TEKA Kom. Mot. Energ. Roln. – OL PAN, 2008, 8, 163–170

AN INFLUENCE OF ABRASIVE PARTICLES ON THE CHARACTERISTICS OF COHESION IN WHEEL-AND-RAIL CONTACT

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Summary. There have been presented the results of the experiments in defining the coefficient of locomotive and rail cohesion within the presence of hard particles of different abrasive powders in contact zone in the terms of dry, wet, lubricated and interacting surfaces in the article. There have also been given the results of the experiments in defining wear value of steam of friction-swinging with slipping with the presence of contact zone of the same abrasive materials. The research was conducted on the natural board set of wheel-and-rail system and with the usage of SMTS-2 friction car.

Key words: wheel-rail, cohesion, wear, hard particles.

INTRODUCTION

The short term improvement of locomotive-and-rail cohesion coefficient is achieved at the expense of delivery into area of their quartz sand contact in the modern rolling stock. Thanks to the relatively low price of sand and its unique properties as well as to effective action on the wheel-and-rail cohesion process, this device has achieved wide distribution and to great extent it has promoted the railroad transport to getting all-weather forecast reputation, because during a decrease of weather conditions exploitation of the rolling stock without sand usage becomes difficult or even impossible. However, sand usage caused a range of problems, involving technical and economic-ecological aspects. As a result, the search task of abrasive materials alternative to sand and working out the terms of their usage on the locomotives of railroad transport has become crucial. It should provide high cohesion qualities of locomotive wheels with rails and eliminate or diminish the drawback by sand usage. One of the directions of solving this task is the usage of electromagnetic systems of short-term improvement of locomotive wheel-and-rail cohesion [3, 4], performing the delivery of abrasive material (possessing magnetic peculiarities) into contact zone by means of electromagnetic forces.

There have been considered the results of natural experimental research of locomotive wheel-and-rail cohesion within the presence of abrasive materials, alternative to sand in zone of their contact: iron oxide – magnetite ($FeFe_2O_4$, whose hardness is 5,5-6,0 according to the mineralogical scale) and metal slag ($FeOFe_2O_3$, whose hardness is ~6,5), as well as quartz sand itself (hardness is ~7,0) in the terms of dry, wet and lubricated interacting surfaces. Besides, the evaluation of the influence of the given abrasive materials on the value of wheel-and-rail cohesion pair wear with the usage of friction car SMTS-2 has been made. The choice of the abrasive materials, considered as alternative to sand, is conditioned by the following choice criteria (they are considered in greater detail in [3]):

- the presence of magnetic properties at abrasive material;
- hardness of the pouring material is one of the main factors influencing the wear conjugation as well as the value of tangential efforts, delivered by hard particles by means of mechanic gear;
- minimization of intensity of hard particles' fractioning, which is necessary for the decrease of wear, caused by them;
- labour-effectiveness of preparing pouring material of a given fractional component structure (in case when the material is not related to pouring ones in its initial state).
- ecological nature of abrasive material.

EXPERIMENTAL RESEARCH OF COHESION COEFFICIENT

The research in defining the coefficient value has been conducted on natural board of wheel-and-rail system. Board set allows to reproduce the terms of the power interaction of wheel-and-rail in real scale of power time, geometric sizes, heat currents as well as physical-chemical state of contact surfaces [1].

The principal scheme of board set is shown in Fig. 1.

The board represents rail section 1, R65 mark, which can be moved in linear direction, locomotive wheel 2 is attached to it with radius 0,525 m. The board is equipped with the apparatus 3 of radial loading for the creation of normal wheel-on-rail landing, the board includes prop, elastic elements and hydraulic jack with pressure manometer 4 (maximum pressure measured is 25 MPa, accuracy class is 2,0). Wheel 2 is shortly connected with pulley of cargo break, equipped with limiters 8 of rotation shaft pulley 7 through reactor 5.

For the creation of tangential efforts, delivered by rail to wheel 2, the right end of rail 1 is attached by chain 9 with limiter 10 of mechanism 11 of tangential wheel 2 loading. Besides, the mechanism 11 includes pattern dynamometer 12 with micrometric indicator 13 and hydraulic jack 14. Stand construction with the apparatus of pulley 7 and limiters 8 allows to turn wheel 2 precisely to little corner (~10°). Conjugation of mechanism 11 with rail 1 allows to replace rail as minimum for the length of chain link 9 (~ 0,05 m) with the help of chain 9.

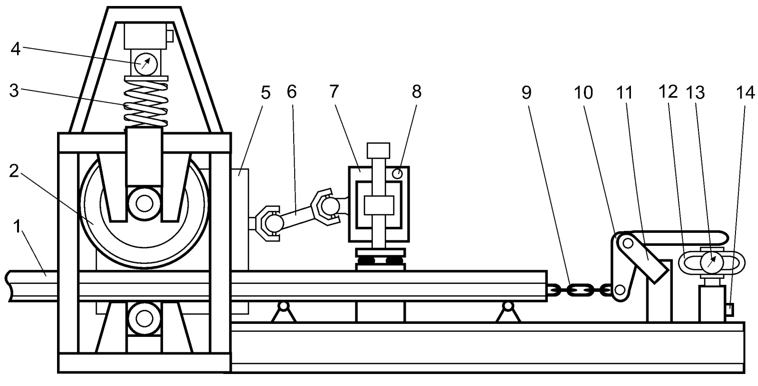

Fig. 1. Natural board of wheel-and-rail system

The experiment conduct was performed on the board in the following order. Contacting bandage surfaces and rail were decreased and got clear from hard particles, which came into them before each experience (given surfaces were watered well for tests in terms of wet contact). In case of lubricated contact given surfaces were worked up with car oil. In all cases the latitude of contamination sheet did not exceed the latitude of abrasive material sheet). After that, a sheet of abrasive powder of the given 0,06 kg/m^2 fractional component nature, particles of which were placed with closeness of filling contact with the sheet which is optimal, according to given research [2], was put on the rail surface. Rail 1 was delivered under the raised wheel 2 along directing rollers, after that wheel 2 was put down on wheel ground with abrasive material with the help of limiter 8 and it was loaded by mechanism 3 up to certain meaning of axis lading. Calculation of normal effort of wheel on rail was done according to manometer 4 scale, showing oil pressures in the cylinder of hydraulic of jack. New calculation was carried out of readings of manometer 4 into the meaning of normal wheel loading on rail $P_{n,}$ according to the formula:

$$P_n = P_w + \frac{P_m \pi d^2}{4}, \tag{1}$$

where $P_w = 1 \cdot 10^4$ N – own wheel weight;
P_m – manometer readings, Pa;
$d = 92 \cdot 10^{-3}$ m – diameter of hydraulic jack of the cylinder.

Meanings of normal wheel loading on rail were varied in the range from 30 to 150 kN in the process of the experiment.

After radial wheel 2 loading and its fixation tangential loading was done by means of mechanism 11. Rod of hydraulic jack 14 through dynamometer 12, liver 10 and chain 9 transmitted linear effort F on rail 1. Value of this power was defined according to error γ of micrometer indicator (SGS 577-68, point value is $0{,}01 \cdot 10^{-3}$ m, the limit of the allowed main error is $\pm 20 \cdot 10^{-6}$ m) with the consequent new calculation according to tarring characteristics of the pattern dynamometer 12 (DOSM-3-5), taking into account the transmitting attitude of liver 10, equal to i = 2,445.

As wheel is jammed by limiters 8 and is connected with rail 1 frictionally, power F tends to create slipping of wheel relating to rail. Outside reaction for this force appears in relation to rail, cohesion force $F_c = F$, interfering slipping of wheel 2, regarding to rail surface. The meaning of force F, equal to breaking point of cohesion F_c power, is fixed in the moment of cohesion spoil according to indicator 13 scale. Cohesion coefficient is determined according to the formula:

$$f_c = F_c / P_n . \tag{2}$$

Each measurement was done particularly and for many times, providing reliability of the results. After conducting each measurement, surfaces of bandage and rail were replaced with regard to each other.

The results of experimental research in defining the coefficient of locomotive wheel-and-rail cohesion are presented in Fig. 2.

Testing curves 1-7 (Fig. 2) were received for an evaluation of usage effectiveness of the considered pouring materials in the terms of wet and lubricated contact: 1- dry contact without hard particles; 2 – wet contact with sand; 3 – wet contact with slag; 4 – wet contact with magnetite; 5 – lubricated contact with sand; 6 – lubricated contact with slag; 7 – lubricated contact with magnetite.

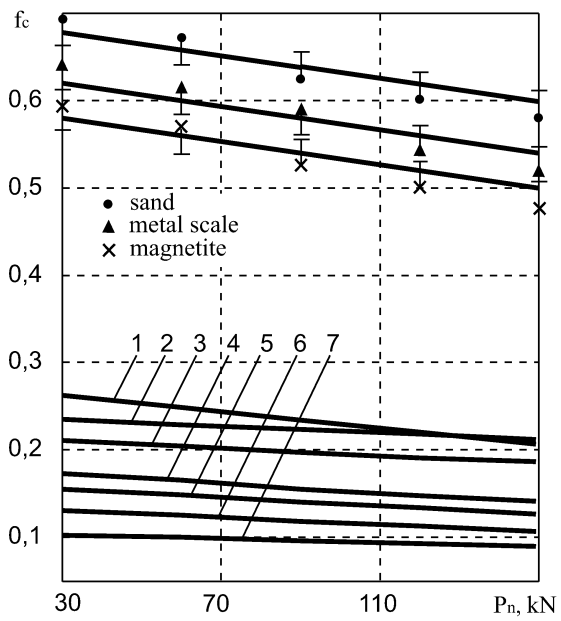

Fig. 2. The dependence of cohesion coefficient from radial wheel-on-rail landing in different terms of contact

The following formula was received for the defining of the borders of the confidence intervals of indirect measurements' error of wheel-and-rail cohesion coefficient value:

$$\Delta f_c = \frac{1}{1 \cdot 10^4 + 0{,}0066\,\overline{P}_m} \sqrt{(15{,}9\,\Delta\gamma)^2 + \left(\frac{0{,}0066 \cdot (15{,}9\,\overline{\gamma} - 1563)}{1 \cdot 10^4 + 0{,}0066\,\overline{P}_m} \Delta P_m \right)^2}\,, \tag{3}$$

where $\Delta\gamma$ и ΔP_m are the borders of the confidence intervals of errors (with the same confidence probability 0,95) of immediately measured values γ (readings of micrometric indicator 13, see picture 1) and P_m accordingly. are average arithmetic meanings of the immediately measured values γ and P_m accordingly.

EXPERIMANTAL DEFINING OF ABRASIVE WEAR VALUE

Experimental defining of wear value of the working wheel and rail surfaces presupposes measurement of volume values of the material (or their mass), canceled from the pointed out surfaces in the process of wear. The given task relatively to the pair of wheel-and-rail friction is not difficult in itself but practically impossible in the terms of providing rather high measurement exactness. That is why working surfaces of wheel and rail were modeled by two cylinder discs of the same diameter ($50{,}00 \cdot 10^{-3}$ m) and width ($11{,}75 \cdot 10^{-3}$ m), placed vertically above each other and made of rail and bandage steel.

Tests for wear were conducted with the help of friction car SMTS-2 by means of the apparatus, shown in Fig. 3.

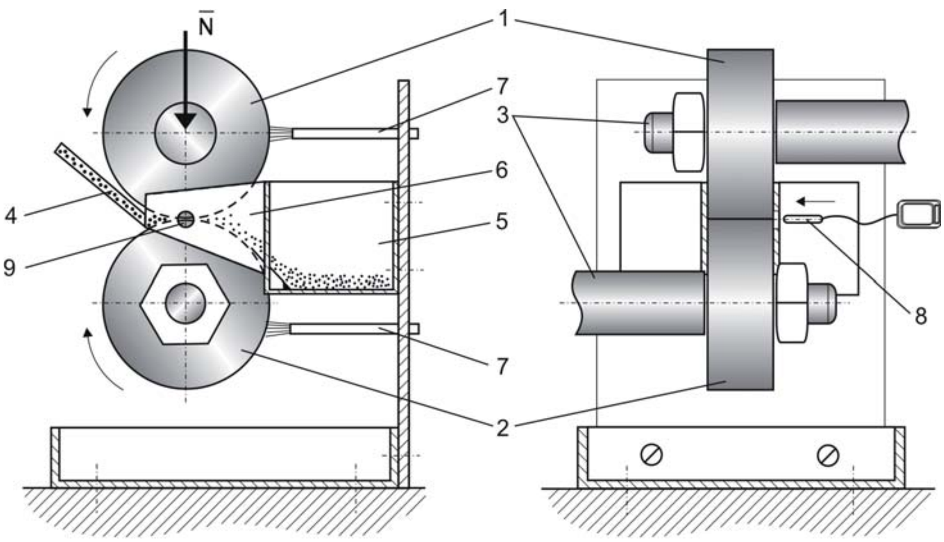

Fig. 3. The scheme of the apparatus for wear testing with the presence of hard particles contact

Tested rollers 1 and 2 were fixed on friction car shafts 3 vertically above each other (slipping of rollers regarding to shafts 3 was not allowed) and they were attached to each other by radial effort N, created by loading mechanism of friction car. Rollers were winding, with regard to each other in the process of testing, which was provided by the apparatus of friction car. Slipping value in all tests equaled 20% (speed of roller 2 winding is 20% higher than the roller's 1 winding speed). Hard particles were delivered into roller contact zone with the help of groove 4, after which, having passed contact zone they got into capacity 5. Within it, terms of maximum contact saturation by hard particles were created. Brushes 7 were used for clearing up the rollers' surface from the hard particles absorbed in them. Thermo-pair 6, contacting with friction surfaces through hole 9 in one of the directions 6 was used for measurement of volume temperature of the tested discs. All construction was strongly fixed to friction car mount.

In all cases, wear of the tested discs was defined within their mass loss in the process of test. Analytic scales VLA-200-M, providing the exactness of measurements up to $\pm 1 \cdot 10^{-7}$ kg, with a set of pattern weight measurements G-2-210, the second class of exactness SGS 7328-65, were used for it. The task of normal loading on discs as well as speed of their rotation, is provided by the construction of friction car. Maximum error is 7% as well as rotation speed is 10% for lower disc 2 (see Fig. 3) within setting the value of the required landing. Maximum task of slipping coefficient is 5%. Volume temperature of the tested discs was measured by digital multimetre DT-838 of "Suns" firm with thermo-pair TP-01A, maximum measurement value is equal to ±3°C for the temperature values within 0°C up to 250°C. Error of converting digital multimetre is not more than 1% of the measured value. Material hardness of contacting disc surfaces was defined by the apparatus for hardness measurement, according to Rockwell method: TK-2 "ZIL" and it comprised 33±1 HRC (for disc 1) and 25±1 HRC (for disc 2). Clarity of disc's working up is equaled to the seventh class according to SGS 2789-73. The division of hard particles grains, used for pouring materials, was done by a set of standard industry SGS 3647-71 on fraction. Size of the main fraction is determined by the size of cells of two nets, through the first of which all grains of the given fraction pass, and stay on the second one. Nominal size of cells side in a net was taken for granularity where hard particles stay.

The following outside factors in a given range varied in the process of tests:

- Normal landing on the disc took the meanings consequently: 400, 900 and 1400 N;
- Corner speeds of disc rotation comprised consequently: 300,500 and 1000 rpm (speeds for disc 2, rotating faster than speeds for disc 1, were pointed. The value of disc slipping coefficient was equaled to 20% of all conducted tests relative to each other);
- Hard particles of the following fractional component structure: 100, 200, 500, 1000 and 1500 μm were used.

Pattern surfaces were worked up with spirit carefully before the test as well as after it. One and the same pair of discs was used in all tests. The delivery of hard particles into contact zone of interacting discs began only after stabilization of volume material temperature of the tested patterns. The temperature of the surrounding air was constant and was equal to 19 °C in the course of the whole experiment.

The delivery of hard particles into contact began after the fact that volume temperature of the tested rollers stabilized. Value of the period of time was 900 s for the most difficult regime tests (rotation speed is 1000 rpm, loading is 1400 N). Thus, hard particles began to be delivered into roller contact at the expiry of the pointed out timed interval. Their delivery lasted for 60 s in each test, i.e. general test duration comprised 960 s.

As a result, wear value of the roller consisted of two comprising elements within single test: wear without the introduction of hard particles into contact as well as wear with the same ones. Average value of roller wear without hard particles in the course of 900 s for all the used combinations of roller rotation speeds and loadings within their tests were defined for their separation from each other. The comprised wear element was defined within the influence of hard particles into contact as the difference of wear sum (the duration was 960 s during the whole test) as well as wear without hard particles (more than 900 s).

Roller material value wear for speed of rotation 1000 rpm and loading 1400 N are presented in Fig. 4 (the most difficult test regime). Each experimental point at scheme is an average meaning of the series of parallel tests. The size of pouring material grain was drawn along abscissa axis schemes, mass surface wear of the tested rollers was drawn along Y-axis.

In all the conducted measurements mass wear value casual error exceeded the systematic one by 3 and more times. The borders of the confidence intervals were defined for confidence probability 0,95 (from assumption of normal distribution of roller mass wear value according to the dependence):

$$\Delta x = t\sqrt{\frac{1}{n(n-1)}\sum_{1}^{n}(\Delta x_i)^2}\ , \tag{4}$$

where Δx – the border of confidence interval; t – Student coefficient for the given confidence probability and a number of measurements n; Δx_i – casual deviation of the observed value from its average arithmetic meaning.

Value of confidence intervals Δx and average square errors s are averaged for the meanings of normal loadings on the tested discs in the range of 400-1400 N, thanks to the similarity of the appropriately defined dispersions.

The conducted experimental evaluation of cohesion qualities of wheel and rail allowed to make the following conclusions concerning the introduction of the considered abrasive materials into contact under different terms.

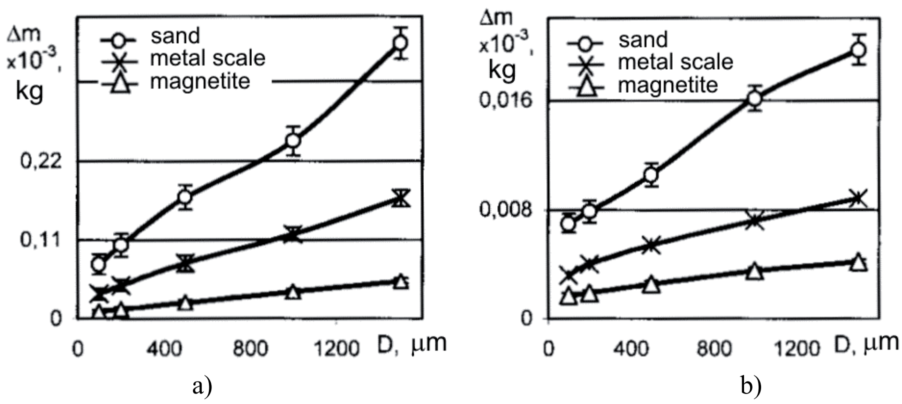

Fig. 4. Mass rollers' wear 1 (a) and 2 (b) within normal loading 1400 N
Corner speed of rotation is 1000 rpm

CONCLUSIONS

- In case of dry, clean surfaces sand allows to provide 9% and 14 % of the cohesion coefficient higher value in average than metal slag and magnetit, accordingly (within normal wheel loading on rail 115 kN cohesion coefficient for sand was 0,64); it was 8% and 18% for wet surface, accordingly (within 115 kN for sand: 0,24); it was 10% and 20 % for lubricated surfaces, accordingly (within 115 N for sand: 0,17). Within this process the particles of the working material were placed in one sheet with closeness 0,06 kg/m^2. Normal loading of wheel onto rail was measured within 30-150kN (wheel radius is 0,525 m).
- An increase of normal wheel lading onto rail in the range from 30 to 150kN leads to a decrease of cohesion coefficient value of the surfaces pointed out, within the presence of particles in contact, which can be explained by the presence of interference effect of material deformations of wheel-rail conjugation.
- Fractional component structure of the tested abrasive powders did not produce visible effect on the cohesion coefficient value, at least, within particle size: 100-1000 μm.
- The least wear was observed within the usage of steel oxide – magnetite ($FeOFe_2O_3$) of small fractions (200-250μm), within each of the considered combinations of outside factors (within loading, rotation speed). Given circumstance can be explained by the fact that magnetite particles possess the least hardness among the tested materials.
- In all the cases an increase of roller wear was observed with the increase of pouring material fraction and (or) rotation speed of the tested rollers. Wear increase was also observed with the growth of normal loading in the majority of cases. Roller 1 (33 HRC), rotating with the least speed was worn more intensively within it. The most average wear for single test was observed at roller material 1 and comprised $0{,}1493 \cdot 10^{-3}$ kg for quartz sand, 1500μm in size, 1400N loading with rotation speed 1000 rpm. The least average wear was registered at roller 2 (25 HRC) during the test, equal to $0{,}0012 \cdot 10^{-3}$ kg, for magnetite powder., 100 μm in size, 40 N lading within rotation speed 300 rpm.
- Wear was practically independent on normal loading (at least in 400-1400 range) in case of tests, used in combination of outside factors within the presence of small fractions (100-200 μm)

in contact. In other words, wear independence from nominal contact area can be supposed in given cases.

- Roller material wear value differed insignificantly from corner roller rotation speed, equaled to 300 rpm (for roller 2) within the delivery into fraction contact 100-200 μm, independently from the type of abrasive powder. Within it, the difference in meanings of mass wear for slag and magnetite was less than for the pointed materials and quartz sand.
- The received experimental values of cohesion coefficient values of wheel and rail surfaces allow to make the conclusion about the expedience of their usage for the improvement of cohesion qualities of wheel-and-rail pair friction in the given alternative systems of cohesion increase within different outside terms, conditioned by the presence of hard particles in contact, which are alternative to abrasive materials' sand (metal slag and magnetite) in combination with contacting surfaces wear, produced by them.

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