

Improvement of Adhesion of the Wheels of the Railway Carriage to the Rails by Means of Supply of the Scale and Magnetite Particles to the Contact Zone

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Abstract—The article proposes a method to improve adhesion of the wheels to the rails of the railway carriage by means of supply of abrasive loose materials as an alternative to quartz sand to the zone of their contact: metal scale (Fe_3O_4) being the waste of rolling and forging, as well as the iron oxide—magnetite ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$) of the natural origin. The comparative assessment of efficiency of use of scale and magnetite was carried out in relation to quartz sand traditionally used for railway transport. The adhesion coefficient and wear intensity are used as comparison criteria.

Keywords: adhesion, wear intensity, wheel, rail, quartz sand, scale, magnetite, magnetization

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INTRODUCTION

Implementation of high traction and braking efforts during motion of a locomotive requires a high level of adhesion of the wheels to the rails. At present, this is achieved only through the supply of the quartz sand to the contact area of the wheels with the rails. Owing to the availability and low cost of quartz sand, as well as its efficiency in relation to an increase in the adhesion coefficient, this method gained absolute prevalence in railway transport and, mainly, contributed to confirming its reputation for all weather conditions in railway transport, because during worsening of weather conditions, operation of the rolling stock without use of the sand becomes difficult, and in some cases, impossible [1–4].

However, the wide use of the sand became the reason for appearance of some problems having, first, technical and economic and ecological significance. Annually, more than ten thousand tons of quartz sand after special expensive preparation, including extraction, transportation, drying, sifting, burning, and filling of the locomotives, are consumed in the systems of the railways of Ukraine, Belarus, Kazakhstan, and Russia to improve adhesion of the wheels to the rails.

The results of this are both direct economic expenditures and net ecological expenditures specified by

the sand extraction with the high content of quartz in river and lake plains, which causes known harm to the ecology.

The large volumes of the sand used for improving adhesion of the wheels to the rails lead to an intense wear of the working surfaces of the wheels and rail, as well as to fouling of the track panel and other railway facilities, which will require expensive cleaning in future.

In addition, during interaction of the wheel and rail, the quartz sand is ground into very fine fractions, which are capable of staying in the suspended state in the air, incurring irreparable harm to health when getting into a person's lungs.

On the basis of the above, the problem of searching for an alternative to the sand abrasive materials and development of the conditions of their use at the rolling stock of railway transport that ensure the high adhesion qualities of the locomotive wheels to the rails upon the condition of minimization of the negative consequences of this process is urgent.

The aim of the work is the comparative assessment of influence of scale, magnetite, and quartz sand on the adhesion coefficient and wear intensity of the wheel and rail surfaces.

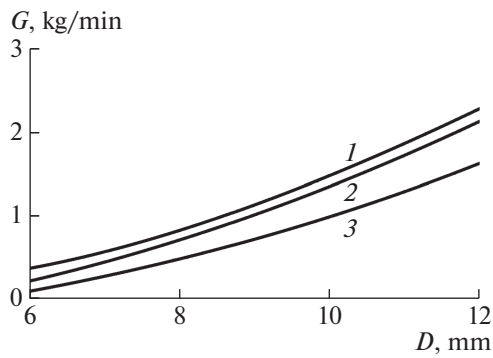


Fig. 1. Mass consumption G of the loose material penetrating through the calibration holes with the diameter D under gravity: (1) sand; (2) scale; (3) magnetite.

MATERIALS AND METHODS

The abrasive loose materials, alternative to the quartz sand, are selected with consideration of the following criteria:

- hardness;
- looseness;
- availability;
- labor intensity of the initial preparation;
- effect on the ecology.

According to these criteria, the following materials were preferred:

- quartz sand (SiO_2 , Mohs hardness ~ 7);
- metal scale (FeOFe_2O_3 , Mohs hardness ~ 6.5);
- iron oxide—magnetite (FeFe_2O_4 , Mohs hardness ~ 5.5 – 6.0).

The metal scale (further, the scale) is the waste of the metallurgic and forging production. The iron oxide (further, the magnetite) is of natural origin [5, 6]. The quartz sand was assumed as the base of comparison during the experiments.

The looseness of the materials was defined on the basis of its capability to “flow” through the calibration holes per time unit. The results of the experiments on determining the looseness of the materials are given in Fig. 1, where the hole diameter is specified along the x axis, and the mass flow of the loose material under the action of its own weight is specified along the y axis. The fractional composition of the abrasive loose materials of 100–500 μm was used.

The experimental surveys on determining the influence of the integral properties of the metal scale, magnetite, and quartz sand on the coefficient of adhesion of the wheel to the rail are conducted at the full-scale test bench, whose base is a natural railway wheel 1050 mm in diameter and a section of the full-size rail. The test bench allows reproducing the conditions of the force interaction of the wheel with the rail in the full scale of the forces, time, geometrical dimensions, and heat flows, as well as the physical and chemical

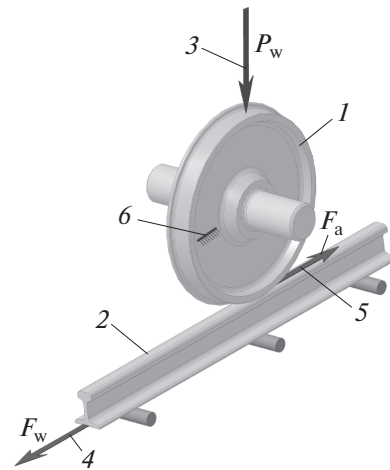


Fig. 2. Basic circuit arrangement of the “wheel–rail” brass board: (1) wheel; (2) rail; (3) normal force of loading of the wheel P_w ; (4) tangential force of loading of the rail F_r ; (5) adhesion force F_a ; (6) wheel pin.

conditions of the contacting surfaces [7]. The block diagram of the bench is given in Fig. 2.

The experimental surveys at the bench are made for the following conditions of the contacting surfaces: dry contact, wet contact, greased contact. When creating the greased contact of the wheel with the rail, machine oil was used, which was applied in a thin layer to the preliminarily cleaned surface.

The scale, magnetite, and quartz sand were distributed on the rail surfaces with the density of 0.06 kg/m^2 . The normal load varied within 30–150 kN.

The adhesion coefficient was determined according to the formula

$$f_a = \frac{F_a}{P_w},$$

where f_a is the adhesion coefficient, F_a is the adhesion force, and P_w is the normal load transferred from the wheel to the rail.

After each measurement of the surface of the tread and rail, they moved relative to each other.

RESULTS AND DISCUSSION

The results of the experimental surveys on determining the coefficient of adhesion of the locomotive wheel to the rail are given in Fig. 3.

The maximum error of determination of the adhesion coefficient was ± 0.03 (confidence level: 0.95). As a result of the surveys, it is established that the quartz sand makes it possible to ensure the adhesion coefficient (on average) of 0.64 for the dry, uncontaminated surfaces of the wheels and rails. This is 9% greater as compared to the use of the scale and 14% greater as compared to the magnetite.

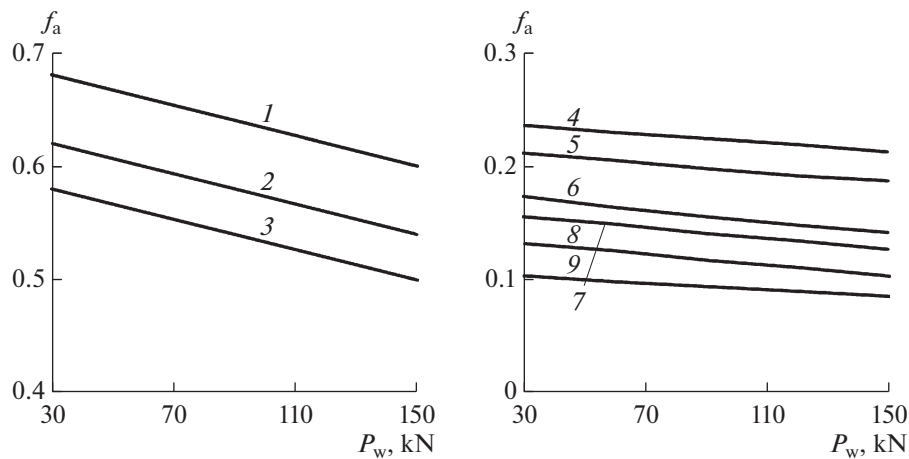


Fig. 3. Dependence of the adhesion coefficient f_a on the normal load of the wheel on the rail P_w upon different conditions of contact: (1, 2, 3) sand, metal scale, and magnetite, respectively, in conditions of dry contact; (4) wet contact with the sand; (5) wet contact with the scale; (6) wet contact with the magnetite; (7) greased contact with the sand; (8) greased contact with the scale; (9) greased contact with the magnetite.

The adhesion coefficient on the wet rails when using the quartz sand achieves the value of 0.24, which is, respectively, 8% greater as compared to the scale and 18% greater as compared to the magnetite.

The value of the adhesion coefficient on the greased rails using the quartz sand achieves 0.16, which exceeds the value of the adhesion coefficient for the scale and magnetite, respectively, by 10% and 20%.

An increase of the normal load of the wheel on the rail in the range 30–150 kN is followed by a corre-

sponding decrease in the value of the adhesion coefficient (for all above-mentioned conditions of the wheel and rail surface, as well as for all used abrasive loose materials). In this case, the qualitative regularity of the excess of the adhesion coefficient when using the quartz sand as compared to the scale and magnetite is maintained.

The fractional composition of the tested materials, within the particle size of 100–1000 μm , does not significantly affect the value of the adhesion coefficient.

The investigation of the influence of the quartz sand, scale, and magnetite on the wear intensity is carried out on the modernized machine SMC-2, whose tribological base is two cylindrical rollers of equal diameter (50 mm) and width (11.75 mm) made of the rail (material hardness 33 HRC) and tire steels (material hardness 25 HRC), which have a possibility of normal loading. When carrying out the experiments, the values of relative sliding of the rollers were 20% in all tests (which was ensured by the features of the structure of the friction machine).

The device for the wear test with the contact of the solid particles is given in Fig. 4.

The abrasive loose materials were supplied to the contact zone of the rollers using the gutter 3, after which, passing the contact zone, they came to the tank 4. In all experiments, the efficiency of supply of the solid particles of the tested materials was equal, ensuring the maximum possible saturation of the contact zone. To clean the roller surfaces from the solid particles attached to them, the brushes 5 were used.

The following external factors varied during the tests:

—force of loading of the rollers (400, 900 and 1400 N);

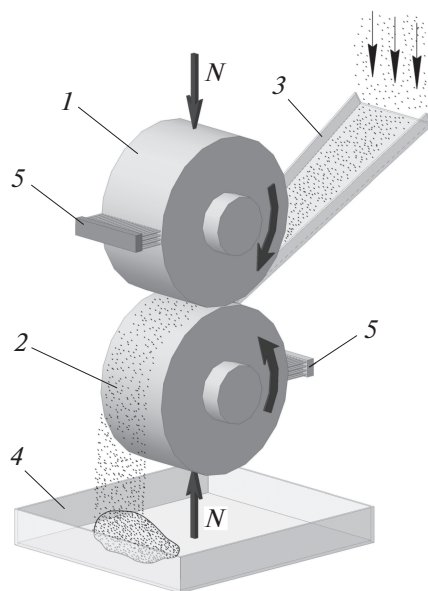


Fig. 4. Device for the wear test using the SMC-2 friction machine in the presence of the solid particles in the contact: (1, 2) experimental samples (on the friction machine shafts); (3) gutter; (4) tank; (5) brushes; N is the normal force pressing the rollers to each other.

Table 1. Steady temperature of the experimental samples (rollers) in the different test modes

Rotation frequency, rpm	300			500			1000		
Normal load, N	400	900	1400	400	900	1400	400	900	1400
Temperature, °C	70	105	135	150	180	205	160	195	235

—rotation frequency of the rollers (300, 500 and 1000 rpm);

—fractional composition of the abrasive loose materials (100, 200, 500, 1000 and 1500 μm).

The supply of the solid particles to the contact started after the temperature of the rollers became stable.

The wear of the rollers was defined according to the mass loss, by means of their weighing on a VLA-200-M analytical scale. The average value was used in the series of parallel experiments. The rollers were thoroughly washed using alcohol before each weighing.

The steady temperature of the rollers was measured using a UT-300B infrared pyrometer (the basic error limit of $\pm 3^\circ\text{C}$ in the range from -18 to 380°C). The temperature values are given in Table 1. The ambient temperature was 19°C during all measurements.

The obtained experimental dependences are given in Fig. 5. Here, the results for the roller are given, modeling the railway wheel (roller 2, see Fig. 4); in this case, Δm is the mass wear of the roller, N is the normal force pressing the rollers to each other, and d is the grain size of the loose material. The rotation frequency for this case was 1000 rpm.

The maximum error limit of determination of the wear value was ± 0.80 , ± 0.34 , and ± 0.20 mg for the sand, scale, and magnetite, respectively (confidence level: 0.95).

The minimum wear with each of the considered combinations of the external factors (load, rotation frequency) was observed when using the iron oxide—magnetite ($\text{FeO} \cdot \text{Fe}_2\text{O}_3$) of small fractions (200–500 μm), which proves the known regularity of influ-

ence of the hardness of the abrasive materials (other things being equal) on the intensity of wear of the working surfaces.

With an increase in the fraction of the loose material and (or) rotation frequency of the tested rollers, an increase in their wear was observed. An increase in wear was also observed with the growth of the normal load.

The maximum average wear per unit test was observed in the material of roller 1 and was 0.1493 for the quartz sand, with the grain size of 1500 μm and load of 1400 N at the rotation rate of 1000 rpm. The minimum average wear per test was registered in roller 2, equal to 1.2 mg, for the magnetite with the grain size of 100 μm and load 400 N at the rotation rate 300 rpm.

In some experiments, the wear with the fine fractions (100–200 μm) in the contact hardly depended on the normal load (in the range of 400–1400 N) for the used combinations of external factors.

For the angular rotation rate of the rollers equal to 300 rpm (for roller 2), during the supply of the fractions of 100–200 μm to the contact independently of the type of abrasive loose materials, the value of wear of the roller material differed insignificantly. In this case, the differences in the value of the mass wear for the scale and magnetite was less than that for the specified materials and quartz sand.

The tested rollers were heated at different rates. Roller 1 rotating slower than roller 2 was heated faster. The maximum average steady bulk temperature of the roller material was $235 \pm 3^\circ\text{C}$, the minimum one was $70 \pm 3^\circ\text{C}$ (the ambient temperature was 19°C).

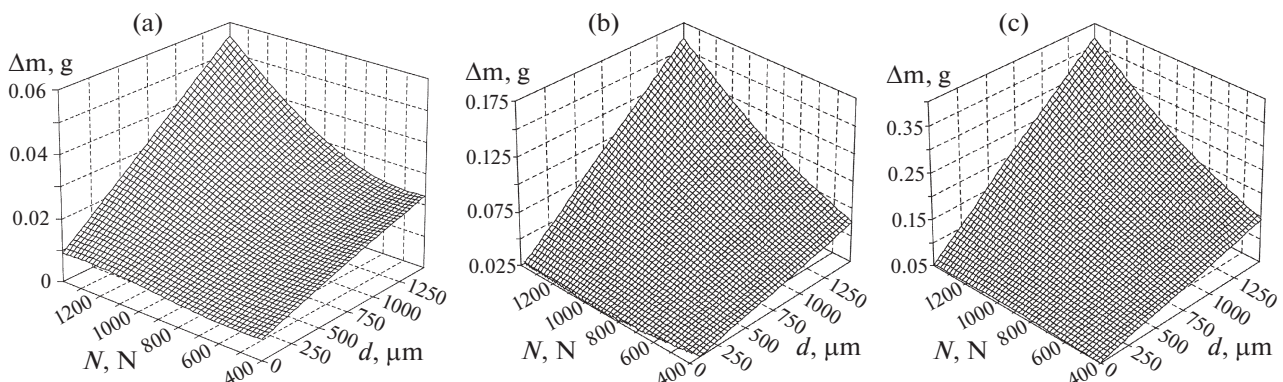


Fig. 5. Mass wear of the experimental sample Δm modeling the railway wheel in the presence of (a) magnetite, (b) metal scale, and (c) quartz sand, depending on the normal force N pressing the rollers to each other and on the grain size of the loose material d .

CONCLUSIONS

(1) The performed investigation made it possible to confirm the efficiency of the scale and magnetite as to an increase in the coefficient of adhesion of the wheel to the rail. In this case, the scale is on average 9% and the magnetite is 18% inferior to the quartz sand on the basis of this criterion.

(2) The intensity of wear of the working surfaces with the successive presence of the particles of the quartz sand, scale, and magnetite in the contact zone, all other things being equal, is specified by the hardness of the material and depends directly proportionally to the latter. This qualitative regularity takes place for all levels of the created loads and relative rates.

(3) The confirmed satisfactory friction properties of the loose abrasive materials based on scale and magnetite give the grounds for recommending them as an alternative to quartz sand to increase the coefficient of adhesion of the wheels to the rails.

(4) The presence of magnetic properties in the scale and magnetite is created by the additional design and engineering possibilities for developing new devices to improve adhesion of the wheels and rails.

NOTATION

D —diameter of the calibration hole for the looseness tests; f_a —coefficient of adhesion of the wheel to the rail; G —mass consumption of the loose material through the calibration hole; F_r —tangential force of loading of the rail; Δm —experimental sample (cylindrical roller) mass wear; N —normal force pressing the

experimental sample (cylindrical rollers) to each other; d —grain size of the loose material.

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