EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF RUBBER FRICTION

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INTRODUCTION

The physical phenomenon of friction appears in many technical applications. One of the most interesting fields is friction of rubber that depends on different parameters e.g. velocity, roughness, normal pressure and temperature. It can cause acoustic problems like noise and squeal and also unwanted mechanical effects like wear. Therefore, friction affects the function of many products in technical applications, e.g. seals, belts and tires. Friction in the contact between a tire and the road is based on two physical effects. The roughness of the asphalt surface causes deformations in the viscoelastic tire material. The consequences are energy dissipation and friction. This effect is called hysteresis induced friction or hysteresis losses. Intermolecular bindings between the tire material and the road surface result in adhesion forces, that cause also energy dissipation and friction. This presentation is focused on the hysteresis and adhesion of rubber. Experiments performed under outdoor and indoor conditions are presented on real road surfaces and on more homogeneous surfaces like glass and safety walk as references.

MODELING

The hysteretic friction of rubber is caused by energy dissipation due to internal material damping during the process of deformation. The deformation itself occurs during the sliding of a rubber element across the asperities of a rough surface. The rubber element can be described by the Zener model also called standard linear viscoelastic solid, which is a linear spring-dashpot combination. A mechanical model of hysteretic friction has been developed using the following steps. In a first step a suitable model including relaxation and creeping properties of rubber material is developed. The behavior of a rubber element is simulated using frequency analysis and a special fit algorithm to obtain the system parameters. In a next step the model is validated by a harmonic excitation due to a sinusoidal surface. Finally, a simulation is performed that includes the material model and surface roughness based on real measurements. The advantage of the method described above is the approximation of the real physical hysteretic friction process and its description in time domain. The dependence of the friction coefficient on the velocity and the normal pressure is validated. The results have been compared with different theories that are mainly formulated in frequency domain, cp. [4]. The results show the same velocity dependence of the hysteretic friction coefficient.

Intermolecular bindings between the tire material and the road surface result in adhesion forces, that also cause energy dissipation and friction. Intermolecular bindings are based on Van-der-Waals or dipole forces. On a rolling wheel without sliding the intermolecular bindings are connected at the run-in and they are separated at the run-out. The forces at the run-in are negligible small in relation to the forces at the run-out. Roberts [9] shows that the forces and the energy dissipation at the run-out depend on the material properties and the separation velocity. Tests using a special adhesion pendulum confirm the velocity dependence of the dissipated energy by adhesion, cp. [5]. In a sliding contact the connection and disconnection of intermolecular bindings can occur frequently in dependence of the micro roughness of the contact partner, the viscoelastic properties of the rubber and the sliding velocity, see Achenbach [1]. The adhesion increases with the true contact area that depends on the macro roughness, on the viscoelasticity and on the sliding velocity and is described by the hysteresis effect. Tests show a strong sensitivity of the adhesion effect with respect to the surface conditions (wet or dry, lubricated or not) thus, in experiments the cleaning procedure of the surfaces is very important.

EXPERIMENTAL INVESTIGATION

The measurement of the kinetic friction coefficients μ between rubber compound and the road surface is limited because of the necessity for complex measuring systems, which are not available in the field. The integration of a measuring device into a mobile robot permits laboratory precision measurements on outdoor road surfaces, see [2] and [3]. To measure the kinetic friction coefficient, a rubber testing wheel that is adopted from the Grosch rubber wear test rig, is pressed onto the road surface by a predefined normal contact force in a closed loop force control. The rubber measuring wheel is driven providing constant macroscopic sliding velocity in the contact zone. By pressing the rotating rubber specimen onto the road surface, a friction force is generated. The kinetic friction coefficient is calculated as the ratio of the measured friction force and the actual normal contact force.

Figure 1: Outdoor measurement robot

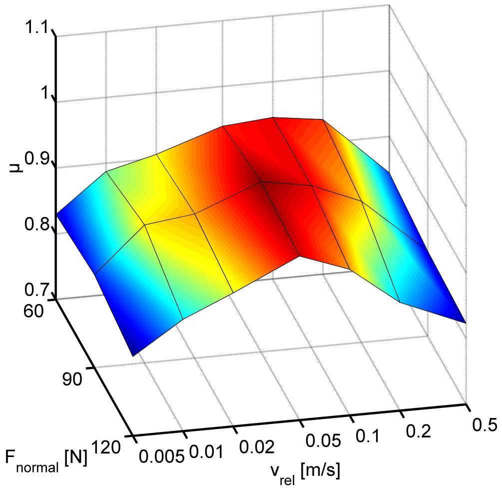

Figure 2: Friction coefficient field (wet road)

Laboratory measurements have been performed on a tribometer test rig. The rig consists of a pin on disc application, where the disc together with an exchangeable friction surface is driven with a predefined velocity and the pin consisting of a rubber specimen is pressed onto the disc in axial direction. Here, homogeneous surfaces like glass and safety walk (corundum like surface) are applied. The kinetic friction coefficient is also calculated as ratio of the measured forces. The measurements discussed below are based on stationary test conditions in which the test parameters remain on a constant level and are varied after every measurement. The kinetic friction coefficient of rubber on different surfaces depends on the relative velocity, the normal pressure in the contact zone as well as on contact temperature and wetness. The temperature in case of the outdoor measurements has been measured and the experiments have been performed in a limited temperature range. In **Figure 2** measurements of the stationary kinetic friction coefficient by the outdoor robot on a wet road surface are shown. Obviously, there is only a slight impact of the normal force but investigations on dry glass surfaces show a larger influence of the normal force, where the friction coefficient decreases with increasing normal force. The dependence on the relative velocity in this case is predicted in Persson [8]. As expected from theory, a maximum of the kinetic friction coefficient with velocity is observed. This effect is due to the hysteresis friction with varying excitation frequencies. On a wet road surface the maximum friction coefficient occurs at $v_{rel} \approx 0.1$ m/s. The theory also predicts a hysteresis based maximum at this velocity where the temperature influence is regarded by calculating an increasing contact temperature with increasing relative velocity. In **Figure 3** the variation of the normal force is shown for two different friction surfaces. The characteristic of the friction coefficient versus normal force is decreasing and steeper for glass than for safety walk. The graph of the friction force versus normal force, however, shows a linear increasing behavior starting at a constant value. Thus, we assume that the friction force can be divided into an almost linear and a constant part. By the observation of limit values the more or less decreasing behavior of the kinetic coefficient of friction versus normal force becomes clear. In the literature, for example [8], it is shown that the occurrence of hysteresis and adhesion causes friction forces proportional to the true contact area. On the glass surface the true contact area is larger than on safety walk where the area grows faster with increasing normal force. A large true contact area during small normal forces causes a large constant part of the friction force and, therefore, a strong decreasing behavior of the kinetic friction coefficient. Another topic of friction investigation is the unsteady behaviour of the friction contact, see [6] and [7], but this should not be discussed here.

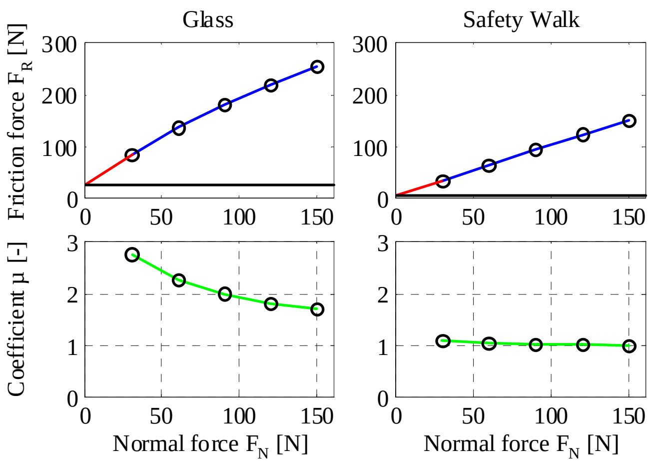

Figure 3: Friction force and friction coefficient versus normal force

CONCLUSIONS

Two effects of rubber friction have been investigated. The dependence of the kinetic friction coefficient on the relative velocity has been shown by measurements and has been predicted by a theoretical model. The dependence on the normal force has been explained and validated by measurements on different friction surfaces. The occurrence of these effects is well known, however, investigations of this type are necessary for the understanding of rubber friction.

References

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