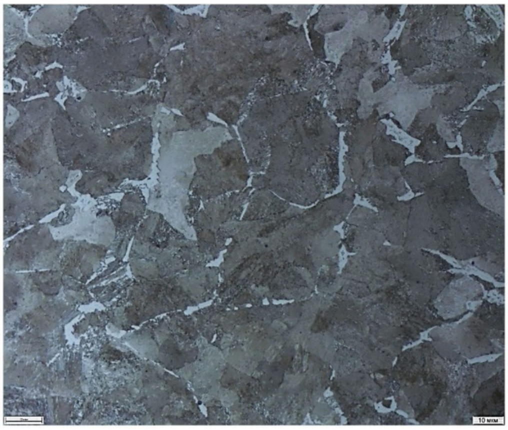
EQUIPMENT AND EXPERIMENTAL TECHNIQUE

The experiments were carried out on real wheelsets made of steel of group 2 (according to GOST [Russian state standard] 398-2010) with hardening of the entire length of the tyres of two wheels. The chemical composition of wheel steel has been identified using a Q8 Magellan spectrometer according to GOST 18895 and is presented in Table 1.

The steel microstructure (Pic. 1) is a thin-lamellar perlite with ferrite fringes 3–7 µm wide along its boundaries. In this case, the size of pearlite grains changes in the range from 35 to 55 µm. The microhardness of such a structure is 295–333 HV0,2.

Laser hardening of wheelsets tyres was carried out on an IPG FL–CPM machine for

[1] Rail steel deoxidised with aluminium. – *Transl. note.*



Pic. 1. Microstructure of main metal of wheel steel of type 2, x1000 [developed by the authors].

Table 1

Chemical composition of wheel steel 2 [developed and compiled by the authors]

C	Si	Mn	Cr	Ni	S	P	Mo	Cu	Co	V
0,595–0,617	0,372–0,397	0,779–0,813	0,025–0,039	0,043–0,073	0,005–0,006	0,011–0,013	0,003–0,005	0,009–0,012	0,025–0,031	0,021–0,025

Pic. 2. Installation for processing bodies of revolution FL-CPM [developed by the authors].

processing bodies of revolution, equipped with an IPG YLS-10000 fiber laser, manufactured by LLC Scientific and Technical Association «IRE-Polus» (Pic. 2).

To increase productivity of the laser hardening process, the tyre was processed with a laser rectangular beam profile with dimensions of 35 x 5 mm. The transformation of the circular profile of the laser radiation spot into a rectangular one was carried out using a specialized module of the IPG IRE-POLUS shaper of the linear spot profile, its external view and internal structure, which are shown in Pic. 3.

Plasma hardening was carried out applying standard equipment, which is used at the enterprises maintain locomotives of JSC Russian Railways.

Laser hardening modes: laser radiation power was of 5–8 kW; linear rate of hardening of tyres was of 5–7,5 mm/s. Transverse air circulation was used to protect the optical elements of the laser head.

Plasma hardening modes: operating power of the source was up to 35 kW; linear speed was of 5–7,5 mm/sec, width of the impact zone was of 28 mm. Nitrogen was used as the plasma-forming and shielding gas. Cooling water consumption was of 0,8 litres per wheelset.

RESULTS

The study of the macrostructure after plasma and laser hardening was carried out on sections cut from the central part of the wheel, which was not subjected to reheating when completing («locking») the process of hardening the surface. Pic. 4 shows cross sections of the hardened sections after plasma and laser hardening, indicating the size of the hardened zones.

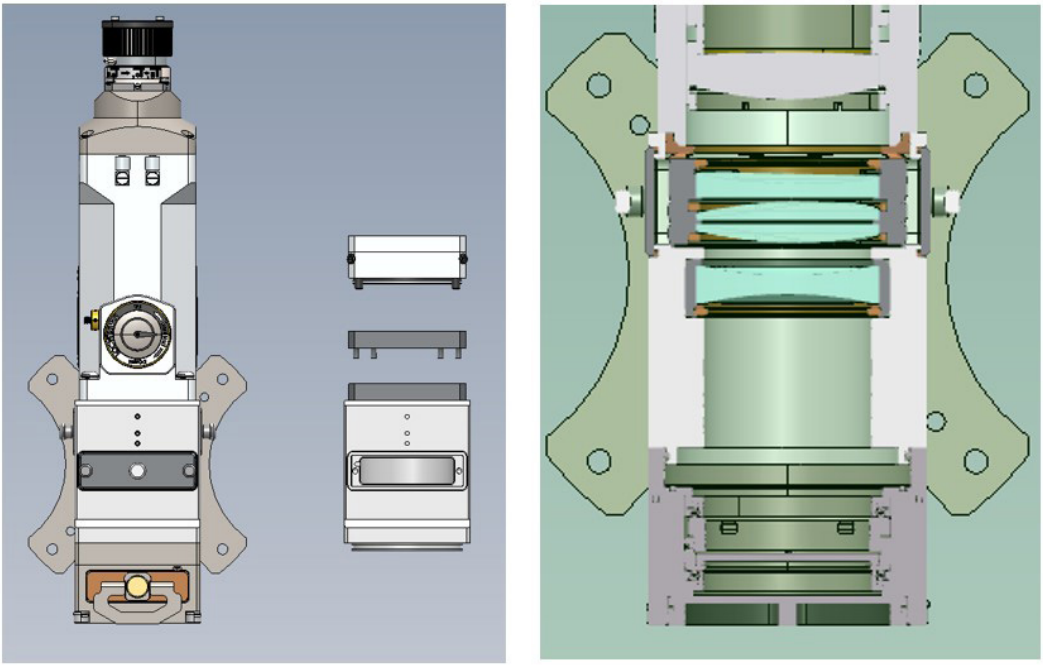
Macrostructures of Pic. 4 show that the maximum depth of the hardened layer after plasma and laser hardening is comparable and is approximately of 1900 μm. Along the edges of the hardened zone, in both cases, a gradual decrease in depth to zero values is observed.

Based on the study of the microstructure and microhardness of the samples after laser and plasma hardening, it was found that the properties obtained in different areas of the tyre, other than the area where hardening was started and completed, are the same, which makes it possible to study only its central part and the area where hardening has completed.

The study of the microstructure was carried out in the areas shown in Pic. 4 and marked with numbers 1, 2, 3. The microstructure and microhardness of the middle section 2 (Pic. 4) for plasma and laser processing are shown in Pics. 5 and 6.

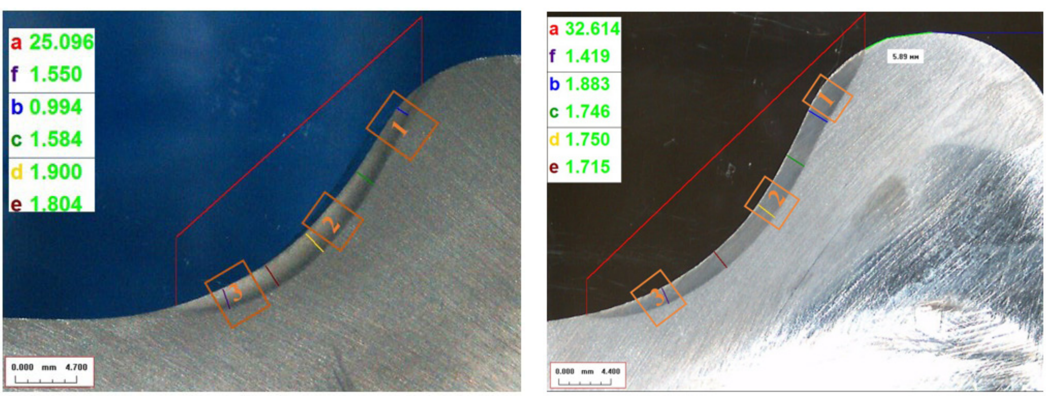
The study of the near-surface layer of section 2 with a depth of ~1100 μm showed that, during plasma treatment, a martensitic structure is formed in the form of blocks, along the boundaries of which inclusions of a ferrite-carbide mixture are observed, the micro hardness values are in the range of 766–857 HV0,2 (Pic. 5a). Upon laser hardening, the microstructure consists of martensite with higher hardness values of 783–879 HV0,1 (Pic. 6a).

Upon plasma treatment, increasing distance from the surface of the area under study to a depth of more than 1100 μm leads to formation



a b

Pic. 3. Shaper of a rectangular spot profile:
a – external view of the assembly; b – assembly design [developed by the authors].



a b

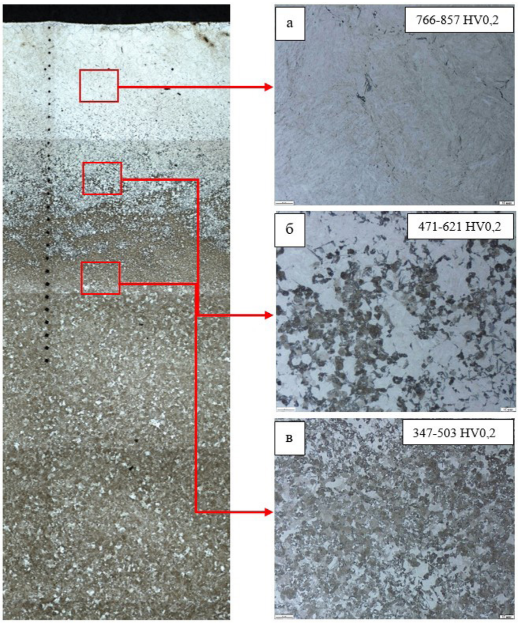
Pic. 4. Macrostructure of the sample cut out from the wheel tyre:
a − after plasma hardening; b − after laser hardening [developed by the authors].

of a 500 μm long zone with a troostite-martensite structure, the microhardness of which is 471–621 HV0,2 (Pic. 5b), while upon laser hardening there is a zone with a length of about ~400 μm with an insignificant decrease in microhardness to 726–783 HV0,1 and formation of a mixture of martensite and troostite in the structure (Pic. 6b).

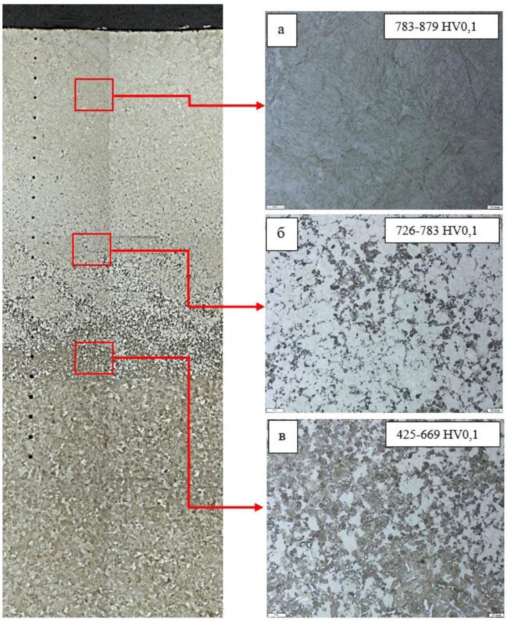
At the depth of more than 1600 μm, in both cases, a transition zone with a length of ~300 μm is observed, the microstructure of which is predominantly a ferrite-carbide mixture with a microhardness of 347–503 HV0,2 (Pic. 5c) upon plasma hardening and a microhardness of 425–669 HV0,1 (Pic. 6c) upon laser hardening.

Thus, the study of the macro- and microstructure, as well as the microhardness of various sections of the central part of the tyre after laser hardening, showed high hardness values throughout the depth of the hardened layer due to formation of a martensitic structure and a highly dispersed ferrite-carbide mixture.

After plasma and laser hardening of the wheelsets tyre, a «lock» area is formed – a place in which reheating occurs due to the closure of the hardened layer. The study analysed this sec-



Pic. 5. Microstructure and microhardness of various areas of the hardened section 2 after plasma hardening.

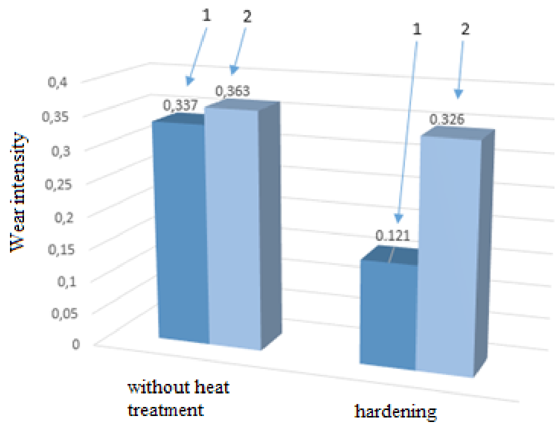


Pic. 6. Microstructure and microhardness of various areas of the hardened section 2 after laser hardening [developed and compiled by the authors].

tion in transverse and longitudinal directions after laser hardening. The depth of maximum hardening at the starting and ending area of hardening is 1500–1900 μm, i.e., practically over the entire hardening depth. A comparative analysis of the microstructure and microhardness within the starting and ending zones of the «lock» area showed formation of a hardened layer over the entire depth, both at the beginning of the «lock» area and at the end, of a structural-phase composition and of microhardness values similar to the central part of the tyre. This is due to the same content of the martensite component in the structure of the zones corresponding to their location. It was found that during laser hardening, the overlap zone is characterised by fine dispersion even after repeated re-hardening and a minimum tempering zone, in which the probability of defects during the operation of wheelsets is significantly reduced. It is also worth noting that when processing using plasma heat sources, the softening zone in the «lock» area is larger, due to the high thermal heating of the processed area during the closure of the hardening zone of wheelsets tyres, which also leads to re-hardening and tempering of the previously hardened zone, which increases the likelihood of various types of defects in this zone.

The microstructure of sections 1 and 3 after laser hardening in the corresponding zones of the hardened layer, both at the beginning and at the end of «lock» area, is close, namely, a martensitic structure with maximum micro hardness values of 860 HV0,2 is formed in the surface zone. As we move away from the surface, we observe release of troostite, and, as a result, the microhardness drops to 750 HV0,2. The transition layer is characterised by a further decrease in microhardness, due to formation of predominantly ferrous-carbide mixture. The study of the «lock» area of the hardened layer after laser hardening showed that the minimum values of microhardness are in the range of acceptable values.

The results of a comparative analysis of various areas of hardened wheelsets tyres indicate that in the case of plasma hardening, the micro hardness values in the surface zone of the hardened layer are somewhat lower than in laser hardening. However, when moving away from the surface towards the base metal, the values of the micro hardness of the corresponding zones differ significantly. Thus, in the case of laser hardening, the micro hardness of the transition zone is approximately by 100–150 Vickers units higher. At low hardness values, the likelihood of «catastrophic wear» of the side surfaces of the wheel and rail flanges increases, associated with the transition to wear via the scuffing mechanism, which requires a relatively long path of continu-



Pic. 7. Intensity of linear wear of samples without heat treatment and after laser hardening: 1 – wheel steel sample; 2 – rail steel counterbody [14].

ous sliding at a relatively low (less than 0,7 m/s) speed and with surface hardness not more than 600 HV [13].

It is shown that both types of hardening lead to formation of a gradient-mixed structure in the hardened layer. In this case, a martensitic structure is formed in the surface layer at high cooling rates, and in the underlying zones, decomposition of austenite is accompanied by formation of a ferrite-carbide mixture of various particle size distribution. It should be noted that during laser hardening, the depth of the surface layer with a purely martensitic structure is greater, which reduces the depth of zones with a mixed structure and lower microhardness values.

In the process of laser heat treatment of steel surfaces in the laser heating zone, phases and structures are formed that are similar in structure to the structures that emerge during classical methods of metal hardening. Due to the short thermal cycle, since there is no long exposure in the austenite region, the microstructure of the hardened area is finely divided as compared to the structure formed after plasma hardening. This effect has a positive effect on the mechanical properties of the near-surface layer of the hardened workpiece, which leads to an increase in the hardness and wear resistance of products.

Thus, high values of microhardness over the entire depth of the hardened layer, the absence of a sharp change in the structure and phase composition during laser hardening, and formation of a predominantly martensitic structure at the depth of maximum hardening can lead to a decrease in wear during operation of the wheelsets tyres.

To determine the rate of influence of laser hardening on the wear resistance of tyre ridges, tests were carried out according to the scheme of a plane (made of wheel steel of type 2) and a ring (made of rail steel) using an MTU-01 friction machine.

Pic. 7 shows the results of tribological tests intended to determine the intensity of linear wear *I* of wheel steel specimens after laser hardening and without it, paired with a rail steel counterbody.

Wear intensity was determined by the formula:

$I = \Delta h / L$,

where L – friction distance, mm;

Δh – wear value, µm.

From the above diagram (Pic. 7); it can be seen that with a slight change in the rate of wear of rails, there is a shape change in resistance of specimens made of wheel steel of type 2. The tests have so shown high efficiency of laser hardening of wheelset tyres.

Thus, the results of the comparative studies carried out allow making a conclusion that it is promising to introduce the technology of laser hardening of the near-surface layer of locomotive wheelsets tyres. Its implementation at repair enterprises will reduce the average intensity of tyre wear and increase their expected average mileage between wheelset turning during scheduled maintenance of rolling stock.

CONCLUSIONS

The depth of the hardened layer after plasma and laser hardening in the central section of the tyre is comparable and is of ~1900 µm, and in the areas located closer to the edge, ~1500 µm.

Therewith, the depth of maximum hardening with increased values of microhardness and of a finely dispersed structure are greater with laser hardening.

Both types of hardening result in formation of a gradient-mixed structure in the hardened layer. In the surface layer at high cooling rates, a martensitic structure is formed, and in the underlying zones, decomposition of austenite is accompanied by formation of a ferrite-carbide mixture with different range of particle dimensions. The microstructure of the hardened steel layer after laser hardening is more uniform.

Tribological tests have shown that with a slight wear of rails, resistance of wheelsets tyres after laser hardening can be increased by 2,8 times.

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