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Investigation and Comparison of Tires Perfomance on Ice

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Abstract. The risk of accident increases significantly when tire rolls on ice comparing to the dry surface. The vehicle tire becomes the main component of force transmission to the road and necessity of investigating the tire behavior becomes of high importance. This paper presents results of tire force transmission measurement with two different winter tires at the same operating conditions. Longitudinal and lateral force coefficient characteristics as the functions of slip ratio and slip angle are presented and discussed. The results showed a different lateral and longitudinal performance because of different tread pattern and rubber compound.

Keywords: ice, tire, force transmission, slip.

Conference topic: Roads and Railways.

Introduction

The friction mechanism at the tire–ice interface is governed by various factors. These factors are in turn dependent on the ambient temperature; the varying ambient conditions alter the properties of these factors. Hence, different tire–ice behavior trends are observed with changing temperature. It is very important for experimental studies to take note of all the testing conditions, as the performance results are valid only for those particular conditions. Test setups must create reproducible testing conditions, namely: ice surface with the same texture, surface roughness, strength, and surface temperature are required. Development of standard test procedures considering different factors influencing the friction coefficient is the need of the hour (Bhoopalam, Sandu 2014).

Knowing the friction mechanisms of winter tires is essential for the development of high performance tires. Ripka *et al.* (2012) presented a new model for the tire tread block-ice friction mechanisms. A dry run-in area was added to the sliding tire tread block. The advantage of sipes was proved comparing the friction properties of tread block elements with different element lengths. The influence of the real contact area was investigated in detail and a new test set up was used. It allowed observe the real contact area of tread blocks during the sliding process. From these experiments, an overall pressure depending friction characteristic was generated.

Macnabb *et al.* (1996) perfomed tire-ice experiments with different tires, at different temperatures, with and without ABS on smooth and rough ice surfaces. Tread condition of the tires was divided into two main groups: good used condition, which meant tires had 60% or better tread remaining; new condition, which meant tires had 95% or better tread remaining. Air temperatures ranged from –25 to 0 °C. Extensive testing of vehicles and tires on various ice surfaces showed that the braking coefficient of friction can vary from 0.04 to 0.19. ABS produced values was higher up to 30% than locked and sliding wheels.

The effects of operational parameters, namely load on the tire, inflation pressure, toe angle, tread depth, camber angle, ice temperature, ambient temperature and type of ice surface were studied using the P225/60 R16 97S standard reference test tire (SRTT), during operation on ice using the Terramechanics Rig. A reduction in the drawbar pull with an increase in the normal load was seen for both, the buffed and the treaded SRTT, for the entire slip ratio range. An increase in the normalized peak drawbar pull was seen with a reduction in the tire inflation pressure. When operating at lower inflation pressures, an increased contact area was observed that leads to increased friction levels at low slips. However, at high slips, with an increased contact area there is also an increased heat generation, which enhances frictional melting of the ice surface, thus the friction levels are lower at higher slips. The tread on the tire plays an important role in increasing the available friction during all conditions of load and inflation pressure, but at high slip ratios the effect of tread is also negligible. The aggregate application also plays a major role in increasing traction on icy roads; heavier particles are preferred, as they do not get thrown as the tire rolls on the ice surface. (Bhoopalam *et al.* 2015a)

The same authors (Bhoopalam *et al.* 2015b) presented the outdoor testing program which led to the understanding of the effect of inflation pressure, normal load, and tread depth during the operation of the SRTT on ice. The variations of friction levels with normal load were seen in an opposite trend compared to indoor testing at low slip ratios and at high slip ratios the effect of the normal load was not noticed. No increasing or decreasing trend of friction levels was observed with variation in the inflation pressure when tested as per ASTM 1805. However, the effect of the tread in clearly improving traction on icy surfaces was captured even with the outdoor testing program. Outdoor testing as per ASTM-1805 is mainly used by the industry for relative performance analysis of different tires, rather than a method to study the effect of different operational parameters, which should be kept in mind. The reasons for differences in the recorded friction levels were investigated, with the temperature, change in tire properties and test setup being identified as major factors causing this discrepancy.

Skouvaklis *et al.* (2012) designed a new linear tribometer for ice friction studies and effect of velocity (0.1 m/s and 1 m/s), temperature (–3.5 °C to –13 °C) and load (0.45 kN to 1.5 kN) Three rubber samples with different viscoelastic properties were investigated on ice. It was found that increases in velocity and temperature led to a drop in friction coefficient in virtually all cases. The effects of the viscoelastic properties (mainly their compliance) of the rubber on friction become more apparent at lower temperatures and lower speeds. Increasing load led to a decrease in friction coefficient in virtually all cases. For the lowest load the difference in friction coefficient between the different rubbers was larger.

Dörrie *et al.* (2010) compared summer and winter tires. For all measurements according to TIME 2 procedure a 205/55 R16 91 H as a standard (ContiWinterContact TS 810 S) and as a winter tire (ContiWinterContact TS 810 S) was chosen. Generally, all tests indicated a more linear shape of the cornering stiffness curves for the inflation pressure 3.0 bar, but due to the smaller contact patch compared to 2.5 bar on a slightly lower level. All measurements, where the standard and the winter tire were included, demonstrated a significant higher cornering stiffness level for the winter tire, due to the increased sidewall stiffness caused by the additional compound insert. The analysis of the test results to validate the hypotheses concerning the influence of the ambient temperature on cornering stiffness clearly demonstrated a significant reduction of cornering stiffness for higher ambient test temperatures than 5 °C. Thereby the biggest impact was found for the increase of the ambient temperature from 5 °C to 15 °C. The investigation was performed for a ramp steer maneuver, lateral transient response, and a single lane change with increasing lateral acceleration level. All investigations showed the strong influence of the tire characteristic changes caused by testing temperature on vehicle behavior independent of vehicle and tire used. Performing winter tire testing at higher ambient temperatures leads to performance deficits compared to lower temperatures.

The basics of tire force transmission and experimental investigation of different tires on ice will be presented in next chapters.

1. Basics of tire force transmission

To describe the tire-road interaction and its force system, it is assumed a flat ground and attached a Cartesian coordinate frame at the centeer of the tireprint as showed in Figure 1. To show the tire orientation two angles are used: camber angle γ and sideslip (or slip) angle α.

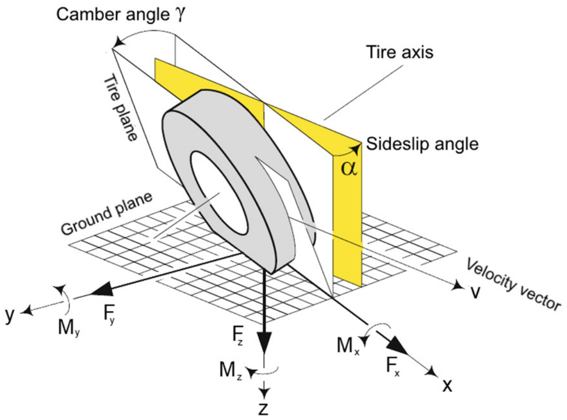

Fig. 1. Tire coordinate system (Jazar 2014)

The resultant force system that a tire receives from the ground is assumed to be located at the center of the tireprint and can be decomposed along x, y, and z axes.Therefore, the interaction of a tire with the road generates a three dimensional force system including three forces and three moments.

Tire is a complex rubber compound. Total friction force developed in sliding over a single asperity may be separated into adhesion and deformation (or hysteresis) term showed in Figure 2.

The main contribution to tire traction force on a dry road is the adhesion friction. Adhesion friction is equivalent to sticking. The rubber resists sliding on the road because adhesion causes it stick to the road surface. Adhesion occurs as a result of molecular binding between the rubber and surfaces. Because the real contact area is much less than the observed contact area, high local pressure makes molecular binding. Bond occurs at the points of contact and welds the surfaces together. The adhesion friction is equal to the required force to break these molecular bonds and separate the surfaces. Higher load increases the contact area, makes more bonds, and increases the friction force.

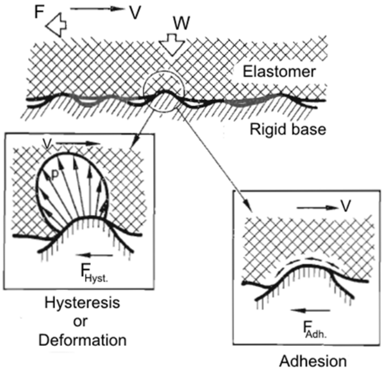

Fig. 2. Components of rubber friction (Moore 1972)

The adhesion friction decreases considerably on a road covered by water, ice, dust, or lubricant. Water on a wet road prevents direct contact between the tire and road and reduces the formation of adhesion friction.

Deformation friction is the result of deforming rubber and flling the microscopic irregularities on the road. The surface of the road has many peaks and valleys called asperities. Movement of a tire on a rough surface results in the deformation of the rubber by peaks and high points on the surface. A load on the tire causes the peaks of irregularities to penetrate the tire and the tire drapes over the peaks. The deformation friction force, needed to move the irregularities in the rubber, comes from the local high pressure across the irregularities. Higher load increases the penetration of the irregularities in the tire and therefore increases the friction force.

According to Ripka *et al.* (2012), the dominating factor which influences the friction on ice is the quasi liquid layer. It disappears or cannot be detected as soon as the ambient temperature becomes very cold. The overall friction force for a sliding rubber on ice can be calculated:

$$F_f = F_{dry} + F_{viscous}, \quad (1)$$

where: F_{dry} – friction force of the dry area; $F_{viscous}$ – viscous shear force of the liquid layer.

Viscous friction occurs in lubricated contacts. The movement of the rubber causes shear forces in the lubricant due to viscous flow. Sometimes the lubricating film separates both components completely so that the total friction force is equal to the viscous friction force. This phenomenon happens during the hydroplaning of a tire. The tire loses the contact to the ground and literally swims on the fluid (Ripka 2012).

2. Measurement equipment and procedure

The measurement of tire-ice interaction were carried out at Insitute of Vehicle System Technology in the city of Karlsruhe in Germany with the Inner Drum Test Bench. The test rig consists of the drum with a diameter of 3.8 m, wherein the tire, mounted on a rigid wheel suspension, rolls on the installed track. The main components of the test rig are presented in Figure 3. Wheel and drum can be driven independently for braking and traction tests. Slip and camber angles, and vertical force are adjusted by hydraulic system. The transmission of the tire forces and moments are measured with a six-component measurement system. The test rig is surrounded by a climate chamber and is equipped with an air conditioning system that enables the whole testing room to be cooled down to an ambient temperature of –20 °C. The main technical speficications of the test rig can be found in (Testing Facilities 2016).

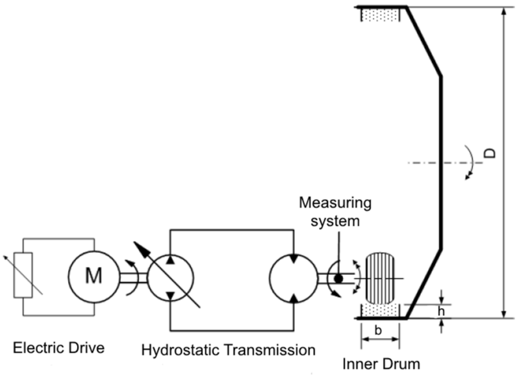

Fig. 3. Schematic view of inner drum test rig

The ice track was produced with pure tap water continuously freezing inside the drum to build up an ice track of 10-mm thickness. This initially uneven ice surface was preconditioned using the sharp blade. After creating a perfectly even and leveled surface, the ice layer is polished by a special tire that is completely covered with a fine siped tread without any tread blocks. After this polishing process, the ice track is ready for measurements.

Two different tires were chosen with different tread pattern showed in Figure 4 and different shore hardness measured with durometer.

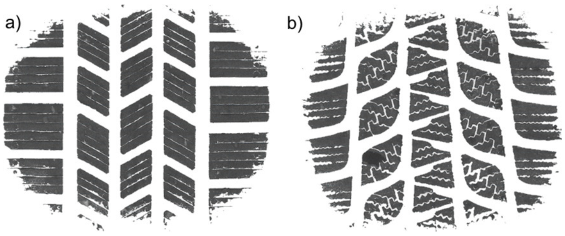

Fig. 4. Footprint of investigated tires a) Tire A; b) Tire B

Tire characteristics and operating conditions during the measurements are presented in table 1. For comparison of different tires it is important to ensure the same operating conditions like wheel load, inflation pressure and etc.

Table 1. Tire characteristics and operating conditions

Tire	Size	Max. load	Pressure	Camber angle	Shore hardness (A)	Tread depth	Ambient temperature
A	205/55 R16	6.3 kN	2.2 bar	0°	57	8.0 mm	–4 °C
B	205/55 R16	6.3 kN	2.2 bar	0°	65	7.8 mm	–4 °C

As can be seen from table 1, tires are the same size and tread depth, but hardness of the tread rubber compound differs. The tire B has harder rubber compound comparing with tire A and this should be seen in the performance.

3. Data evaluation and results

Both tires were rolling at 30 km/h drum speed which is assumed as a driving speed and 5 measurements were performed for each tire. Slip ratio was calculated by:

$$S_x = \frac{\omega r_{dyn} - v_D}{v_D}, \tag{2}$$

where: ω – tire angular velocity; r_{dyn} – tire dynamic radius; v_D – drum speed.

An average chararacteristic curves were evaluated and presented as functions of longitudinal and lateral force coeffiecients versus slip ratio and slip angle respectively. Force coefficients are the ratio of longitudinal F_x or lateral force F_y with the tire reaction force F_z measured with the test rig. Longitudinal force characteristics are presented in Figure 5. It is clearly seen that tire A has much higher traction performance than tire B.

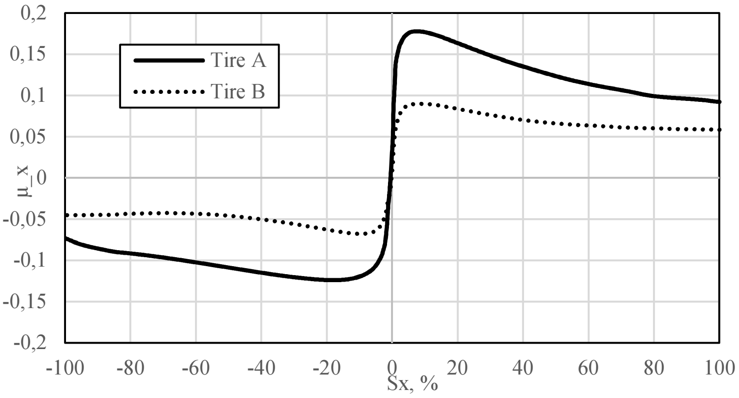

Fig. 5. Comparison of longitudinal tires perfomance

Both tires reach maximum traction at very low 8% slip in driving situation. Maximum force coeffiecient values are 0.18 for tire A and 0.09 for tire B and it shows that tire A performs twice better than tire B.

At braking, the same trend is seen, but maximum force coefficient values are lower. Tire A reaches maximum value of 0.12 at 15% and tire B–0.07 at 8% slip. Tire A reaches maximum at higher slip on braking. A higher drop of force coefficien in the tire sliding region is seen for tire A, but at every slip level it is higher than tire B.

Lateral tire performance is presented in Figure 6 and it is seen that tire A has higher performance as it was in the longitudinal pefromance.

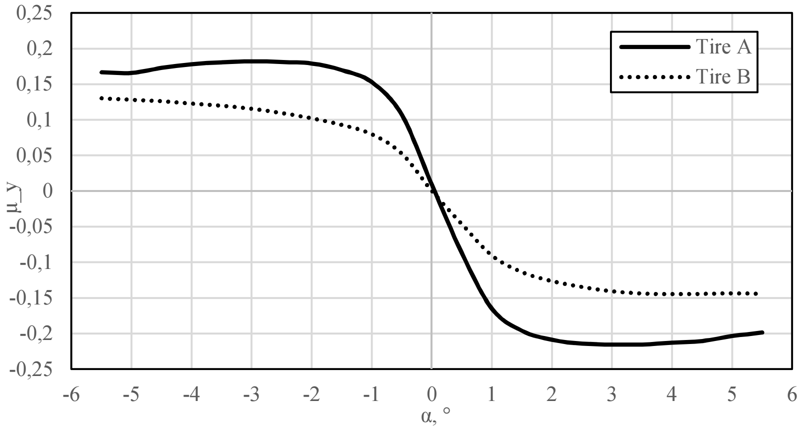

Fig. 6. Comparison of lateral tires peformance

Tire A reaches maximum values at 2.5°. The maximum values differ a bit as in negative angle it is 0.18 and in positive–0.21. This can be effected by the tire tread pattern as it has not even number of sipes in the tread blocks. It is well known that sipes increases traction (Ripka *et al.* 2012). Tire B reahes maximum value only in positive direction and it is 0.14 at 4° slip angle. In negative direction it's not seen a maximum value. This can be effected by tire rubber compound as more measurements showed the same trend.

Conclusions

Testing of different tires performance on ice is rather challenging when the same testing conditions should be ensured. The comparison of two different tires performance on ice was presented in this paper. The tires were the same size and tread depth, but tread pattern and shore hardness were different. The softer rubber tire had more traction in both longitudinal and lateral tire dynamics than harder rubber. The peak performance of acceleration was twice higher and for braking softer rubber tire had 40% more peak traction. For lateral performance it was 30% difference in peak force coefficient values. The low force coefficient values indicate about extreme driving conditions on ice and it is seen as one of the most dangerous winter tracks.

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