Analysis Of Tire-road Contact Under Winter Conditions

Konrad J. WALUŚ, Zbigniew OLSZEWSKI

***Abstract* - Traction and vehicle's ability to respond appropriately to direction are strongly influenced by the mechanical characteristics of the tire. The forces and moments responsible for safety, directional stability and vehicle dynamics are generated in the relatively small areas of contact between tire and road surface. In areas of contact carrier forces are friction process. Determination of the influence of the contact zone the material qualities and environmental values of the friction between the tire and the ground is crucial for determining the characteristic behaviour of the whole vehicle especially in changing weather conditions**

***Index Terms*—Tire, Road, Contact, Friction, Winter**

I. INTRODUCTION

Friction phenomenon occurs in all mechanical systems where a mutual contact of bodies exists. The basic law of friction states that when static body is pressed to the surface by a normal force, and is pushed by tangential horizontal force, when it reaches certain critical value, the body begins to move. At the same time a force will rise to power counteracting this movement called the force of friction.

In the case of tire-surface pair, it is apparent that its application is limited to specific physical conditions such as high tire pressure.[1]. For example, in terms of the actual friction coefficient varies with velocity, as shown in the so-called. Stribeck curve (Fig. 1). The coefficient of friction decreases with velocity, reaches a minimum value and then increases for higher speeds.

The coefficient of friction called in case of tire-surface system, traction coefficient is dependent on many factors related both with associated materials and external factors. In tire-surface system friction forces are caused by two main mechanisms - the adhesion and hysteresis [2].

II. ADHESION

The area of actual contact between the rubber and the hard rough surface (road) is strongly dependent on the adhesive properties of the substrates. In the case of hard materials with limited elastic properties, the effect of adhesion is not revealed in the macroscopic scale. Contact occurs between randomly distributed over both surfaces inequalities and ceases immediately after their separation, without any additional force generation. In the case of rubber and other adhesive materials hyper elastic interaction is cause by van der Waals forces. Thanks to its flexibility rubber under the influence of external load penetrates deeper into the material surface, which allows contact of the two materials at the molecular level, so that it becomes possible for electrostatic forces to work between molecules (Fig. 2) [3], [4], [5].

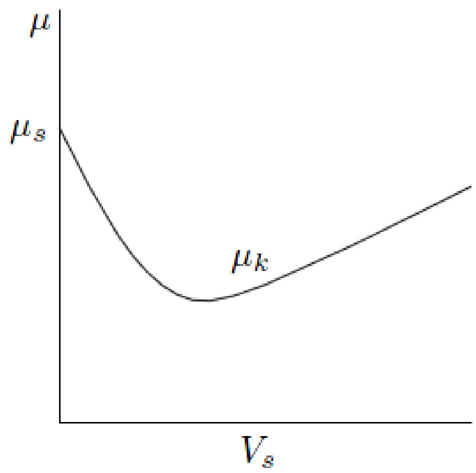

Fig. 1. Stribeck curve where: μ –coefficient of friction, μs – static coefficient of friction, μk – kinetic coefficient of friction, Vs – sliding velocity [3].

Breaking forces acting in such a combination, which cause the interruption of the contact elastic deformation of the rubber causes through the mutual attraction between molecules of both materials increase of the opposite reaction. Adhesive friction is most important on dry, clean surfaces, and its importance is declining in the case of wet or icy pavement. Dominant influence on the adhesive friction is used for example in car racing, where slick tires are used.

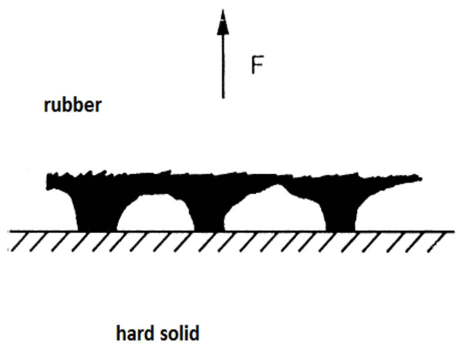

Fig. 2. Schematic representation of a micro-contact area between rubber solid and a heterogeneous surface [5]

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III. Hysteresis

Treatment of variable load the rubber pad causes for the displacement force F has a higher value during the loading, unloading than unloading (fig. 3). Similarly, in a situation in which a not rotating tire is sliding on an uneven surface at the zero-friction material of the tire is subjected to further cycles of loading and unloading. In this idealized case where there is no friction during movement of the rubber on the road, the normal forces are generated in the direction of the surface. The sum of the loading forces is less incriminating than the sum of the forces associated with unloading of rubber, which creates a force directed opposite to the direction of motion.

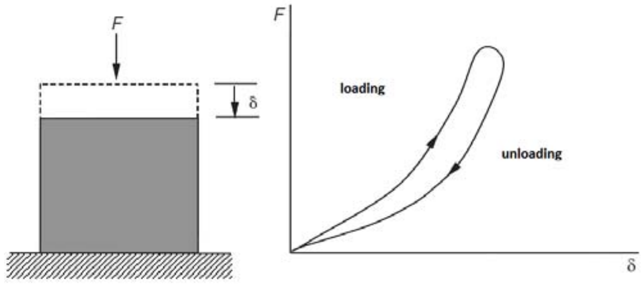

Fig. 3. Hysteresis in a rubber block [5]

IV. Friction coefficient

One of the earliest attempts to describe the coefficient of friction for rubber cooperation with the rough surface is the work of Grosch [7], which presents the results of tests for various types of vulcanized rubber. In [5] the author showed that the friction between the rubber and the surface is caused by the process of energy dissipation. This work has shown that the relationship between phase delay and the speed of sliding, corresponding to the relationship between friction and sliding speed (fig. 4).

Based on the results of experiments Grosh, Savkoor [8], [9] has developed a model through which described the shape of the isothermal curve using an empirical relation

$$\mu_k(V_s) = \mu_s + (\mu_m - \mu_s)\exp\left[-\left(\frac{h^2}{2}\right)\log^2\left(\frac{|V_s|}{V_{\max}}\right)\right]$$

where: μ_s – corresponds to a coefficient of static friction, μ_m – the maximum value of the coefficient of friction $|V_s| = V_{\max}$, h – is a dimensionless coefficient corresponding to the width of the speed range in which the following significant changes in sliding speed. Persson [5] while connected with each other hysteresis, energy dissipation, internal friction and the coefficient of friction. Created model provides a description of friction phenomena with the surface geometry described using the theory of fractals.

V. Traction coefficient under winter conditions

Deterioration of traction conditions in the winter is caused by to the introduction of additional tire-surface environmental factors, snow or ice. In this situation, diminished, or completly reduced becomes the adhesion between the tread of the tire and asphalt, as dominant becomes the friction resulting from hysteresis.

Lowering temperature below 0 °C can cause a number of phenomena affecting the steerability of the vehicle. These phenomena include: black ice, condensation, frost, snow and freezing rain, snow or hail [10].

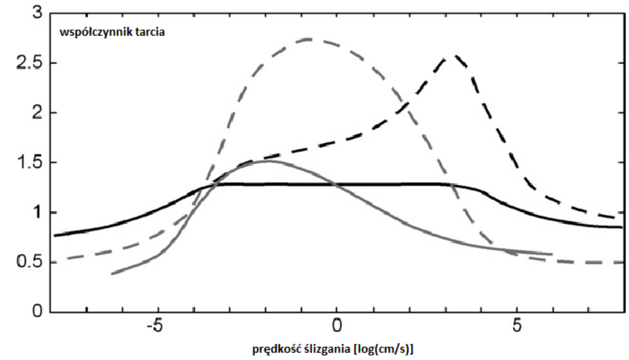

Fig. 4. Relation of friction coefficient from sliding veleocity for butadiene acrylinintrorubber in 20C temperature and different surface conditions [10]

One of the most hazardous weather phenomena to the driver is black ice. The main cause of black ice is the presence of crystals of ice and water mixture. There may be two reasons for that phenomena - the first is to equate the temperature of the dew point in the given conditions of pressure, temperature and humidity, which leads to freezing of condensate on the road surface. The second is the freezing of molten residue after snowfall. The formation of black ice is a process dependent on many factors such as temperature and humidity, wind strength and direction, number and concentration of chemicals used to lower the freezing point [11], [12].

In the case of the occurrence of black ice the process of friction between tire and pavement becomes replaced by the friction between ice and rubber. In such conditions, the traction coefficient is strongly dependent on temperature and increases with its decrease (Fig. 5).

The appearance of rime frost, black ice or snow layer deposited on the road leads to a significant extension of braking distances, and increased risk of loss of vehicle control by reducing the value of the traction coefficient in the tire-surface system [14]. In conditions close to melting point of ice, liquid water is introduced to the tribological system by thermodynamic and tribological processes. (Fig. 5). This leads to the weakening of the adhesive interaction between rubber and the pavement, and also impairs the ability to "capture" the surface inequality structures, extending the duration of deformation and thus reducing the hysteresis [15].

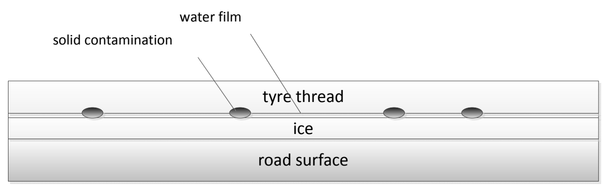

Fig. 5. Tribosystem tire-road under winter conditions[15]

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In the case of wheel movement on a layer of snow, as a result of lakes sticking to the tread surface, tire-surface association may have occurred in tandem ice - ice or snow - snow, which greatly reduces the grip.

While the concept of snow may not be limited to the one type. It occurs in many different variations depending on temperature, thickness, retention time, traffic, humidity and other factors [16]. The value of traction coefficient for the different varieties of snow is not the same and can vary widely. The dependence of the friction coeficient on the temperature and surface state is shown in Fig 5 and has been determined experimentally by the authors of [13] The values of the traction coefficient seen in winter conditions are shown in Table 1

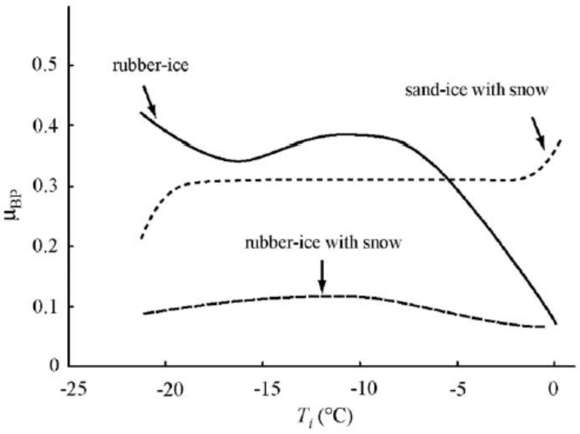

Fig. 4. Temperature – friction coefficient relation[13]

In real driving conditions the friction can take place in the presence of sand located on the road, or specially added in order to improve coefficient. The presence of grains of sand can affect traction by increasing the hysteresis value by increasing the value of the strain. In the case of braking, presence of sand between tire and road can have a positive impact on the value of the traction coefficient. At the time of locking the wheels, sand grains scrubs the surface of ice, increasing the surface roughness and thus improving traction properties. The research reported in [13] suggest that the addition of sand on icy roads does not always have a positive effect on the value of traction coefficient. Author of paper cited the relation of one of Norway's airports service staff, according to which sanding the runway may in certain specified cases, lead to a reduction traction due to the so-called "rolling bearing effect" when free particles of sand are taking place between the tire and the surface of ice.

TABLE I TRACTION COEFFICIENT RANGE FOR DIFFERENT ROAD CONDITIONS [18]

	coupling: tire – road conditions	conditions / Traction coefficient range	
1.	ice	0°C 0,054	-25°C 0,019
2.	ice and tires with chains	0°C 0,12	-18°C 0,18
3.	black ice	-5°C 0,12	-40°C 0,26
4.	snow and ice	0,12	0,39
5.	snow and ice on traffic lights	-40°C 0,09	-8°C 0,22
6.	snow and ice with sand and gravel	depending on the amount of gravel less 0,15	 more 0,45
7.	snow and ice covered with fresh snow	-10°C 0,15	-40°C 0,42
8.	compacted snow	not strongly dependent on temperature 0,24	 0,37
9.	uncompacted snow	0°C 0,15	-10°C 0,42
10.	white frost	0,45	0,58
11.	deep snow	0,92	0,95
12.	dry asphalt	-40°C 0,59	-10°C 0,72

In real conditions that can be encountered on public

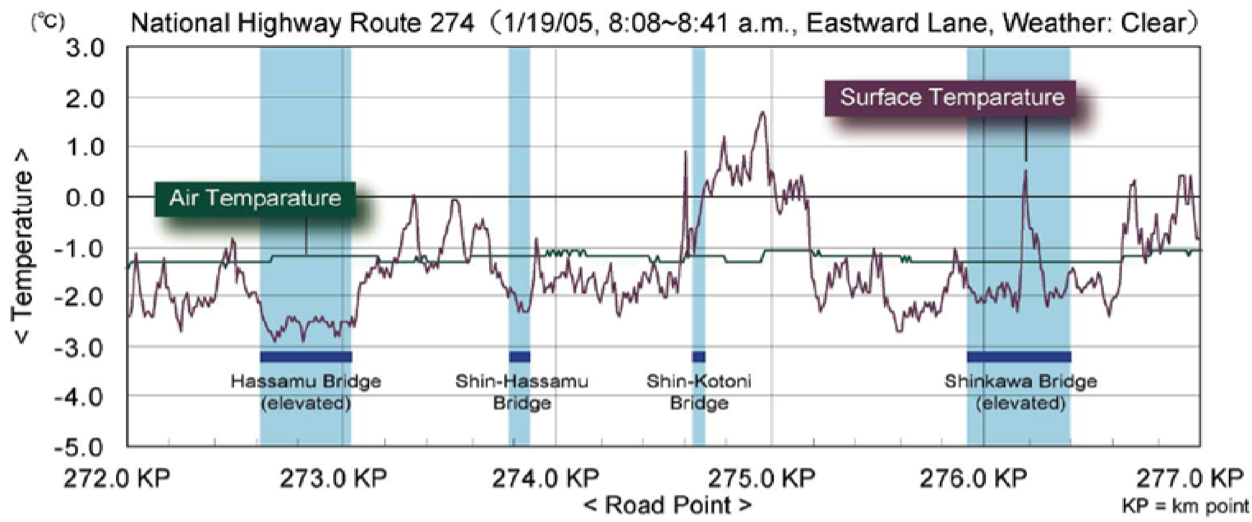

Fig. 5. Example of thermal road map, showing temperature variations at different network points [19]

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roads, state roads and thus the coefficient will vary depending on geographic location, surrounding zoning, and infrastructure locally occurring, [11], [12], [19]. These factors have an impact on surface temperature, humidity, air flow rate and influencing the parameters of the road. Thermal characteristics of the sample path shown in Figure 7

This shows how the different conditions even in a relatively short stretch of road may be movement of the vehicle.

In case of delay on the road a thick layer of snow, the use of anti-skid chains in areas where they are permitted, allowing the vehicle to improve traction when accelerating. The authors of [17] did not notice at the same time improving characteristics of tires during braking.

VI. Summary

Taken theme is of great importance for road safety. It is necessary to determine the effect of the tires, and used assistive devices such as chains or spikes on the characteristics of vehicle traction in winter conditions. It is also experimental confirmation of the presence, and to define the role of film in the processes of water on the tire - road surface, the influence of environmental conditions, and to create a description of the physical processes occurring in the contact area.

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