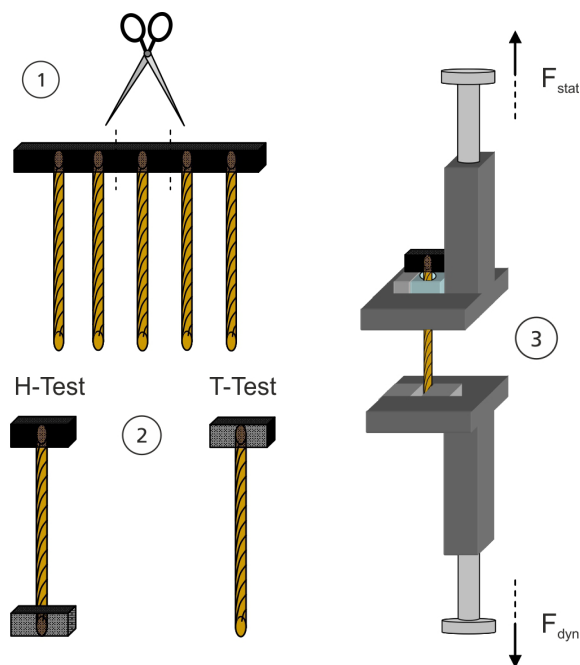


Adhesion Behavior of Tire Cords, Measured by Means of DMTA – Temperature Dependence and Stress Limits

Dr. Horst Deckmann, Dr.-Ing. Herbert Mucha and Dr. Gabriele Kaiser



1 Sample preparation and fixation for dynamic H-Tests or T-Tests to determine the adhesion behavior of tire cords

Introduction

For the reinforcement of rubber components such as car tires, conveyor belts or v-belts, tire cords and/or meshed materials are used. During the production process, these materials are vulcanized to become the rubber compound.

However, it is not only the dynamic-mechanical properties of a rubber compound or a mesh that are of interest. Information on the adhesion between the tire cord and rubber is also often needed; this is mainly affected by the temperature, material properties, mechanical stress and the tackifier used.

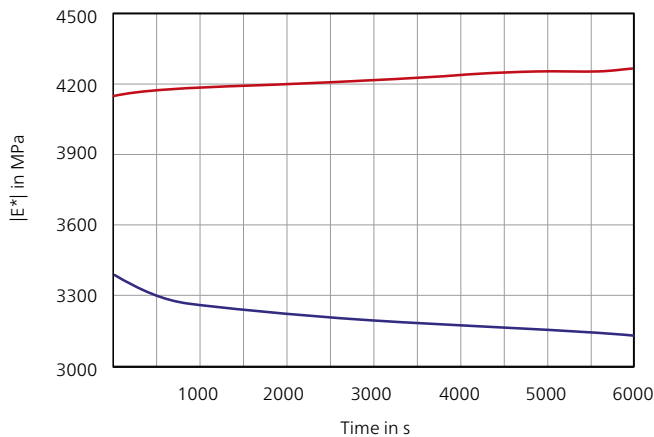
A tackifier is a mixture which is applied to the tire cord surface to tailor the adhesive strength between the rubber compound and the tire cord. During the use of a tire, tensile, shear and compression stress occur when the wheel rotates, as well as during braking, starting or cornering.

For these reasons, knowledge about the adhesion of the tire cord within the rubber matrix is essential in order to develop products with reliable and durable dynamic properties. These properties are influenced by the performance of the tackifier, which can be qualified using a high-force DMTA system such as the EPLEXOR® 500 N by NETZSCH GABO Instruments. Not only is the EPLEXOR® 500 N able to perform tensile tests based on ASTM D4776 to determine the maximum pull-out force, but it also allows for deeper insight into a materials' properties by applying an oscillating force to the sample. Figure 1 shows the arrangement used in the so-called T-Tests or H-Tests (denomination is based on the sample's shape) to determine the dynamic properties of embedded tire cords.

A) Temperature Influence

Figure 2 depicts a fatigue test performed on two cord-rubber composites of the same material to characterize the adhesion behavior at different temperatures.

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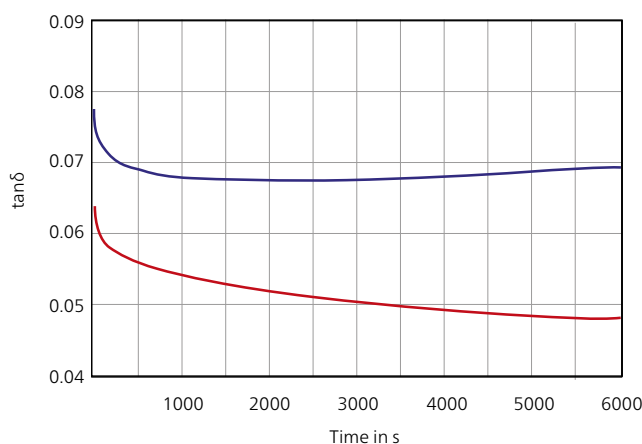


2 Complex modulus $|E^*|$, fatigue tests in the tension mode at 100°C (red) and 150°C (blue)

The temperature of the experiment was 100°C for sample 1 (red) and 150°C for sample 2 (blue). The test was carried out in the force-controlled mode; i.e., with a static force of 20 N and a dynamic force of 2 N. The test frequency was 60 Hz for 6000 sec (360000 cycles). The increase in the complex modulus of sample 1 (red) can be explained as having been caused by the fact that at 100°C, the curing process proceeds. At 150°C, the complex modulus of sample 2 (blue) decreases. This is due to the fact that the rubber compound has already begun degradation here.

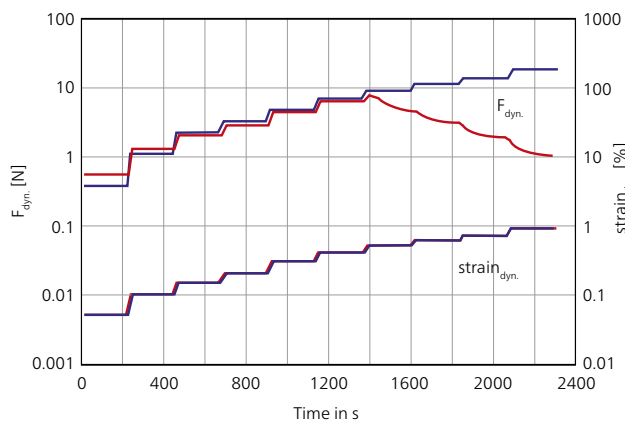
Figure 3 displays the damping behavior ($\tan\delta$) of the two samples. Different temperatures result in different damping properties.

The reasons for this are the same as mentioned before. With respect to the red curve (at 100°C), $\tan\delta$ decreases due to crosslinking (curing); with respect to the blue curve (at 150°C), it increases due to decomposition.



3 Comparison of $\tan\delta$ of tire cord rubber composites at 100°C (red) and 150°C (blue); the measurements were carried out in tension mode

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4 Static dynamic sweep (tension mode) of two samples (curves in red and blue), based on the same cord-rubber matrix but with different tackifiers

B) Identifying Stress Limits

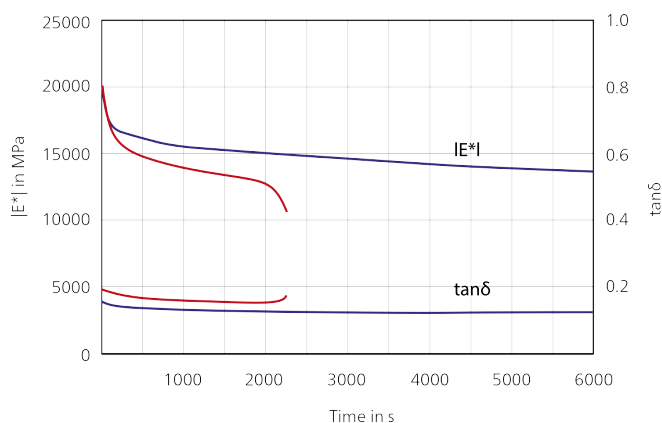
Figure 4 displays the results obtained by means of analyses performed on two identical cord-rubber composites but including different tackifiers. The objective of this test was to determine the dynamic-mechanical stress limits.

The static dynamic sweep in the strain-controlled mode increases in the static and dynamic strain step by step: 0.5% static load/0.05% dynamic strain; 1%/0.1%; 2%/0.2% ... 9%/0.9%.

The test frequency was 10 Hz. For every load step, 20 data points were recorded to display the expected force decline once the maximum stress is reached.

The blue lines show the behavior of the cord-rubber composite with good adhesion properties, whereas the red curve originates from the material with insufficient adhesion. As can be seen from sample 1 (red curve), the tire cord already starts to pull out of the rubber matrix at 6% static strain and 0.6% dynamic strain. The 6%/0.6% stat./dyn. load step indicates the start of the non-linear material behavior.

Knowing the stress limits, further tests can be carried out to obtain more information on the material. Figure 5 depicts the time dependence of the complex modulus and $\tan\delta$ during a fatigue test applied to the same samples as used in figure 2.



5 Fatigue tests in tension mode on two samples (marked in red and blue) from the same kind as in fig. 4

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The test was carried out in the strain-controlled mode at a static load of 5% and a dynamic load of 0.5% at a frequency of 50 Hz. The conditions were selected so as to be close to the failure limit of 6%/0.6% derived from figure 4, with the objective of inducing a quick degradation of sample 1. The test was carried out at room temperature.

Figure 5 shows the expected results. The mechanical aging of sample 1 (red) takes place faster than that of sample 2 (blue). After 2300 sec (115000 cycles), the cord of sample 1 starts to pull out of the rubber compound, which can be seen as a decreasing complex modulus E^* .

The complex modulus of sample 2 (blue) decreases only slowly during the measurement.

Conclusion

Continuous dynamic load tests (fatigue tests) are suited for characterizing the adhesion between the cord and rubber matrix when tackifiers are applied to the cord surface. Due to the high forces and amplitudes required, the EPLEXOR® instrument series by NETZSCH GABO Instruments, in particular the EPLEXOR 500 N, is well suited for loading the samples dynamically for thousands of cycles.

For the analyses, samples in T or H shape were used; these consisted of one tire cord each and rubber material at either one end (T-Test) or on both ends (H-Test).