DOI: https://doi.org/10.30932/1992-3252-2021-19-1-48-59

Increasing Service Life of a Railway Wheel with Surface Hardening Technology

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ABSTRACT

The article presents surface hardening technology as applied to solid-rolled wheels of rolling stock. The obtained results of the theoretical study on the process of strengthening the metal of the wheel will make it possible to develop scientifically grounded technological and technical solutions to prevent formation and development of defects on the rolling surface, as well as to eliminate them during maintenance.

The objective of this work is to identify the optimal method for surface hardening of a railway wheel with defects.

At present, the issue of extending service life of elements and critical parts of rolling stock is becoming increasingly acute. Due to the limited economic feasibility and limited availability of existing production technologies, it becomes necessary to create a new material modified with nanoclusters and hardened with surfactants.

Nanoclusters have high plasticity and hardness values. To determine the hardness value of nanomaterials, the Vickers hardness test method is used, in which hardness is determined by the size of the area of the indentation after removing the load from the pyramid shaped diamond.

Superplasticity is observed in nanostructures. For nickel and nickel-aluminium alloy $NiAl_3$, low-temperature superplasticity is observed in the temperature range 450–470˚C, which is three times lower than their melting point [1].

Keywords: *railway, railway wheel, defects, chemical analysis, mechanical properties, surface hardening, service life, nanoengineering.*

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Article received 18.01.2021, accepted 26.02.2021.

For the original Russian text of the article please see p. 48.

BACKGROUND

The use of powder materials is among main ways to obtain functional materials in nanoengineering. Methods for obtaining modified layers of metal on the surface of materials are widely known in various fields of mechanical engineering. Most of these methods are considered as nanotechnology methods that allow creation of nanostructured layers on the surface of a material, parts, and their assemblies. Also, this method involves creation of modified nanocomposite materials in the form of nano- and micro-products.

Surface hardening methods:

• Technologies based on physical processes.

• Technologies based on chemical processes.

The most common surface hardening technologies are:

• PVD technology.

• CVD technology.

MATERIALS AND METHODS

PVD (Physical Vapour Deposition) technology is a method for producing metal-based hard coatings by means of physical vapour deposition [2].

PVD technology is based on the technological process of physical phenomena, as a result of which the material passes from a solid state to a liquid phase following evaporation under the influence of thermal energy or of sputtering due to the kinetic energy of collision of material particles. Then, the beam of the obtained gas phase is transported by means of an electromagnetic field to the surface to be hardened, that is heated to no more than 500˚C. The ionised material then collides and evenly condenses on the surface that therefore hardens.

The main types of PVD coatings and their properties:

• Titanium nitride TiN is a universal coating for low-carbon steels, increases the service life of a part or assembly, acting as a mechanical, thermal, and chemical protection between friction surfaces.

• Titanium carbonitride TiCN increases productivity of parts and assemblies, provides, as compared with titanium nitride, higher mechanical properties of the processed surface.

• Aluminium-titanium-nitride AlTiN is a coating with a unique nanocomposite structure that increases hardness, heat resistance and resistance to shock loads. Excellent test results unambiguously indicate an increase in the life of a part or assembly.

• Aluminium-chromium-nitride AlCrN has a unique nanocrystalline lattice, that significantly increases hardness and heat resistance. It is best used where uniform wear and tear resistance is required due to its high temperature resistance and high performance in severe operating conditions.

Advantages of PVD coatings:

• Application of a material with higher melting point at a relatively low temperature, a more gentle mode of action on the metal of the part being hardened.

• Small layer thickness with equal performance characteristics.

Disadvantages:

• The physical deposition process is carried out in a vacuum and is incomparably more expensive, because involves the use of expensive equipment that requires highly qualified personnel [3].

The essence of CVD coating method is to create a thin TiC film on the surface of the spart being hardened, which allows increasing hardness and speed of its treatment without changing the internal structure of the alloy. This idea has received further development though the use of titanium nitride and aluminium oxide.

The method is based on the process, following which in the chamber, in which the temperature is maintained up to 1200˚C, the coating material is supplied in a vapour aggregate state and, under the action of high temperatures, interacts with the surface to be hardened.

Basic properties of CVD coatings:

• Titanium carbide TiC increases wear resistance, prevents spalling.

• Titanium nitride prevents formation of burrs and adhesion to the processed surface, improving quality of the technological process.

• Aluminium oxide Al_2O_3 significantly increases resistance to high temperatures, prevents critical heating, being a good thermal insulator.

Advantages:

• Relative simplicity and low cost of the process.

Table 1

Mechanical properties of the wheel rim steel (compiled by the author)

Wheel steel grade	Ultimate resistance, N/mm² (kgf/mm²)	Relative elongation, %	Relative contraction, %	Hardness, HB
		No less		
1	882–1078 (90–110)	12	21	248
2	911–1107 (93–113)	8	14	255

Table 2

The chemical composition of the steel of the defective wheel (spalling) (compiled by the author)

C	Mn	Si	P	S
0,52	0,85	0,25	0,035	0,04

Table 3

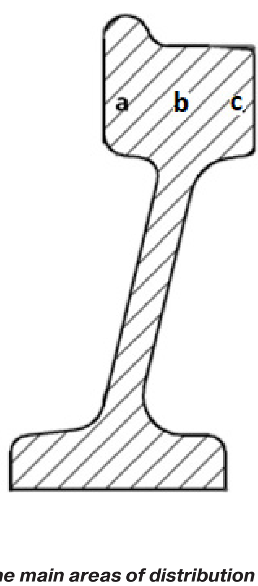
Chemical content of the metal in the weld-on deposit area (compiled by the author)

C	Mn	Si	Cr	P	S
0,53	0,85	0,23	0,06	0,035	0,04

Table 4

Mechanical properties of a defective rim (compiled by the author)

Wheel steel grade	Ultimate resistance, kg/mm²	Fluidity limit, kg/mm²	Relative elongation, %	Relative contraction, %	Impact viscosity, kgm/cm²
1	105,0	93,0	10,0	18,2	1,75
2	110,6	95,0	11,6	19,0	1,5



Pic. 1. The main areas of distribution of hardness over the section and on the rolling surface of the rim (compiled by the author).

• Creation of coatings of a predetermined thickness.

• The ability to create complex, multi-layer coatings with unique properties and various number of combinations of these layers.

Disadvantages:

• Strong heating of the treated surface during the coating process to obtain adhesion, under the influence of strong heating the strength of the base material decreases.

• The chemicals used in the part coating process and by-products are toxic, flammable and corrosive.

• High material costs.

To assess feasibility of the technology under consideration, it is necessary to clearly understand which exact objectives we are pursuing while using the concepts of performance and service life.

First, the objective is to neutralise *defects*, namely:

• Spalling in the wheel rim area.
• Chipping on the rolling surface.
• Weld-on deposits on the rolling surface.
• Slid flats.
• Fracture of the wheel rim.

Therewith, the mechanical properties of the steel of the rim of the railway wheel after the operations of hardening treatment must correspond to the standard values (Table 1) [4–8].

The reason for spalling in the wheel rim area is mainly separation of the metal from the rim of the underlying layers, which indicates the presence of shear stresses that exceed the ultimate strength of the metal.

The conducted chemical analysis of the defective wheel (Table 2) shows that the composition met the requirements for the wheel

Table 5

Wheel hardness control (compiled by the author)

No. of the sample	Sample hardness HB, kgf/mm^2	Area of hardness testing
1	331–375	In the area of the centre line of the wheel's rolling circle, while the wheel is operating under normal operating conditions
2	331–331	At the edge of the rolling circle of the same wheel
3	130–197	In the weldability area of the metal of the same sample
4	128–140	In the area of the rolling surface with metal layering
5	130–143	In the area of the hardness of the weld-on deposit petals

steel in accordance with GOST [Russian State standard] 10791-2011[1].

Chipping on the rolling surface appears due to flaking or chipping of the metal, occurred due to high contact stresses between the rail and the rolling surface.

Weld-on deposit on the rolling surface appears following a mechanical or large thermal effect on the rolling surface during braking of rolling stock.

The conducted chemical analysis of the enveloped metal petals shows a reduced content of carbon and manganese in comparison with the initial content of these elements in the wheel steel. It can be assumed that with high heating of the metal during braking, these elements burn out. Chemical analysis data are given in Table 3.

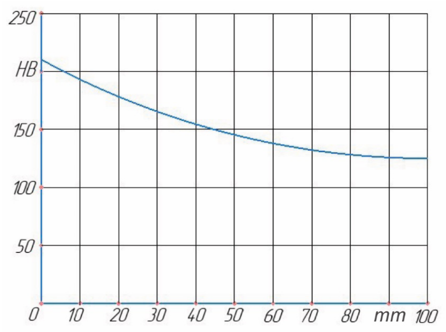
Slid flats appear due to jamming (skidding) of the wheelset on the rolling surface, the mechanical reason for skidding is destructive friction.

Fracture of the wheel rim can occur due to a manufacturing defect, or due to gradual fatigue destruction of the wheel metal, the mechanical properties of the rim material are presented in Table 4.

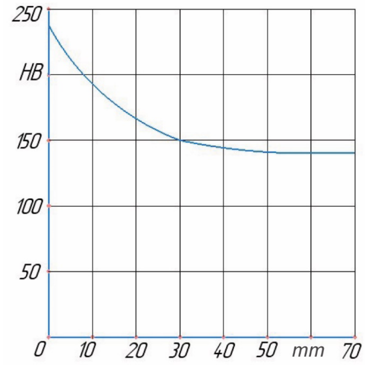
The *objective* of this work is to establish the optimal method for surface hardening of the surface of a railway wheel with defects.

RESULTS

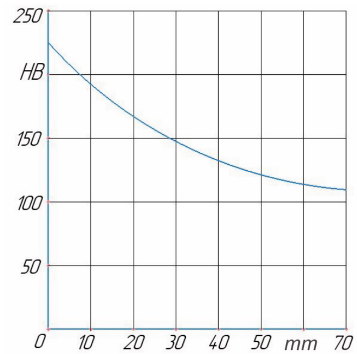
Measurements of hardness of the wheel material along the section areas *a, b, c* (Pic. 1)[2] have been made. As a result, the curves of the dependence of hardness on the depth of the metal have been obtained in the section areas



Pic. 2. The curve of dependence of hardness on the depth of the metal in the section area a (compiled by the author).



Pic. 3. The curve of dependence of hardness on the depth of the metal in the section area b (compiled by the author).



Pic. 4. The curve of dependence of hardness on the depth of the metal in the section area c (compiled by the author).

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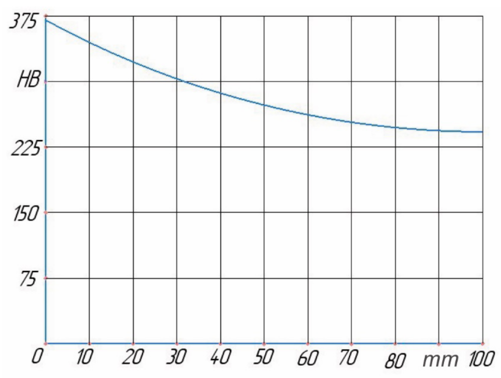
[1] GOST [Interstate Standard] 10791-2004. Wheels are solid-rolled. Specifications. Moscow, Standards Publishing House, 2004, 24 p. [Electronic resource]: https://docs.cntd.ru/document/1200037631. Last accessed 12.01.2021.

[2] GOST [Interstate Standard] 9012-59. Metals. Brinell hardness measurement method. Moscow, Standards Publishing House, 2007, 40 p. [Electronic resource]: http://docs.cntd.ru/document/gost-9012-59. Last accessed 12.01.2021.

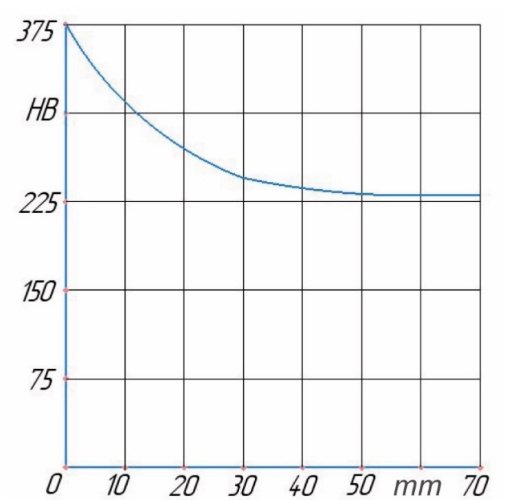
Table 6

The values of hardness indicators (compiled by the author)

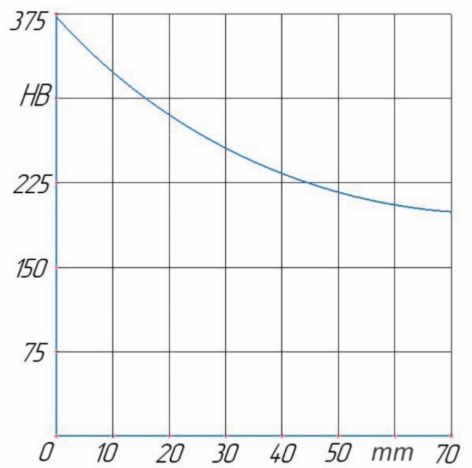
No. of the sample	Hardness of samples HB, kgf/mm^2	Area of hardness testing
1	345–375	In the area of the centre line of the rolling circle of the wheel operating under normal operating conditions
2	341–370	At the edge of the rolling circle of the same wheel
3	355–370	In the rolling area



Pic. 5. The curve of dependence of hardness on the depth of the metal after surface hardening in the section area a (compiled by the author).



Pic. 6. The curve of dependence of hardness on the depth of the metal after surface hardening in the section area b (compiled by the author).



Pic. 7. The curve of dependence of hardness on the depth of the metal after surface hardening in the section area c (compiled by the author).

before and after surface hardening (Pics. 2–4). Based on the curves the expediency of using surface hardening processing methods is obvious.

The increase in brittleness during operation is explained by the presence of numerous non-metallic inclusions that reduce density of the metal of the surface layers during prolonged braking.

Measurements of hardness in different parts of defective wheels have resulted in the values shown in Table 5[3, 4].

Having considered the main defects of the wheel set, we might draw a conclusion that surface hardening by PVD and CVD methods allows solving the problems of increasing survivability of the wheel by increasing wear resistance [9–15]:

• Titanium carbide TiC will increase wear resistance of the metal, and significantly reduce probability of spalling.

• Titanium nitride TiN will create a protective layer that increases the mechanical wear resistance of the wheel and resists contact stresses, which will reduce probability of chipping on the wheel surface.

• Aluminium oxide Al_2O_3 significantly increases the thermal stability of the metal,

[3] GOST 10791-2004. Wheels are solid-rolled. Specifications. Moscow, Standards Publishing House, 2004, 24 p. [Electronic resource]: https://docs.cntd.ru/document/1200037631. Last accessed 12.01.2021.

[4] GOST 9012-59. Metals. Brinell hardness measurement method. Moscow, Standards Publishing House, 2007, 40 p. [Electronic resource]: http://docs.cntd.ru/document/gost-9012-59. Last accessed 12.01.2021.

reducing the likelihood of weld build-up on the rolling surface when the rolling stock is braking.

• Aluminium-titanium-nitride AlTiN will create a unique composite structure that increases hardness of the metal, heat resistance and resistance to shock loads, which will avoid the wheel rim fracture.

• Aluminium-chromium-nitride AlCrN contributes to an increase in hardness, which will lead to the most uniform wear and to a decrease in the number of sliders during operation of the wheel set.

The hardness values in different parts of the wheel after application of hardening technology are given in Table 6.

The curves of the dependence of hardness on the depth of the metal after surface hardening in the section areas are shown in Pics. 5–7.

CONCLUSIONS

Thus, the applied methods of PVD and CVD surface hardening technologies allow preventing or eliminating most of the known defects of a solid-rolled wheel, hardening the rolling surface and the wheel rim, thereby increasing service life of the wheel.

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