Study of rubber/road dry friction in rolling sliding and onset of sliding conditions

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1. Introduction

For safety and energy consumption reasons, tire/road friction has become an important property when designing tires. However the friction forces in the contact are not well understood. Particularly the relation between rolling/sliding friction behavior and the friction behavior at the onset of sliding. We carried out experiments in those two different kinematic conditions to understand the tire/road friction behavior in dry condition. An analytical model has also been developed to calculate friction force in the rolling sliding condition assuming the friction behavior during the onset of sliding. In this paper we will present the different experiments and the model. We first study the influence of the different kinematic parameters on the onset of sliding. Then we study the effect of the tire and road velocities on the rolling/sliding friction behavior. We finally discuss how the model can be used link the different results.

2. Method

2.1. Experiments

In order to analyse the tire/road friction behavior, two experimental devices have been designed. We first consider the onset of sliding behavior. Figure 1 shows a diagram of the device used to realize onset of sliding experiment.

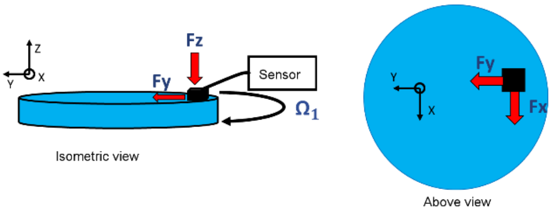

Figure 1 Diagram of the device

We put in contact a 20mm*20mm*2mm bulk of elastomer with a sample of road. The disk of road is put in rotation at different velocities. The velocity of the road at the contact location varies from 0.5 mm/s to 50mm/s. We test also three normal forces 5N, 10N and 15N. The forces are measured with a PCB 260A11 three axes piezoelectric sensor. We measure the displacement of the road sample with a Renishaw RGA optical encoder. The temperature of the sample is also measured with a micro-epsilon KF04784 infrared sensor. According to the rate and state friction law presented in Rice and Ruina [1], not only the charging velocity has an influence on the friction behavior but also the age of contact. The device enables control of the time in static contact before the shearing of the contact interface. The age of contact was varied from 100ms to 100 s.

To perform rolling/sliding experiments, a cylinder of elastomer is set in contact with a sample of road (Fig. 2). The cylinder of 20mm diameter and 22 mm length is put in rotation at a peripheral velocity V_r, and the sample of road at a velocity V_p at the contact's location. During the experiment the sliding ratio defined as,$s = (V_p - V_r)/V_p$ is varied to characterize the behavior of the contact in the rolling/sliding condition. During the experiment the driving speed, corresponding to the average speed between the road velocity and the tire velocity, $V_e = (V_p + V_r)/2$ is kept constant. We study the rolling/sliding for several driving speeds from 1mm/s to 500 mm/s. We measure the different forces on the elastomer with TEI FSB101 sensor. The temperature is also measured at the rear of the contact with the same infrared sensor as for the previous device.

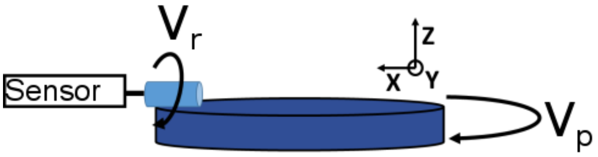

Figure 2 Diagram of the rolling/sliding device

The normal load is imposed at the beginning of the experiment. The experiment are done for the same three normal loads as for the onset of sliding experiments.

2.2. Model

To establish a link between the rolling/sliding friction behavior and the onset of sliding behavior, a model is developed to calculate the distribution of shear stress along the contact in rolling/sliding conditions. The model is an extension of the classical model of Carter [2]. We assume a quasi-static contact. The contact pressure is assumed to be Hertzian. We assume that there are three regions within the contact: one where the road and the tire are sticking; another where the tire fully slides on the road; between the two, there is a transition region in which the local friction coefficient drops from its static value down to its dynamic value. The pressure and shear stress are calculated along the contact. The integral of the shear stress along the contact gives the friction force induced on the tire.

3. Results and discussion

The onset of sliding experiments highlighted three variables in the friction behavior: the static friction coefficient μ_s, the dynamic friction coefficient μ_d and the sliding distance d_c which corresponds to the slip distance necessary to pass from μ_s to μ_d. The different variables are presented in Fig.3 which represents the evolution of the friction coefficient as a function of the road displacement.

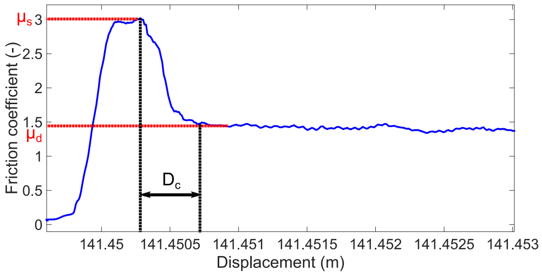

Figure 3 Evolution of the friction coefficient with respect to the road displacement

We study the evolution of these three different variables according to the sliding velocity and the age of contact. Indeed as it has been proved by Rice and Ruina[1], the sliding velocity and the age of contact are two parameters which drive the friction behavior. We observe an increase of the static friction coefficient when the age of contact increase. Similarly when we increase the sliding velocity the dynamic friction coefficient also increases.

Now, in the rolling/sliding configuration, the evolution of the friction coefficient according to the slip ratio,$s = (V_p - V_r)/V_p$, is presented Fig. 4.

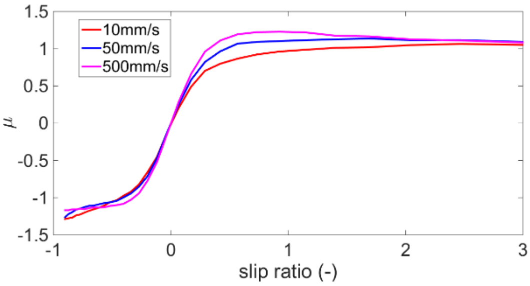

Figure 4 Evolution of the friction coefficient according to the slip ratio for several driving velocity

For each value of the slip ratio, the value of the friction coefficient corresponds to a mean value of the ratio F_x/F_z at this slip ratio when the slip ratio is constant, typically the slip ratio is constant during one turn of road. We observe an increase of the friction coefficient from zero, when the slip ratio is zero, which correspond to a pure rolling condition, until a limit value close to 1 when the slip ratio tends toward infinity, which corresponds to a pure sliding condition. This limit should be equal to the dynamic friction coefficient that was measured in the onset of sliding experiment. For high driving velocity, the rolling/sliding friction curves present a peak, the value of which increases with the driving velocity.

With the analytical model we calculate the evolution of the tangential force according to the slip ratio. The results show the same evolution as in the experiment. We studied different friction law. The evolution of the friction coefficient for two friction laws is presented in Fig. 5.

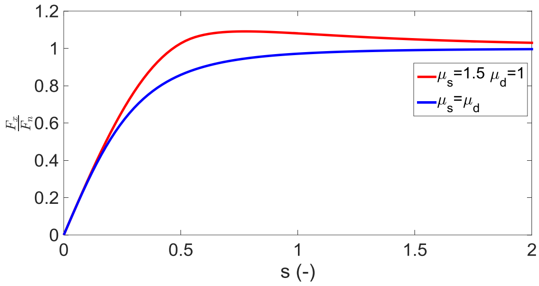

Figure 5 Evolution of the friction coefficient for two friction law, according to the slip ratio

We observe that for a friction law with a high ratio μ_s/μ_d the curve presents a peak, in agreement with the experimental results.

4. Conclusion

We studied the friction behavior of a tire/road contact in two kinematic conditions. Our results show that we can use three parameters to describe the friction behavior in pure sliding conditions, which are the dynamic friction coefficient, the static friction coefficient and the critical slip distance. As shown in Rice and Ruina [1], the age of contact increases the static friction coefficient and the sliding velocity increases the dynamic friction coefficient. We showed in the rolling/sliding experiment that the evolution of the friction coefficient presents a peak for high driving velocities. Moreover the intensity of this peak increases with the driving velocity. The model has shown that the peak is influenced by the μ_s/μ_d ratio and that an increase of this ratio increases the amplitude of the peak.

5. References

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