CHAPTER 3

Contact between Solid Surfaces

3.1. Physical Properties of Polymers

For particulate magnetic media that have a polymeric binder, tribological behavior of the head–medium interface is affected by the physical properties of the polymers. Therefore, it is important to obtain a grasp of the physical properties of polymers.

3.1.1. Physical States of Polymers

Polymers exist in four physical states: the crystalline and the three amorphous states (glassy, rubbery, and viscous flow). Polymers that exist in glassy or crystalline states are called rigid. At temperatures lower than the glass transition $T_g$, polymers deform in the manner of a rigid glass (or elastic solid). A significant increase in reversible strain occurs at temperatures above this, entering the rubbery state. In this range, the elastic modulus changes little with temperatures up to the flow temperature, $T_f$. Above this flow temperature, a polymer behaves as a liquid of high viscosity (see Fig. 3.1).

The mode of deformation of rubbery polymers is viscoelastic. The term viscoelasticity is commonly applied to materials that are neither ideal solids nor liquids, but in fact possess characteristics that are typical of both. The classical theory of elasticity deals with the mechanical properties of perfectly elastic solids, where in accordance with Hooke’s Law stress is proportional to strain, but independent of the rate of strain. On the other hand, for perfectly viscous fluids, in accordance with Newton’s Law, stress is directly proportional to rate of strain, but independent of the strain itself. In a viscoelastic material, the stress depends on both strain and rate of strain together.

3.1.2. Complex Modulus and Compliance

In viscoelastic (rubbery) materials, the stress $P$ is generally out of phase with the resulting strain $e$, and we may express the ratio of stress to strain as (Ferry, 1980):
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Fig. 3.1. Temperature dependence on the complex modulus and tangent modulus.

\[ p/\varepsilon = E^* = E' + iE''; \quad |E^*| = E'^2 + E''^2, \]  \hspace{1cm} (3.1)

where \( E^* \) is a complex modulus comprising real and imaginary contributions \( E' \) and \( E'' \), respectively. \( E^* \), \( E' \), and \( E'' \) are functions of frequency (or time or strain rate) and temperature. The real part \( E' \) suggests an in-phase relationship between \( p \) and \( \varepsilon \), and \( E'' \) describes the out-of-phase component. The ratio \( E''/E' \) determines the phase relationship between \( p \) and \( \varepsilon \) and is described as the damping factor or the tangent modulus (\( \tan \delta \)), so we can write

\[ \tan \delta = E''/E'. \]  \hspace{1cm} (3.2)

An alternative procedure to using the complex modulus concept is to describe the ratio of strain to stress by a complex quantity \( J^* \), so that

\[ \varepsilon/p = J^* = J' - iJ''; \quad |J^*|^2 = J'^2 + J''^2 = 1/E^*, \]  \hspace{1cm} (3.3)

and

\[ \tan \delta = J''/J' = E''/E'. \]  \hspace{1cm} (3.4)

Figure 3.2 shows the interrelationship of the quantities defined by Eqs. (3.1) to (3.4). It is clear from this figure that the complex modulus describes how the stress leads the strain with phase angle \( \delta \), whereas the complex compliance illustrates how the strain lags the stress by the same angle.

The component \( E' \) is frequently called storage moduli, whereas \( E'' \) is called loss moduli. Similarly \( J' \) is called storage compliance and \( J'' \) is called loss moduli.