Influence of tire tread pattern wear on characteristics of its longitudinal adhesion with bearing surface

A I Fedotov¹, A S Markov¹, D E Makhno¹,² and M A Vikulov³

¹Irkutsk National Research Technical University, Department of Road Transport, 83, Lermon-tov Street, 664074, Irkutsk, Russia
²Irkutsk National Research Technical University, Department of Mining, 83, Lermonov Street, 664074, Irkutsk, Russia
³North-Eastern Federal University, Department of Mining, 58, Belinsky street, 677027, Yakutsk, Russia

E-mail: fai.abs@rambler.ru

Abstract. The aim of the research was to carry out the experimental study of the influence of tire tread pattern wear on characteristics of the longitudinal adhesion with the bearing surface in order to detect functional relationships of the adhesion coefficient against the value of tread pattern wear and the value of normal load. The experiments were carried out according to the original methodology on the laboratory tester of a modular type that allows studying the processes occurring in the elastic tire area contacting with the flat, one cylindrical, two cylindrical bearing surfaces. The experimental research allowed obtaining the 35.3% decrease of the longitudinal coefficient of elastic tire adhesion while increasing the value of tread pattern wear from 10% to 90%. The study of brakeage of the wheel with elastic tire on one bearing roller showed the 18% decline of the adhesion longitudinal coefficient with the tread pattern wear varying from 10% to 90%. During the wheel braking on two bearing rollers and the tread pattern wear increased from 10% to 70% the longitudinal coefficient of adhesion fell by 23.8% on the front bearing roller and by 48.4% on the rear roller. The result of the given research is detected functional relationships of adhesion longitudinal coefficient against the values of tread pattern wear and normal load for three types of the bearing surfaces.

1. Introduction

Automobile transport is the most popular one in the whole world. According to the statistics provided by the traffic police of the Russian Federation, 169,432 road traffic accidents (RTA) occurred in 2017; 19,088 people died and 215,374 people had injuries of varying severity in these accidents [1]. The overwhelming majority of accidents is accompanied by the process of a motor vehicle transport (MVT) brakeage. It is known that mechanical validation of the braking system on modern roller testers is performed by checking each axis by turn, which cannot provide an objective assessment of their associativity under the road conditions. The service braking system effectiveness under the road conditions is measured by the value of the mean fully developed deceleration and the brake path; the fundamental parameter of these indicators is the longitudinal friction coefficient [10].

According to the legislation of the Russian Federation, when performing the technical inspection of MVT, the residual height of the tire tread pattern is measured. The minimal values of the residual height of the tire tread pattern by MVT categories are given in Table 1 [2]. However, articles, scientific
literature and monographs do not present any information about the change in the longitudinal coefficient of a car tire adhesion in response to increasing tire tread pattern wear when in use, as well as about the way it affects the brake effectiveness of an MVT [3].

| MVT Category | Minimal Residual Height of the Tread Pattern |
|--------------|---------------------------------------------|
| L            | 0.8 mm                                      |
| N2, N3, O3, O4 | 1.0 mm                                      |
| M1, N1, O1, O2 | 1.6 mm                                      |
| M2, M3       | 2.0 mm                                      |

2. Experimental Procedure Description
To study the given issue, the group of scientists of the laboratory of the Department of Automobile Transport in Irkutsk National Research Technical University designed and assembled a modular tester that allows studying the processes involving the area of elastic tire contacting with three types of the bearing surface (a flat one, one cylindrical and two cylindrical surfaces). The general view of the tester is presented in Figure 1. The designed tester is equipped with several systems of measurement: the system of braking force measurement; the system of measuring tangential and normal responses distributed along the length of the elastic tire area contacting with the bearing surface; the system of measuring the rotational speed of the rotating wheel and bearing rollers [4, 11].

![Figure 1](image1.png)

Figure 1. General View of the Modular Tester for Studying the Processes Involving the Elastic Tire Area Contacting with Flat and Cylindrical Bearing Surfaces: (a) with the flat bearing surface; (b) with the cylindrical bearing rollers.

The functional chart of the tester with the installed module of the flat bearing surface is presented in Figure 2. The flat bearing surface is driven by the electromotor via the worm gear; the speed of forward movement of the bearing surface can vary within the range of 0-1.1 m/s. The strain-gauge indicator is built in the bearing surface; it is made of spring steel in the form of a plating with resistive strain sensors stuck on it and connected as the Wheatstone bridge (Figure 3).
The functional chart of the tester with the installed bearing rollers module is shown in Figure 4. The design of this tester allows the elastic tire wheel to slide forward against the bearing rollers. This sliding
gives an opportunity to carry out the experimental research on both one and two bearing rollers as well as upon the offset of the wheel spindle against the reference axis of the bearing rollers unit.

The bearing rollers are driven by the electromotor via the worm gear; the bearing rollers are connected by chain transmission; their rotational speed can vary from 0 to 11 rad/s. An elastic tire wheel placed on the tester is locked and remains standstill in order to study the process of locked wheel brakeage. The surface of the bearing rollers is equipped with strain-gauge indicators which have the same design as indicators installed on the flat bearing surface. Strain-gauge indicators belong to the system of measuring the longitudinal tangential and normal responses distributed along the length of the elastic tire area contacting with bearing surface.

For research the authors chose Bridgestone Sneaker tires of 185/70 R14 type; they have different residual heights of the tire tread pattern (Figure 5). The normal load on the wheel intermittently varied from 1,750 N to 4,750 N in increments of 500 N, the tire pressure was 0.21 MPa. In order to decrease measurement inaccuracy caused by the increased temperature of friction surfaces in the contact area, the previous findings [5] were taken into account and the experiments were carried out with a specified interval allowing the bearing surface to get cold.

**Figure 4.** Functional Chart of the Tester with Installed Cylindrical Bearing Rollers Module: 1, 2 – electromotor; 3, 4 – worm gear; 5 – cardan drive; 6 – chain; 7, 11 – bearing rollers; 8, 12 – strain-gauge indicator; 9 – wheel; 10 – measuring sensor of accumulated braking force; 13, 14, 16 – rotational velocity sensor; 15, 17 – trolley collector.

**Figure 5.** Tires Used in Experimental Research: (a) tire with 10% of wear; (b) tire with 90% of wear.
3. Research Findings
The research of brakeage process of the locked wheel with elastic tire resulted in detecting functional relationships between the longitudinal coefficient of adherence and the value of normal load on the wheel as well as the value of the tire tread pattern wear that are presented in Figures 6-8.

![Graphs of adhesion longitudinal coefficient of Bridgestone Sneaker 185/70 R14 88S tire during the locked wheel braking on the flat bearing surface with various tire tread pattern wear and normal load.](image1)

Figure 6. Graphs of adhesion longitudinal coefficient of Bridgestone Sneaker 185/70 R14 88S tire during the locked wheel braking on the flat bearing surface with various tire tread pattern wear and normal load.

![Graphs of adhesion longitudinal coefficient of Bridgestone Sneaker 185/70 R14 88S tire during the locked wheel braking on one cylindrical bearing surface of the tester with various tire tread pattern wear and normal load.](image2)

Figure 7. Graphs of adhesion longitudinal coefficient of Bridgestone Sneaker 185/70 R14 88S tire during the locked wheel braking on one cylindrical bearing surface of the tester with various tire tread pattern wear and normal load.

The results obtained during the locked wheel braking on one bearing roller also show the minimal influence of the normal load value on the coefficient of the elastic tire adhesion with the bearing surface. The increase of the tire tread pattern wear from 10% to 90% caused the 18% decrease of the longitudinal coefficient of adhesion at the normal load of 1,750 N.

The experimental studies of the locked wheel braking on two bearing rollers show the following: the normal load also does not influence a lot the value of the longitudinal coefficient of adhesion with the bearing surface. The increase of the tire tread pattern wear from 10% to 70% caused the 23.8% decrease of the longitudinal coefficient of adhesion on the front roller of the tester at the normal load on the wheel of 2,260 N. On the rear roller the decrease amounted to 48.4% at the load of 1,750 N with the same values of the tread pattern wear.
Figure 8. Graphs of adhesion longitudinal coefficient of Bridgestone Sneaker 185/70 R14 88S tire during the locked wheel braking on two cylindrical bearing surfaces with various tire tread pattern wear and normal load: (a) longitudinal coefficient of the tire adhesion with the front roller; (b) longitudinal coefficient of the tire adhesion with the rear roller.

4. Summary and Conclusions
The findings indicate a significant influence of the elastic tire tread pattern wear on the longitudinal coefficient of adhesion, whereas the value of the normal load has little impact on its change both on flat and cylindrical bearing surfaces.

The given results are correlated with the previous findings and complement them [5-8]. A car tire can be unstable in producing longitudinal tangential responses [9].

During the locked wheel braking on the flat bearing surface the longitudinal coefficient of adhesion can be reduced up to 35.3%; when braking on one bearing roller the decrease can be 18%; during braking on two bearing rollers the decrease on the front roller amounts to 23.8% and on the rear one – 48.4%. The findings allow developing multidimensional regression models of the longitudinal coefficient of adhesion in order to use them in mathematical models that will help to increase modelling accuracy [12].

References
[1] Information on Indicators of the Road Traffic Safety [Electronic Resource]. Available at: http://stat.gibdd.ru/
[2] On the Safety of Wheeled Vehicles: Technical Regulations of the Customs Union TR TS 018-2011 [Electronic Resource]. Available at: http://docs.cntd.ru/document/902320557

[3] Petrov M A973 Car Wheel Performance under Braking Conditions (Omsk: Western-Siberian Publishing House) 224 p

[4] Boyko A V, Khalezov A V, Yankov O S, Markov A S 2015 Dyno Roller for Studying the Interaction between Elastic Tire with Two Chassis Dynamometers Automobile for Siberia and the Far North. Design, Operation, Economy: Proceedings of the 90th International Scientific Technical Conference (Irkutsk: ISTU Publishing House) 115–123

[5] Fedotov A I, Markov A S, Yankov O S, Ovchinnikova N I 2017 Impact of Tire Tread Pattern Wear on Its Adhesion with the Bearing Surface Bulletin of Irkutsk State Technical University 21(11) 216–225 DOI: 10.21285/1814-3520-2017-11-216-225

[6] Isaev E U, Solomatin N S, Kevtun V V, Karpov V M 2005 Stages of Designing a Car (Tolyatti: TSU Publishing House) 82 p

[7] Fedotov A I, Zedgenizov V G, Ovchinnikova N I 2017 Experimental Studies of Elastic Tired Wheel Braking under Variable Normal Load IOP Conf. Ser.: Earth and Environm. Sci.

[8] Fedotov A I, Zedgenizov V G, Ovchinnikova N I 2017 Dynamic Analysis of Elastic Rubber Tired Car Wheel Braking under Variable Normal Load IOP Conf. Ser.: Earth and Environm.1 Sci.

[9] Ilarionov V A, Pchelin I K 1979 Road Responses Influencing the Braking Wheel of a Car. Study of Car Brakeage and Pneumatic Tire Performance: Inter-University Collection (Omsk: OmSI) 160 p

[10] Fedotov A I, Zarschikov A M 2007 Design, Calculation and Consumer Properties of Automobiles Study Guide 334 p

[11] Fedotov A I, Boyko A V, Khalezov V P 2011 Complex for Studying the Interaction in the Tire Contact Area with the Surface of Roller and Road Problems of Diagnostics and Operation of Transport: Proceedings of the III International Scientific and Practical Conference. (Irkutsk: ISTU Publishing House) 218–223

[12] Fedotov A I, Boyko A V 2007 Multi-Mass Model for Studying the Process of a Car Braking on a Tester with Rollers Bulletin of Irkutsk State Technical University 4 67–71