RELATION BETWEEN SLIP AND ENERGY DISSIPATION IN VISCOELASTIC ADHESIVES

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ABSTRACT

The adhesion strength of a viscoelastic adhesive were measured on a series of substrates of varying local mobility. The substrates were silicon grafted with organic silanes or siloxane chains. The adhesion on the series of substrates was found to correlate, not with the thermodynamic work of adhesion as conventional theories predict, but with the slip resistance and local mobility of the substrate. This result was explained in terms of a simple model of energy dissipation at the crack tip.

KEYWORDS

Adhesion, pressure sensitive adhesive, viscoelastic dissipation, wall slip.

INTRODUCTION

The adhesion to a substrate of an elastomeric polymer (a polymer that is at a temperature above its glass transition temperature, T_g) has been studied by many workers as a function of both the detachment rate and the chemical nature of the substrate. The conclusion of much of this work has been that the adhesion is controlled by the viscoelastic properties of the adhesive and, if there are no covalent bonds formed between the polymer adhesive and the substrate, by the thermodynamic work of adhesion W_a between the substrate and the adhesive. Within this model the toughness of the joint G_{Ic} is given a a relation of the form

$$G_{Ic} = (1 + \phi(V,T))W_a \tag{1}$$

where ϕ is a viscoelastic function of temperature T and velocity V that increases monotonically with V. This expression has been found to work well for a series of substrates that give a range of values of W_a, but in all cases the substrates were glassy or crystalline materials that had little mobility at the segment level and so there was probably little interfacial slip.

The viscoelastic energy dissipation represented by equation (1) is thought to occur in a annulus of material round the crack tip for which the time scale of the deformation caused by the crack propagation corresponds to a frequency at which the viscoelastic loss is maximized. The increase of ϕ with V is explained by the increase on the volume of material within the annulus with V.

In this work we chose substrates that have been shown to have a range of slip resistances caused by a range of local mobility's. We examined the adhesion of a standard commercial pressure sensitive adhesive (PSA) tape to a series of substrates made by self assembly techniques that slowed a range of both surface energies and local mobility's. The slip of a polydimethylsiloxane (PDMS) elastomer over the substrates had previously been measured.

EXPERIMENTAL TECHNIQUE

The substrates in this work were all based on silicon wafers. The silicon was covered with either a layer of end-attached PDMS chains or short chain self assembled monolayers. the former were made by directly reacting vinyl ended PDMS with the silicon wafer. The fluorinated and hydrogenated self assembled monolayer films were made by reacting the silicon wafer with fluorinated and hydrogenated 10 and 16 carbon short chain trichlorosilanes. The latter substrates are expected to show much less local mobility than the PDMS coated substrates and have been shown to have higher slip resistance than the PDMS coated substrates. In addition the fluorinated substrates showed greater friction than the hydrogenated substrates.

Adhesion was measured by peeling a commercial pressure sensitive adhesive (PSA) tape from the substrate at fixed load and fixed peel angle.

RESULTS AND DISCUSSION

Figure 1 shows the peel force as a function of rate for the adhesive tape on the range of substrates. It is clear that the peel force was very low on the surfaces grafted with a thick layer of PDMS, intermediate on a hydrocarbon self assembled monolayer and greatest on the fluorocarbon self assembled monolayer.

The work of adhesion W_a between the adhesive on the PSA tape and the substrates is not known precisely. However one can estimate from surface energies that it would be highest on the PDMS and PS, intermediate on the hydrocarbon self assembled monolayer and lowest on the fluorocarbon monolayer. It is immediately evident that the measured adhesion shows no correlation with W_a. In contrast it is clear that the adhesion correlated well with the resistance to slip on the substrates, particularly as it has previously been shown that slip resistance is higher on the fluorocarbon than on the hydrocarbon monolayer. The resistance to slip itself is strongly influenced by the local mobility of the substrate so we conclude that substrate local mobility can have a strong influence of the adhesion of viscoelastic adhesive to that substrate.

The relation between slip and adhesion can be understood as follows by the use of a simple model of the energy loss processes close to the crack tip. This model is based on the assumption that the detachment process of the viscoelastic adhesive, is very similar to dewetting of a liquid from a solid surface. The similarity is caused by the combination of the mechanical properties of the adhesive and the fact that the adhesive is highly constrained by being sandwiched between the high modulus substrate and backing. The shape of the crack tip, shown in figure 2, is such that one can define a dewetting angle θ. We propose that the geometry of the crack tip is

controlled mainly by the elastic properties of the material but the dissipation is estimated assuming that the material is viscous. If the adhesive is considered to be elastic with a shear modulus G the angle θ can be related to G and the maximum shear stress σ_s at the interface. It is assumed that the interface shows static friction, there is no slip at a shear stress below σ_s but unlimited slip at higher shear stresses. The actual detachment must occur by a combination of two processes. If there is no slip the detachment must occur by the highly dissipative rolling motion in a wedge typical of liquid wetting and dewetting. If there is slip there can also be partial detachment by slip as the slip process permits extension of the adhesive normal to the interface. The dissipation in the wedge increases as the angle θ decreases, hence as σ_s increases, the decrease in θ causes the dissipation to increase.

This model predicts that the toughness increases linearly with the interfacial shear stress, the detachment velocity and the effective viscosity of the adhesive. The absolute values of toughness predicted are of the same order as the those measured.
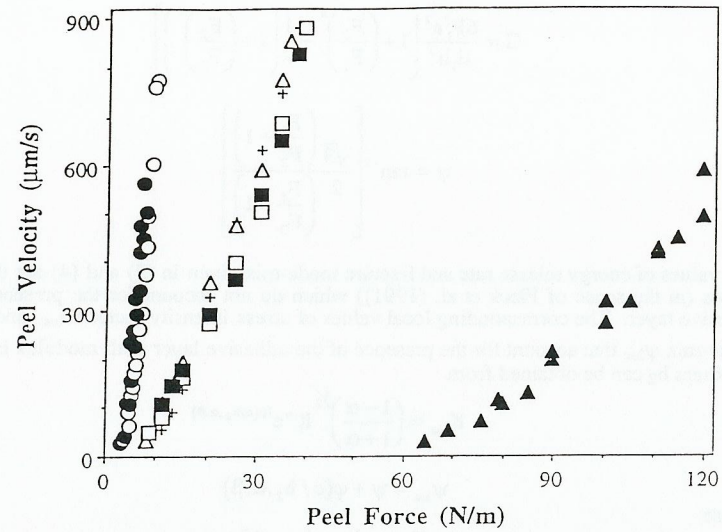
Fig. 1 The peel adhesion results of a viscoelastic adhesive on three types of surfaces at a peel angle of 40^0. Within a certain class of organic film, the adhesion does not depend significantly on film thickness. PDMS: 50 Å thick (O), 100 Å thick (●); hydrocarbons: C_{10} (△), C_{11} (+), C_{14} (□), and C_{16} (■); fluorocarbon (▲).
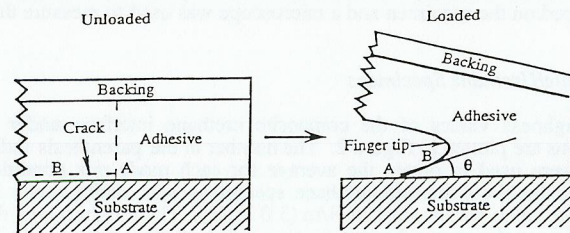

Fig. 2. Schematic of how the deformation in the adhesive causes a shear stress at the adhesive-substrate interface.