Technological methods for improving the tribotechnical properties of materials of rail transport wheels

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Abstract. The paper presents the results of metallographic studies and tribotechnical tests of samples of grade 2 wheel steel in the form of bushings, the end surface of which was processed using turning and milling operations. It was found that the greatest influence on the microhardness of the surface layers during milling was exerted by the tool feed rate. When turning samples without coolant, the microhardness of the modified layer is higher than when processing with the use of coolants in various variants. It is shown that three factors influenced the microhardness during turning, the temperature in the cutting zone, the oxidation of the surface and the magnitude of plastic deformations. The regularities of changes in the coefficients of friction from the type of processing were obtained, and after milling they were significantly lower than after the flow. The modified layers after milling had greater depth and wear resistance compared to similar layers after turning. Key words: surface modification, microhardness, coefficient of friction, wear resistance

1 Introduction

The prevention of fatigue damage is very important for the rolling surface of rolling stock wheels. The research of a number of authors is focused on improving the fatigue characteristics of materials [1], which arise on the surface of materials and progress deeper [2], [3]. Based on this, it is extremely important and effective to improve mechanical properties, such as reducing grain size [4], increasing hardness [5], and creating residual compression stresses [6]. The mechanisms of wear of the wheel–rail system can be divided into three types [7] adhesive wear, which occurs during relative movement when irregularities are welded, at high loads in certain areas and are torn on the opposite surface [8-10], abrasive wear, when solid particles or solid protrusions on the contacting surfaces touch and move along the surface [11-13], fatigue wear occurs because the contacting surfaces are subjected to cyclic loading with the formation and propagation of cracks and separation of wear particles [14-16]. When turning and milling, a riveted layer with increased microhardness is formed on the surface of the part. To study the effect of milling

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[17] on the surface layers, alloy steel grade 4340 with a hardness of 450 ± 5 HV was used. All samples were heated to a temperature of 870 °C, then hardened in oil and tempered at a temperature of 425 °C. Rectangular samples with dimensions of 20×40×40 mm were used. All experiments were carried out on a MIKRON HSM 700 CNC milling machine with a maximum feed speed of 20,000 mm/min and a maximum spindle speed of 42,000 rpm.

Tungsten carbide end mills with 2 TiAlN coated grooves with a diameter of 6 mm manufactured by HAMTOOLS were also used. The cooling device is equipped with a spray nozzle in which the flow of air and oil flows through separate channels into the nozzle. The air flow rate is much higher than the oil flow, which breaks the oil into small droplets at the outlet of the nozzle. These oil droplets create an air-oil jet to lubricate the cutting area. The MQL method was applied using mineral oil with a flow rate of 240 ml/h at a pressure of 0.6 MPa. To improve the operation of the lubrication system, two nozzles with an angle of inclination of 45 degrees relative to the axis of the tool were used. Milling parameters, including cutting speed, feed rate, axial and radial cutting depth, were used at three levels. All parameters of solid milling had an impact on the increase in microhardness. feed rate by 73.1%, cutting speed by 14.4% and axial cutting depth by only 5.1%. The thickness of the white layer obtained as a result of solid milling changed from 7.6 microns to 16.1 microns when the cutting conditions changed. The cutting speed (81.3%) and feed rate (9.4%) were the only parameters that affected the thickness of the white layer.

To assess the effect of turning [18] on the modification of surface layers, medium-carbon ferrite-pearlite steel AISI 1045 was selected. The active medium in the emulsion mist method (MQCL) was six percent EMULSIFIER-S, an emulsion concentrate based on mineral oil and 94% water; it was prepared using an ES21H type electromagnetic agitator. A Lenox 1LN micronizer was used to form an emulsion mist with the possibility of regulating the emulsion flow rate (E = 1.4-100 g/h), air flow (1.2-5.8 l/min). The obtained values of microhardness in the surface layer indicate that the hardness of the surface after dry cutting is higher than that of the surface when cooling MQCL. For the upper layer during dry cutting, the hardness of perlite was 419 HV0.05, and the hardness of ferrite was 357 HV0.05, whereas when using the MQCL method, the hardness of perlite grains was approximately 342 HV0.05, and the hardness of ferrite grains was 321 HV0.05. When studying the cooling conditions of the cutting zone, it was noticed that cooling using MQCL has a greater effect on reducing the hardness of perlite grains; the difference in hardness between the considered cooling conditions in the upper layer was 18.3% for perlite and 10% for ferrite. Under dry cutting conditions, it was observed that the hardness of the surface layers increased only up to 500 microns, whereas for the MQCL method it was reached up to 300 microns. The differences between the hardness values in the upper layer and in the core can be explained on the basis of three fundamental mechanisms. The first of them is the effect of temperature in the cutting zone on both turning modes considered. An intense temperature gradient at the tool-workpiece interface causes phase changes in the workpiece and, consequently, an increase in hardness. Reactions related to the environment, such as oxidation, which occur on the surface being machined during the cutting process, represent the second mechanism. Plastic deformations are the third mechanism; they lead to grain size changes and recrystallization.

Machining tests [19] were carried out using an Interact IV milling machine equipped with a CNC system powered by a 7.5 kW motor. The workpiece material used in this study was AISI 1047 steel with dimensions: 455×128×150 mm. For the experiments, carbide plates with a monolayer TiAlN were used – ISO tool designation (class P40) GC 4240 R245-12 T3 M-PM from the tool manufacturer Sandvik. Only one plate was installed in a 125 mm diameter milling cutter, which is designed for 8 plates. The coolant used in machining tests for both low-flow systems and filling feed systems was Vasco1000 manufactured by Blaser Swisslube with a concentration of 5%. It is a vegetable oil with additives and antioxidant components. The coolant was supplied to the cutting zone at a pressure of 0.8 MPa through two nozzles for the MQL method. The surface roughness (parameter Ra) of the treated surfaces was recorded after each pass using a portable Surftest Mitutoyo device with a base length of 0.8 mm for all processing modes. Based on the general results obtained in this work and taking into account the economic factors of machining, the best conditions for milling AISI 1047 steel with coated carbide plates are those in which the following combination is used: liquid with reduced flow rate (15,000 ml/h), cutting speed 200 m/min and feed the speed is 0.14 mm/rev. A flow rate of 15,000 ml/h is equivalent to about 5% of the 276,000 ml/h used in flooding. This means significant savings on the purchase, disposal and recycling of liquids and, consequently, increased productivity.

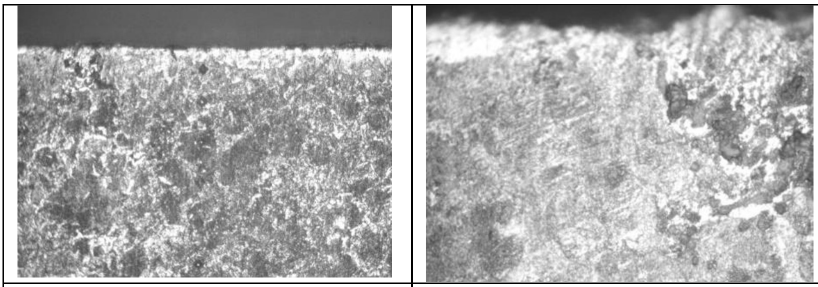
The purpose of our research was to determine the effect of turning and milling of grade 2 wheel steel on the size of the modified layer and its tribotechnical properties.

2 Materials and research methods

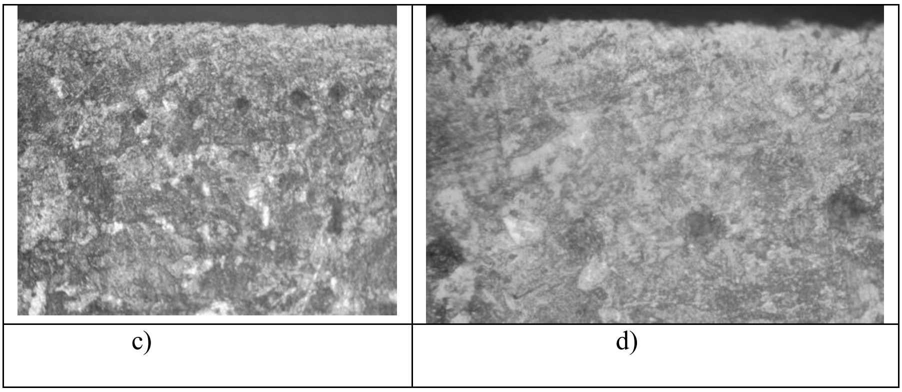
For the research, samples of grade 2 wheel steel were used in the form of bushings with the processing of their end surface by turning and milling. Metallographic studies were performed using the MS 1000 optical system, a PMT-3 microhardness meter with a load of 0.98 N. Microshelves were made according to a standard technique, a 3% aqueous solution of nitric acid was used for etching. Tribotechnical tests were carried out according to the scheme "the end of the ring sample (grade 2 wheel steel) is a plane (the wide side of a flat counter–plate made of rail steel). Before the tests, a semi-liquid special railway lubricant "PUMA" was applied to the samples. The friction coefficients were determined using the readings of the friction moment sensor and subsequent calculations. The intensity of wear was determined by the ratio of the thickness of the worn layer to the friction path.

3 Results

Fig. 1 shows the microstructures of samples after turning, Fig. 1, a (100×), b (500×) and milling of samples of wheel steel grade 2. The average microhardness and thickness of the modified layer was 240, 260 MPa and 250-300 and 300-360 microns for samples after turning and milling, respectively. Typical graphs of microhardness are shown in Fig. 2. Microhardness measurements were carried out from the surface deep into the base material in increments of 100 microns and along the surface in increments of 0.01 mm zone depth (Fig. 2, c and d) for both types of processing.

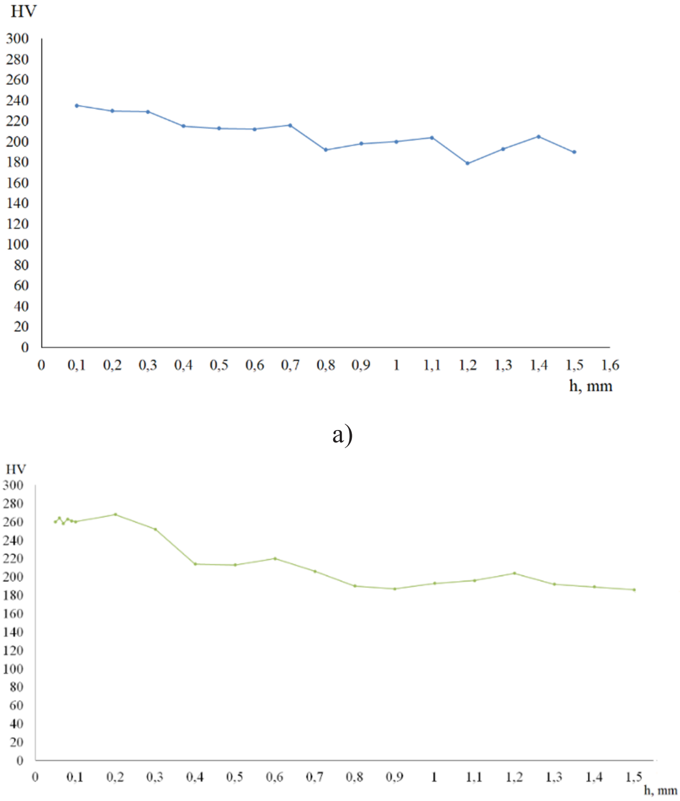


a) b)



c) d)

Fig. 1. Microstructures of surface layers of samples after turning a) -100×, b) -500× and milling c) -100×, d) -500× treatments



a)

b)

Fig. 2. Change in microhardness by depth of samples of wheel steel grade 2: a – turning, b – milling

The tribotechnical tests carried out showed that the averaged friction coefficients for three samples after turning and milling treatments had values of 0.165-0.176 and 0.1-0.12, respectively (Fig. 3).

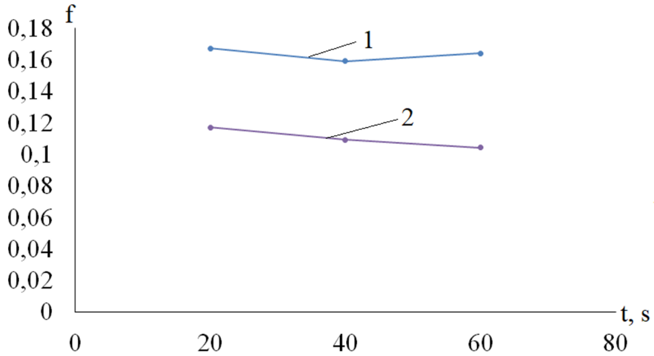


Fig. 3. Averaged values of friction coefficients for three samples: 1- turning, 2 – milling.

The wear rate of the samples is shown in table 1 samples 1-3 after turning and 4-6 milling.

Table 1. Wear rate of wheel and rail steel

Sample No	**The wear rate of the sample, $I_1 \cdot 10^{-8}$**	**The wear rate of the counter-tile, $I_2 \cdot 10^{-8}$**	**Arithmetic averages**	
			$I_{1m} \cdot 10^{-8}$	**$I_{2m} \cdot 10^{-8}$**
1	1,134	0,712	1,202	0,787
2	1,186	0,687		
3	1,287	0,964		
4	0,891	0,839	0,808	0,749
5	0,776	0,638		
6	0,759	0,772		

Analysis of the results of wear intensity studies showed that the samples that underwent the milling operation had wear resistance, the inverse of the wear intensity, 1.49 times higher than the samples after turning. Counter-samples of rail steel paired with samples after turning were slightly inferior to a pair of samples with milling-rail steel.

4 Conclusions

1. Metallographic methods have established that the microhardness and thickness of the modified layers after milling is significantly higher than after turning.
2. The average values of the friction coefficients for the three samples are lower for a pair of friction, a milled sample is wheel steel, compared with a pair of chiseled sample is wheel steel.
3. The wear intensity of the modified layers after milling is lower, and the wear resistance is higher than that of the samples after turning.

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