Experimental Investigation of Adhesive Friction Properties of Rubber on Wet Surfaces

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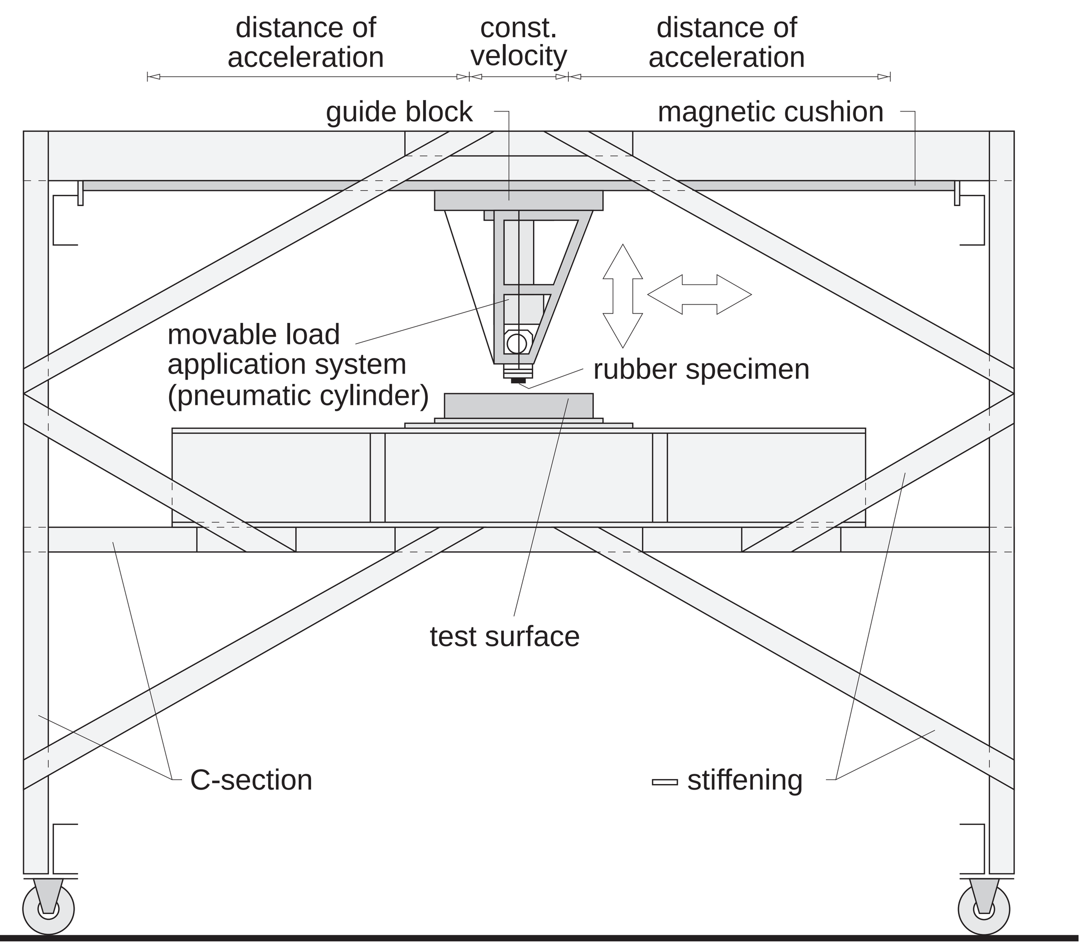
Introduction

The lack of sufficient and reliable experimental data concerning the mechanical interaction between automobile tires and different road surfaces was the motivation for carrying out a comprehensive experimental investigation. The objective of this study is to obtain insight in the local traction mechanism of single treads moving on plain surfaces such as wet and dry concrete and asphalt or snow and ice in order to provide information about the influence of the rubber stiffness and of the geometry of the treads on their traction performance. The experimentally obtained temperature, sliding velocity and pressure dependent friction law is a necessary prerequisite for realistic numerical simulations by means of the finite element method.

One specific part of the experimental study was concerned with the determination of the influence of different rubber compounds (M1…M4) and tread geometries (G0, G1, G3, G4) at wet concrete surfaces on the resulting sliding load transmission (friction coefficient μ). The considered parameter were: vertical pressure of 0.5 to 5.0 bar, sliding velocity of 0.1 to 1000 mm/s and environmental temperature between 9 and 27 °C. About 5000 experiments were carried out by means of a recently developed testing device [1] - [3].

In general, the movement of a tread results in a non-uniform pressure distribution in the contact zone between rubber specimen and test surface. Moreover, a strong stress concentration was found at the front edge of the specimen. Therefore, in order to separate this so-called edge effect from the real material behavior further investigations have to be done.

Developed Testing Device



Characteristic Features of Testing Device

- Independent determination of horizontal and vertical forces.
- Application of continous controlled constant vertical pressure to the tread resulting in vertical forces of F = 100-1200 N.
- Progressively adjustable sliding velocity in a wide range of v = 0.1-1000 mm/s.
- Utilizability at low temperatures (e.g. -20 °C) for investigation of snow and ice-covered surfaces.

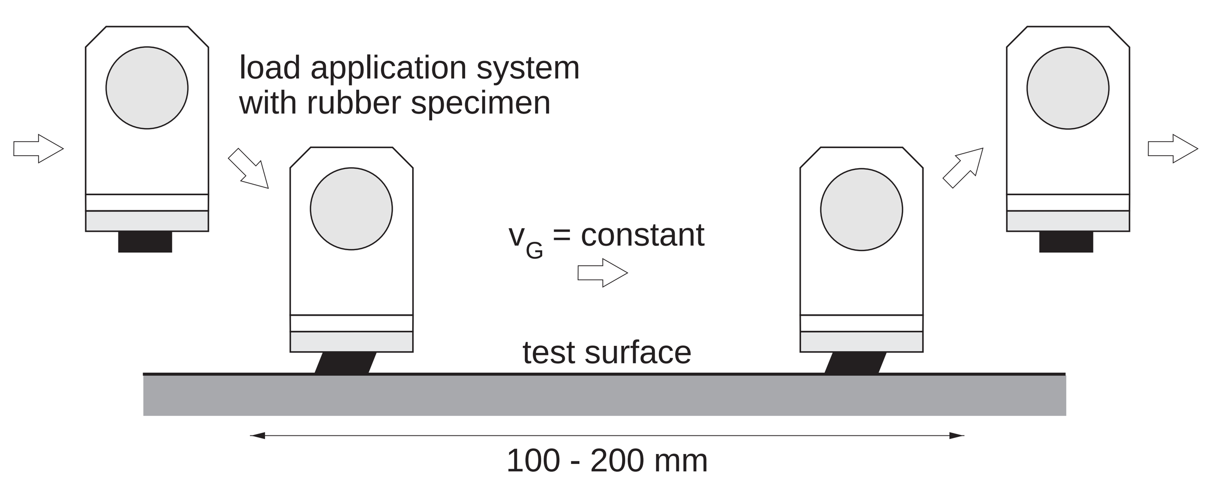
References

[1] Eberhardsteiner, J.; Fidi, W.: Experimental Investigation of the Adhesive Friction Behavior of Rubber Using a New Testing Device. *Extended Summaries of the 14th Danubia-Adria Symposium*, Porec, Croatia, 1997.

[2] Eberhardsteiner, J.; Fidi, W.; Liederer, W.: Experimentelle Bestimmung der adhäsiven Reibeigenschaften von Gummiproben auf ebenen Oberflächen. *Kautschuk Gummi Kunststoff*, 1998, in print.

[3] Lahayne, O.: Bestimmung des Reibungskoeffizienten von verschiedenen Gummiprofilen auf nassem Asphalt und Beton durch Messungen mittels eines Linearprüfstandes. *Report at Continental AG*, Hannover, March 3,1998.

Experimental Scheme



Friction Model for Rubber Treads

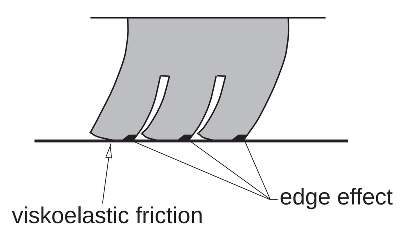
The sliding friction coefficient μ of a rubber block is treated as the sum of viscoelastic friction in the contact surface and the effect of pressing the edge of the rubber block on the surface (edge effect).

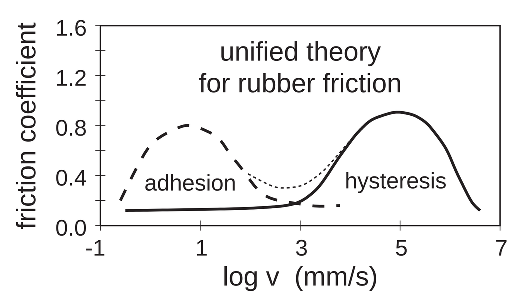
Therefore, friction is described as the sum of dynamic friction of the compound and of friction due to the so-called edge effect.

μ(tread) = μ(adhesive & hysteretic friction) + μ(edge effect)

Viscoelastic Friction

Viscoelastic friction consists of two components, commonly described as adhesive and hysteretic friction.





Exciting frequency f_e

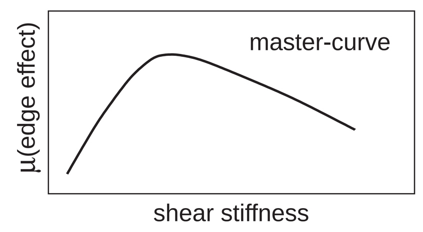
hysteretic friction component: $f_e = 10^3\ \mathrm{Hz} - 10^5\ \mathrm{Hz}$

adhesive friction component: $f_e = 10^5\ \mathrm{Hz} - 10^{10}\ \mathrm{Hz}$

Edge Effect:

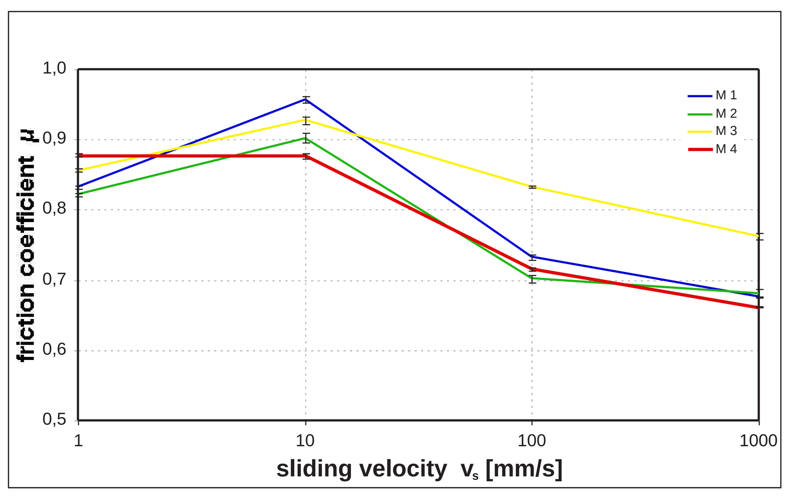
The edge effect depends on

- geometry of the rubber block
- shear stiffness of interaction between tread design and tread compound



Experimental Investigation on Friction Coefficient μ

Influence of Sliding Velocity



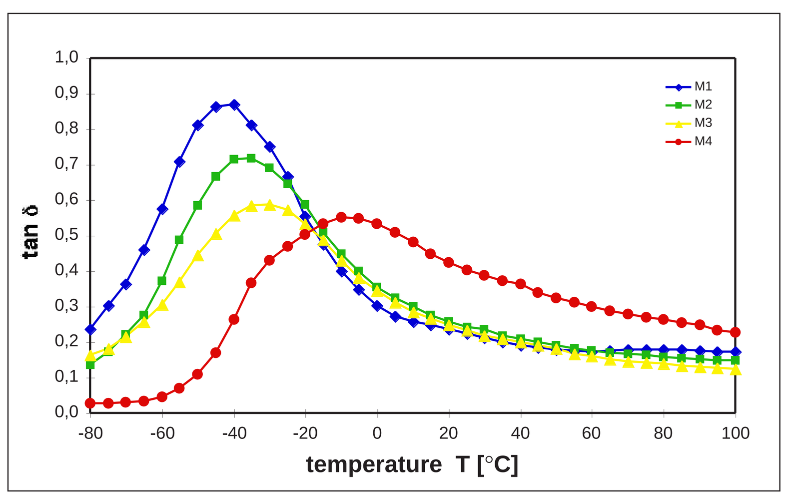
Experimental parameter: concrete surface, tread geometry G0, pressure p = 2 bar, temperature T = 18 °C

Identification of adhesive friction enforces the application of WLF theory (by Williams, Landel and Ferry):

Frequency can be expressed by temperature

$$\mu = F(v_s) = F(f_e) \qquad \tan\delta = F(T)$$

Viscoelastic friction behavior can be estimated by standard material test.



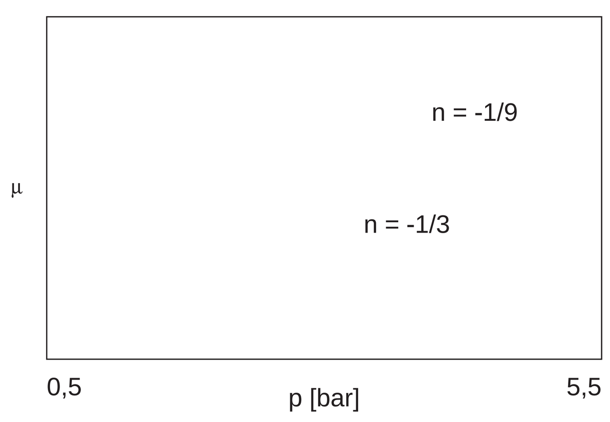
Validity of WLF theory is confirmed by comparison of experimental results (max. μ), e.g. for compounds M1 and M4

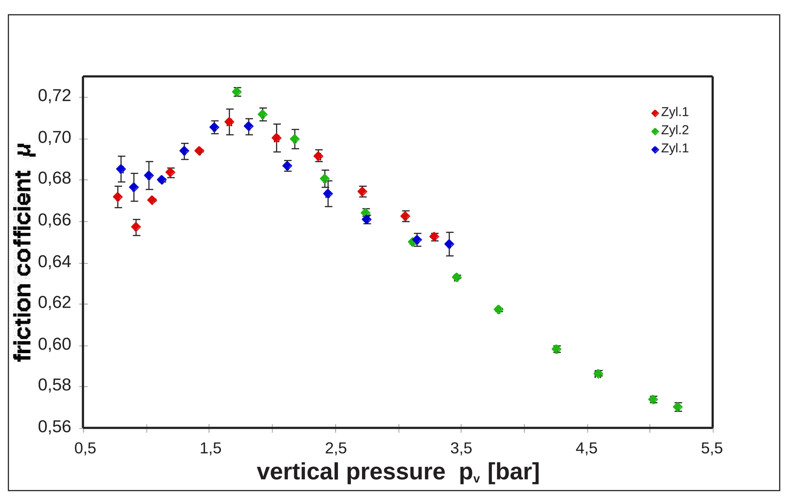
Influence of Vertical Pressure

In the literature the pressure dependent friction behavior – decrease of μ with increasing p – is often described by an exponential law.

$$\mu(p) = a e^{np}$$

$$-\frac{1}{3} \le n \le -\frac{1}{9}$$





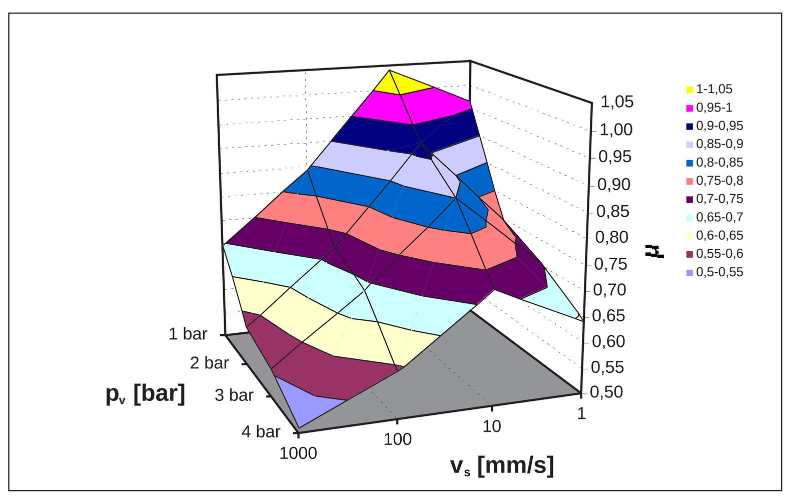
Experimental parameter: compound M1, concrete surface, tread geometry G0, sliding velocity v = 100 mm/s, temperature T = 18 °C

Experimental data show maximum of μ at p = 1,7 bar

–> exponential law valid for p > 2 bar only!

–> assumption: pressure dependent friction behavior is also related to exciting frequency!

Summarized Influence of Sliding Velocity and of Vertical Pressure



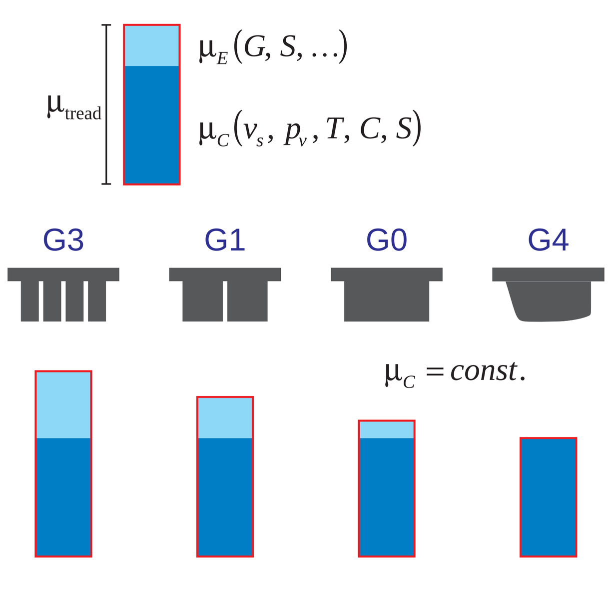
Experimental parameter: compound M1, concrete surface, tread geometry G0, temperature T = 18 °C

Determination of Edge Effect

The long-term objective of the experimental investigation is the description of the edge effect of different tread designs by single master curves for each test surface.

μ(edge effect) = F(shear stiffness of tread system)

μ(edge effect) = μ(tread) - μ(compound)



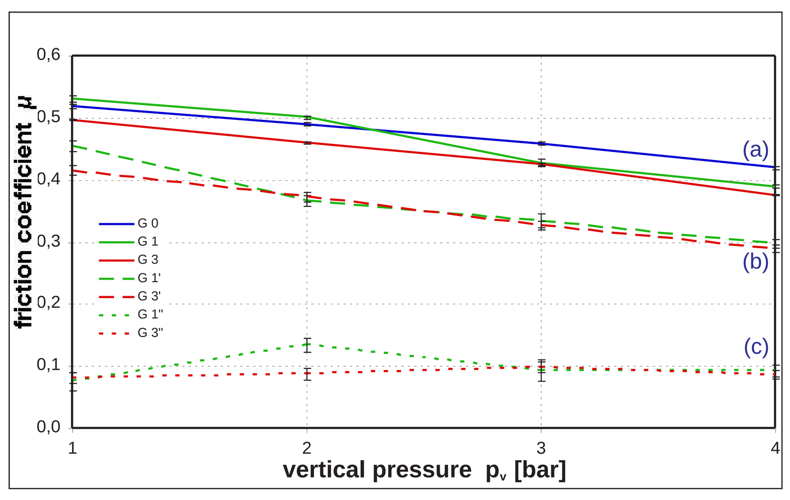
Assumption:

Pressure dependence is assigned to viscoelastic friction (compound) only

Edge effect is an additive quantity (interaction between edge and friction surface)

Problem:

Inhomogeneous pressure distribution in contact surface



Experimental parameter: compound M1, asphalt surface, sliding velocity v = 1000 mm/s, temperature T = 9 °C

(a) measured friction coefficient μ for tread geometries G0, G1 and G3

(b) transformed friction coefficient $\mu(p_2) = \mu(p_1)\left(\frac{p_2}{p_1}\right)^n$

(c) μ_E obtained by subtraction

Further Investigations

- Experimental determination of real pressure distribution of the contact surface under sliding conditions
- Development of a tread ensuring a constant pressure distribution in the contact surface (see e.g. geometry G4)
- More realistic estimation of edge effect as a function of tread stiffness
- Development and calibration of a suitable friction law and numerical verification of experimental results
- Realization of similar experiments on ice and snow covered surfaces