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MEASUREMENT OF FRICTION AND DAMPING PROPERTIES OF RUBBER

MĚŘENÍ TŘECÍCH A ÚTLUMOVÝCH VLASTNOSTÍ PRYŽE

Abstract

Friction of rubber depends on different parameters e.g. velocity, roughness, normal pressure and temperature. The coefficient of friction is measured by ball-on-disc method at ambient temperature. The dependence of the coefficient on different sliding velocities and on different normal forces is observed. The coefficient of friction is compared with the rubber damping properties determined by dynamic mechanical analysis.

Abstrakt

Tření pryže závisí na řadě parametrů jako je rychlost, drsnost povrchu, přítlačná síla a teplota. Koeficient tření je měřen metodou „ball-on-disc“ při pokojové teplotě. Je sledována závislost koeficientu tření na rychlosti a na přítlačné síle. Součinitel tření je porovnán s útlumovými vlastnostmi pryže stanovenými pomocí dynamické mechanické analýzy.

1 INTRODUCTION

The friction which develops between a rubber body sliding onto a hard solid surface is important from the fundamental and technological point of view in car industry (tire construction, wiper rubber blades etc.) The major difference in the frictional properties of rubbers with respect to other solids arise from their low elastic modulus E, and the high internal dissipation that is present over a wide frequency range [1]. The friction force between a rubber body and a hard rough solid substrate has two major contributions which are the hysteretic and the adhesive ones. The hysteretic component arise from the oscillating forces that the surface asperities exert onto the rubber surface leading effectively to cyclic deformations and energy dissipation due to internal frictional damping [1]. As a result the hysteretic contribution will have the same temperature dependence as that of an elastic complex modulus E(ω). On the other hand, the adhesive component is important for clean and relative smoother surfaces [2]. Adhesive component of friction correlates with relaxation spectrum i.e. the loss modulus curve of the rubber. The hysteretic friction, on the other hand, correlates with the loss factor. The friction of rubber becomes almost independent of velocity and temperature at low velocities of sliding [2]. After Persson [3] the coefficient of friction due to the hysteretic contribution associated with the long-wavelength surface roughness of the substrate can be expressed as

$$\mu \approx -C\frac{\operatorname{Im}E(\omega_0)}{\left|E(\omega_0)\right|}, \qquad (1)$$

where $E(\omega_0)$ is the complex elastic modulus at the frequency ω_0 corresponding to the maximum of the loss factor and C is a constant depending on the surface roughness. Most other polymers exhibit

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much lower sliding friction than rubber. One extreme case is Teflon for which the static and kinetic friction coefficients typically are smaller than 0.1. This implies that for most polymers the internal friction gives a much smaller contribution to the sliding friction than for rubber. Finally, we note that because of its low elastic modulus, rubber often exhibits elastic instabilities during sliding. The most well-known involves the compressed rubber surface in front of the contact area undergoing a buckling, producing detachment waves which propagate from the front to the back end of the contact area. These so-called Schallamach waves were first discovered in 1971 and have been intensively studied [3].

2 EXPERIMENT

The present study focuses on the characterization of two nitrile-butadiene rubbers using dynamic mechanical analysis (DMA) and tribological experiments. We investigated the behaviour of two rubber materials with different contents of carbon-black: material A with the Shore-A hardness 80 and carbon black content of 60 phr and material B with 60 Sh-A and 50 phr. The DMA tests were carried out in the Hydrodynamic laboratory of TUL. The friction tests were carried out in laboratory of Dept of Material Engineering and Engineering Metallurgy of ZCU at the pin-on disc friction device.

2.1 Dynamic mechanical analysis

DMA tests were performed at the computer-controlled servo hydraulic testing device under strain control at ambient temperature. The displacement of the loading head was measured by the extensometer and the force response was measured by the load cell. All data were recorded using a personal computer. Both the diameter and the length L0 of the undeformed cylindrical specimens were 20 mm. In order to exclude the Mullins effect, all specimens were preconditioned with a cyclic strain controlled process. Subsequent to this preconditioning process, three different constant compressive pre-strains were applied subsequently and for each of them four ascending amplitudes of the superimposed harmonic strain varied between 0.01 and 0.06. The frequencies varied in 5 steps between 1 and 10 Hz for each of strain amplitudes. The test setup is obvious from Fig. 1.

In order to determine the storage and loss moduli of material, the static pre-deformation u_0, the amplitude Δu and the frequency f of strain controlled loading, corresponding parameters of the force response and the phase angle δ must be extracted from the recorded raw signals. We supposed that the raw signals, i.e. head displacement u(t) and force F(t), are approximately harmonic functions and we used several numerical methods for their processing [4].

The experimental data of the dynamic E' and E'' belonging to pre-strain ε_0 = -0.17 are plotted in Fig. 2 and 3 for different strain amplitudes and frequencies. We observe a decrease of the storage and dissipation moduli with increasing strain amplitudes. Since the storage modulus is a measure for the stiffness of material, it is proportional to the number of intact physical bonds which can transfer forces on the microscopic scale. Its monotonic decline is caused by a decrease in the number of intact bonds with increasing amplitudes. The dissipation modulus is a measure for the energy loss per loading cycle and is proportional to the breakage rate of the bonds. The values of dynamic properties of the softer material B with lower content of carbon-black are about 50 percent of values of material A as is apparent at Fig. 3. The amplitude and frequency dependency is similar for both materials.

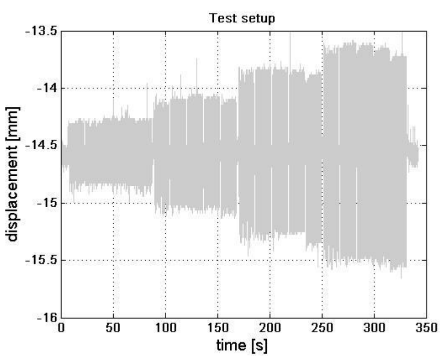

Fig. 1 Test setup

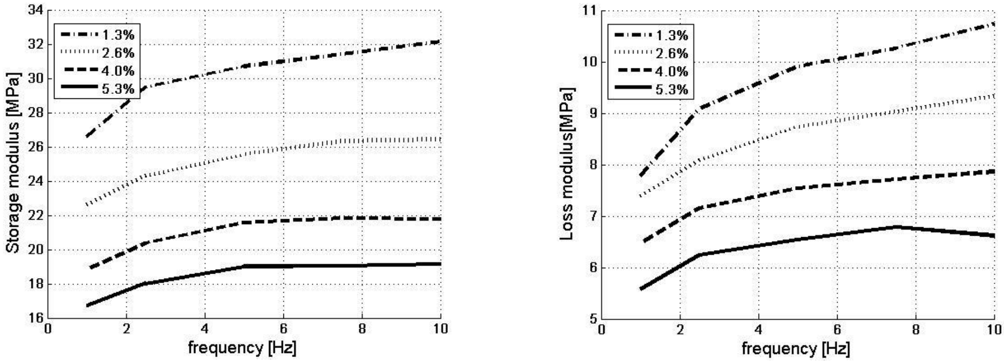

Fig. 2 Storage and loss modulus for different strain amplitudes - material A

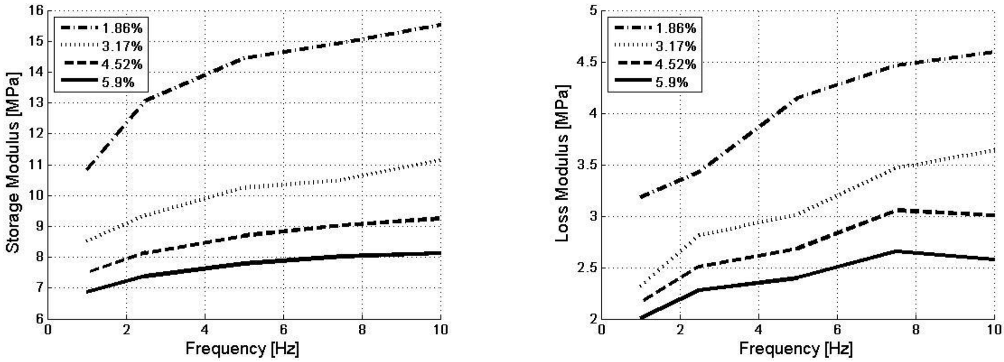

Fig. 3 Storage and loss modulus for different strain amplitudes - material B

2.2 Tribological tests

Our tribological tests are sliding friction tests between a steel ball of diameter 6 mm and a disk of the studied rubbers, under dry conditions. As shown in Fig. 4 and 5, cyclic tests are carried out by rotating of the disc of rubber under the sliding ball loaded with constant forces F_n of 1N, 2N and 10 N produced by weights. The sliding velocities were 1.25 and 2.5 cm/s respectively. The tangential force F_t and thus the friction coefficient μ are measured.

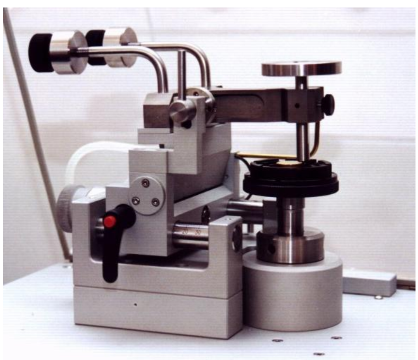

Fig. 4 Tribometer ball-on-disc

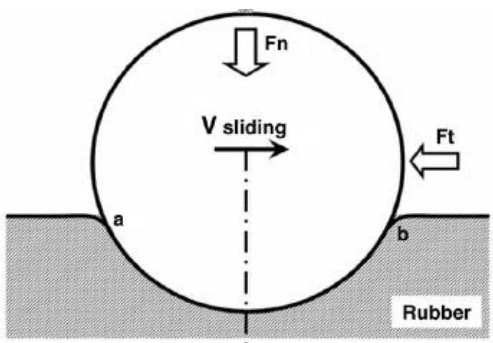

Fig. 5 Ball-plane contact

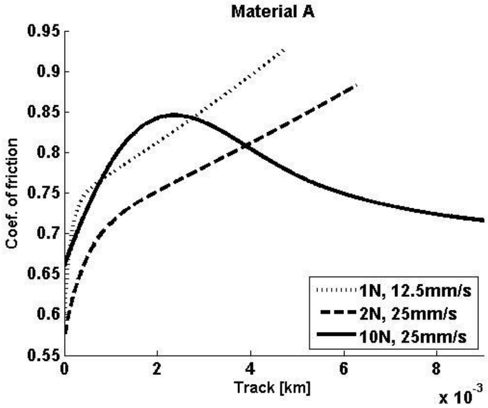

Fig. 6 Friction coefficient material A

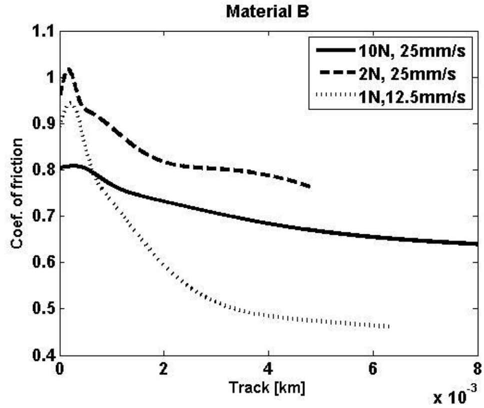

Fig. 7 Friction coefficient material B

For the same tribological solicitation, i.e. the same normal load, the same temperature T_o and the same sliding speed v, differences between the two rubbers appear. Material A has a lower static friction coefficient μ_{stat} than rubber B as can be seen from Fig. 6 and 7. However, the main difference occurs during the first hundred cycles, when the kinetic friction coefficient of the rubber A increases in contrast with the rubber B. At this time, rubber B is starting to wear with a visible trace, unlike rubber A on which negligible wear appears. As the temperature at the contact was not measured, the sliding tests were terminated early in order not to allow the essential temperature rise.

3 CONCLUSIONS

We observe in DMA experiments that the storage and dissipation moduli of filled rubber depend on the deformation amplitude and on the frequency. These effects are caused by history-dependent viscosities with recovery properties. We identified the material parameters i.e. the storage and the loss modulus and the loss tangent. We envisage the temperature measurement in future frictional tests by a thermocouple placed at the top of the ball with a view to monitor the friction temperature dependence. The duration of the sliding tests then will be enlarged until the friction coefficients reach the steady-state value. The test sampling frequency will be enlarged also to allow the observation of the friction periodic fluctuation in course of a cycle and the stick-slip frictional behaviour of rubber.

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