The potential capacity of tires to create cornering forces on the roads covered with chemical anti-icing materials

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Abstract. The paper presents the results of the study of the influence of chemical anti-icing materials on the capability of tires to create cornering forces that affect road holding and steerability of a vehicle. In this article bench and road methods of testing of tires rolling along the planes covered with chemical anti-icing materials have been applied. It demonstrates a research method used to determine the stationary and non-stationary characteristics of the elastic tires pull rolling along the planes covered with chemical anti-icing materials. The experiments are obtained in bench conditions on a special tire tester developed by scientists of the Department “Road transport” of Irkutsk National Research Technical University, as well as in road condition on a tire tester developed by scientists of the Department "Road transport" of Irkutsk National Research Technical University and the Department “Automobiles” of East Siberia State University of Technology and Management. The experimental results are presented in graphs. Obtained results allow concluding that on the roads covered with chemical anti-icing materials (CAIM) the capability of tires to create cornering forces is sharply reduced.

1. Introduction

A car was and still remains the most dangerous mode of transport at the present time. The danger of the car is that the material object has a mass of up to 50 tons or more, can move at high speeds, is held on the road only due to the friction forces of the roadwheels on its surface [1-3].

More than half of accidents in Russia occurred as a result of the loss of road holding and steerability. In terms of road safety these properties of a vehicle are the most important and determined by the stability of road tire contact [3,4].

The stability of tire traction of a vehicle depends on many factors including the tire type and tire pressure, engineering status of suspension, the type and condition of the road surface [3, 5-9]. In particular, there is a significant decrease in sideways adhesion of tires to roads covered with CAIM [1,7].

Skid force $F_y$ acts on a roadwheel with elastic tire which will keep a steady movement till a condition is met [3]:

$$ R_y \leq \sqrt{R_z^2 \phi^2 - R_z^2} $$

(1)

where $R_z$ – normal reaction in flat spot of the tire of a roadwheel with the surface of the road; $\phi$ – coefficient of adhesion of the tire with the surface of the road; $R_y$ – cornering force; $R_z$ – normal reaction.
One can determine the parameters of the equation (1) both experimentally and analytically [3]. Any action of the side force on the vehicle is necessarily accompanied by rolling of the roadwheels with side slip angles of the tires. The study of the characteristics of tire breakaway allows one to establish qualitatively and quantitatively the patterns of their interaction with roads covered with chemical anti-icing materials.

For this purpose, the tire tester having a system of measuring the power and kinematic parameters [10] was used to carry out the experimental studies of the characteristics of tire break-away on the surface with a high coefficient of adhesion. The general view of the tire tester is shown in figure 1.

![General view of the tire tester](image)

**Figure 1.** General view of the bench used to study stationary and non-stationary dynamic characteristics of the elastic tire in the movement process of slip angles: 1 – load screw with sensor mount of normal load bearing, 2 – transducer measuring normal load DST 9035, 3 – spring with absorber being tested, 4 – fork shaft, 5 – PCs, 6 – steering wheel, 7 – frame bench, 8 – chassis dynamometer with a special polymer coating, 10 – transducer checking wheel turning angle, 11 – laser, 12 – transducer measuring normal load DST 9035, 13 – case, 14 – gearbox, 15 – grip, 16 – electric motor.

Experimental studies of the tire breakaway characteristics on the surface with a high coefficient of adhesion were carried out in order to analyze the potential coupling properties of tires when the wheel moves with the slip angles. At the first stage, stationary and non-stationary-dynamic characteristics of elastic tires were investigated on the tire tester.

2. Methods

The stationary characteristics of the elastic tire were determined first in the course of the bench experiment, then the non-stationary characteristics at an unsteady slip angle with a variation of the roadwheel rolling speeds along the plane of the bench chassis dynamometer. This approach made it possible to determine the critical breakaways, at which there was a failure of the flat spot with the plane.

The method of the experiment used to determine the stationary characteristics of the tires in the mode of breakaway included:

- starting of the electric motor 16 with the clutch disengaged 15 (Figure 1);
- using the selector lever of the change gearbox 14 we put in the first gear and engaged slowly the clutch bringing the torque through the gearbox and chain drive to the bench chassis dynamometer;
- by rotating the screw 1, the roadwheel was loaded with a normal load of 3000 N as a result, the roadwheel with the testing tire also began to rotate together with the chassis dynamometer;
- during 15-20 minutes the tire was warmed up to operating temperature by the method of rolling.
by means of the steering box (step of 1 degree) the tire slip angles of the roadwheel were established, bringing the slip angle to 17 degrees;

- the measured signals of the power and kinematic parameters of the process were recorded using the ZETlab program; the measurement results were stored on the hard disk of the computer;

- changing the load on the wheel and varying the speed, we obtained the results of measuring the parameters of the interaction of tires with the plane of the chassis dynamometer;

- the results of the experiment were processed using the “Microsoft Excel” program to obtain the real values of the measured physical quantities;

- the obtained results were used to construct graphs of the investigated dependencies;

- critical slip angles were identified as the values of this angle at the maximum value of the cornering force.

3. Results and discussion

The method of the experiment used to determine the unsteady characteristics of the tires in the breakaway mode differed from the above technique in that during the rolling of the loaded wheel. Its slip angle was changed continuously from zero to 17 degrees and then back from 17 degrees to zero.

As an example, Figure 2 shows both stationary and non-stationary characteristics of tires model Michelin 195/65 R15 loaded with a normal load of 2500N and 3000N at speed of 44 km/h.

![Figure 2. Non-stationary and stationary characteristics of unsteady tire breakaway MICHELIN 195/65 R15, tire pressure P=0.21 MPa.](image)

The obtained characteristics of the side-on adhesion indicate that on coatings with high adhesion ($\phi_{\text{max}} = 0.8 \div 0.9$) the values of the critical slip angles are in the range of 9-13.5 degrees. At the same time, the decrease in the friction properties of the tire at large slip angles (more than critical) is insignificant and is at the level of 2-7%.

The values of the critical slip angles were summarized in Table 1.

Road experiment to determine stationary characteristics of tyres on roads covered with chemical anti-icing materials was carried out with the help of a road tire tester [7] developed by scientists of Irkutsk National Research Technical University (Irkutsk) and ESSUTM (Ulan-Ude). The appearance of the tire tester for the experimental study of coupling properties of road tires is shown in figure 3.
Table 1. Values of critical angles

| Normal reaction, (H) | Wheel line speed, (km/h) | Critical slip angle, (degree) |
|----------------------|--------------------------|-------------------------------|
| 1500                 |                          | 13.5                          |
| 2000                 | 14.4                     | 12.4                          |
| 2500                 |                          | 11.3                          |
| 3000                 |                          | 9.7                           |
| 1500                 |                          | 11.3                          |
| 2000                 | 24.4                     | 9.5                           |
| 2500                 |                          | 8.8                           |
| 3000                 |                          | 8.2                           |
| 1500                 |                          | 9.7                           |
| 2000                 | 44.3                     | 9.2                           |
| 2500                 |                          | 8.8                           |
| 3000                 |                          | 7.9                           |

Figure 3. Appearance of the tire tester for experimental research of coupling properties of tires with the road.

The experimental method to determine the stationary characteristics of tires on roads covered with chemical anti-icing materials included:
- each roadwheel tester was loaded sequentially with normal load of 2880 N, 2320N and 1800N by load securing to the console tester;
- with the help of the screw mechanism of the tester (increments 1 degree) the tire slip angles of 2 roadwheels were changed discretely, bringing their value to 12 degrees;
- at each fixed value of the slip angle the power and kinematic parameters of the tires were measured using the ZETlab program and the measurement results were stored on the computer hard disk;
- the load on the roadwheel and speed was changed;
- measurements of parameters of the investigated process were repeated;
- the results of the experiment were processed using the “Microsoft Excel” program to obtain the real values of the measured physical quantities;
- the obtained results were used to construct graphs of the investigated dependencies;
critical slip angles were identified as the values of this angle at the maximum value of the cornering force.

In the course of the study, the dependences of the coefficient of side-on adhesion of tires model Michelin 195/65 R15 were obtained both on the road covered with a “sandwich” of CAIM (Figures 4 and 5a) and loose snow (Figures 4 and 5b).

Presented in figures 4 and 5 graphs show clearly that the capability of the tire to create cornering force on the roads covered with chemical anti-icing materials, is greatly reduced.

In contrast to the interaction characteristics of the tires with planes which have high values of the coefficient of adhesion ($\phi_{\text{max}} = 0.8 \div 0.9$), the characteristics of tires on a winter “sandwich” and on loose snow have significant qualitative and quantitative differences.

Figure 4 – Graphs of the side coefficient of adhesion $\phi_y$ of tires model Michelin 195/65 R15 on the road covered with a “sandwich” with CAIM: (a) and on the road covered with loose snow; (b) at a speed of 5 km/h.

Figure 5. Graphs of the side coefficient of adhesion $\phi_y$ of tires model Michelin 195/65 R15 on the road covered with a “sandwich” with CAIM: a) and on the road covered with loose snow; b) at a speed of 15 km/h.
4. Conclusions
Comparison of the results of the road experiment with the results of bench studies (figure 2) allows concluding:

- on roads with low coefficients of adhesion ($\phi_{\text{max}} = 0.15 \div 0.33$) the critical slip angle of the tire decrease to values of 4 to 5 degrees. In comparison with the results of bench tests on surfaces with high adhesion ($\phi_{\text{max}} = 0.8 \div 0.9$) makes the reduction of this parameter is approximately 2.5 times;

- on roads with low coefficients of adhesion ($\phi_{\text{max}} = 0.15 \div 0.33$), frictional properties of the tires at slip angles that are more than critical ones are reduced quite significantly. This reduction is 32-57%, which greatly reduces the capability of tires to create cornering forces;

Comparative analysis of the study results of the capability of tires to create cornering forces on the road covered with the “sandwich” of CAIM is presented in figures 4 and 5, a) with the results of the study conducted on loose snow (figures 4 and 5, b);

- on the road covered with the “sandwich” of CAIM (figures 4 and 5, a) maximum values of coefficients of adhesion is $\phi_{\text{max}}$ of 10-12% lower than on loose snow (figures 4 and 5, b);

- on the road covered with the “sandwich” of CAIM (figures 4 and 5, a) reduction of the coefficients of adhesion $\phi_s$ in the zone of “supercritical” slip angles on average is at 24% lower than their decrease $\phi_s$ in the zone of “supercritical” slip angles on loose snow (figures 4 and 5, b).

From the results obtained, the following conclusions are drawn: the application of chemical anti-icing materials on winter roads reduces significantly the capability of tires to create cornering forces, therefore negatively affects the road holding and steerability of a vehicle.

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