15 Viscoelastic Properties of Elastomers

15.1 Introduction

Rubber and other elastomers play an important role in many tribological applications. They are used where large frictional forces are demanded. In particular, they find applications as materials for tires, feed rollers (e.g. in printers), sports shoes, seals, rubber bands, and materials in electronic devices (e.g. keyboard contacts), as well as adhesive fixtures.

The two most important properties of elastomers are: (1) an extremely small modulus of elasticity (ca. 1 to 10 MPa, meaning 4 to 5 orders of magnitude smaller than normal “solid bodies”) and (2) extremely high deformability: elastomers can often be stretched to multiple times their original length.

The cause for these two fundamental properties of elastomers lies in their structure. Elastomers consist of polymer molecules which interact relatively weak with one another. In thermodynamic equilibrium, they are in a statistically favored coiled state. If a mechanical stress is applied to an elastomer, then the polymer molecules begin to untangle (Fig. 15.1). If the stress is then removed, then the polymer molecules relax once again to their coiled state. While for “normal solid bodies” the equilibrium state primarily corresponds to a minimum in potential en-
ergy, for elastomers equilibrium is reached primarily when entropy reaches its maximum. This has become known as *entropy elasticity*\(^1\).

In order to prevent the complete disentanglement of the chains under tensile loading, the rubber chains are connected to each other by sulfur bridges – this treatment is known as *vulcanization*\(^2\). By the addition of a large amount of sulfur during vulcanization, hard rubber is formed; by adding less sulfur we get softer rubber. In order to achieve an optimization between elasticity, wear resistance, and adhesive ability, rubber is mixed with soot during the manufacture of automobile tires. The composite material that results is known as “soot-filled rubber.”

Fig. 15.1 Schematic representation of the changes that occur in the structure of an elastomer during tensile loading.

It is generally accepted that the contact and frictional properties of elastomers are due primarily to their rheological properties. In other words, the tribological properties of elastomers are largely determined not by their surface properties, but rather by their volume properties. This is the reason why, in this chapter, we initially devote ourselves to the detailed analysis of the rheological properties of rubber as well as methods to describe them. The terms and methods introduced in this chapter will be used in the next chapter in order to discuss the friction of elastomers. Thereby, we treat elastomers as *linearly* viscoelastic materials. The treatment of non-linearities is beyond the scope of this book.

### 15.2 Stress-Relaxation

We consider a rubber block that is being acted upon by shear forces (Fig. 15.2). If it is quickly deformed, then the stress reaches a high level \(\sigma(0)\) in the first moment and afterwards slowly relaxes to a much lower level \(\sigma(\infty)\) (Fig. 15.3), whereby with elastomers, \(\sigma(\infty)\) can be 3 to 4 orders of magnitude smaller than \(\sigma(0)\). The physical cause for this behavior is clear: in the first moment, the poly-

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1 In this sense, the elasticity of rubber is similar to the “elasticity” of an ideal gas, where the interactions between the molecules play no role and the elasticity is, likewise, of pure entropic nature.

2 Vulcanization was developed by Charles Goodyear in 1839.