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EXPERIMENTAL AND ANALYTICAL INVESTIGATION ON RUBBER CONTACTS WITH ADHESION

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ABSTRACT

In a dry contact interactions between the atoms or molecules of both contact partners can be observed. Intermolecular bindings between the contact partners are the physical basis for the adhesion effect. They originate from bipolar interactions or Van-der-Waals forces. Results of the adhesion are larger breakaway forces and larger kinematic friction forces on bodies which are in sliding contact. This can influence the function of the entire system or can induce vibrations and noise. But the increase of friction can also be useful, like in tire-road contacts. The number of intermolecular bindings and, therefore, the adhesive effect increase with the real contact area. Materials like rubber with a small Young's modulus, which build comparatively large contact areas, can show large adhesion effects. If the material has viscoelastic properties, the adhesion during dynamic separation is strongly increased.

Static models of the contact with adhesion between two spheres or a sphere and a flat counterpart are developed by Johnson, Kendall and Roberts [1] or Derjaguin, Muller and Toporov [2]. They provide the steady contact area and the minimum normal force during quasi-static separation. In contacts, where the contact area changes dynamically, the boundary of the contact can be interpreted as a crack tip. This becomes important, if the material behaves viscoelastic, which is fulfilled in case of rubber. Then, the static models are not able to describe the behavior in the contact. The magnitude of the contact area shows transient effects after a change of the normal load or the normal displacement. Parts of this effect can be observed in a timescale of milliseconds or seconds while others occur in the timescale of hours or days. Barquins [3] models the transient behavior of the contact area considering the strain energy release rate G, the work of adhesion w and a function $f(\vartheta, v_{crack})$ describing the viscoelastic properties of the material in the vicinity of the crack tip by

$$G - w = wf(\vartheta, v_{crack}) \tag{1}$$

in dependence of the temperature ϑ and the velocity of the crack tip v_{crack}.

To get information about the adhesion effect and the influence of the viscoelastic properties on the adhesion, different experimental tests can be conducted. One optical possibility is the measurement of the contact radius between a glass lens and a flat rubber sample with a microscope. Roberts and Thomas [4]

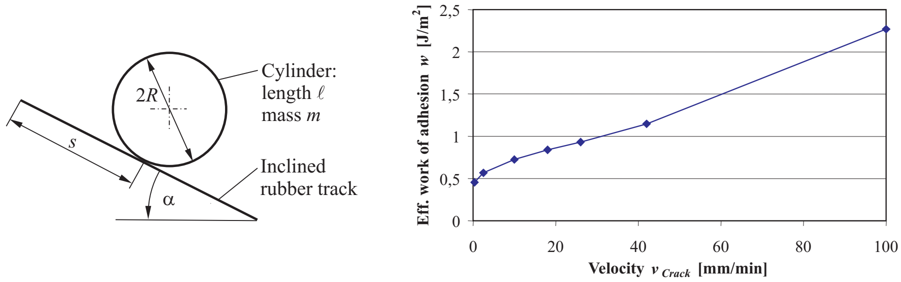

Figure 1: Sketch of the rolling cylinder test configuration and effective work of adhesion w_{eff} in dependence of the crack velocity v_{crack} measured on a natural rubber track with varied inclination angle

describe further experiments e.g. a ball sticking on a flat rubber sample forced by the gravitation or a ball impact on a flat sample. Very useful and simple is the velocity measurement of a cylinder (length ℓ, mass m) rolling down an inclined rubber track with an angle α to the horizontal, see Fig. 1. If the amplification of the work of adhesion due to the viscoelastic properties is large enough the cylinder rolls with a constant speed. This can only occur if the potential energy is dissipated by the adhesion losses. Neglecting aerodynamic losses and adhesion at the run-in, which can be assumed in a large velocity range, the adhesion losses at the run-out can be calculated by $W_{adh} = w_{eff}\,\ell s$ with the rolling distance s. The change of potential energy yields $W_{pot} = mgs\sin\alpha$ with the gravitational acceleration g. For a constant rolling velocity the potential energy W_{pot} is equal to the adhesive losses W_{adh} and the effective work of adhesion w_{eff} can be calculated by

$$w_{eff} = \frac{mg\sin\alpha}{\ell} = w[1 + f(\vartheta, v_{crack})]. \quad (2)$$

A change of the mass m, the cylinder length ℓ and the inclination angle α influences the effective work of adhesion w_{eff} and, further, the rolling velocity v. Assuming a steady rolling process the rolling velocity v is equal to the velocity v_{crack} of the crack tip. Therefore, this simple test gives information about the dependency of the effective work of adhesion w_{eff} on the crack velocity v_{crack}, see Fig. 1.

This knowledge is necessary to simulate much more complex dynamic problems like the impact of a ball on a rubber plate, cp. Kröger [5] or like the adhesion contribution to the sliding friction process of a rubber sample on a rough road surface, cp. Le Gal and Klüppel [6].

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