ELSEVIER

International Journal of Adhesion & Adhesives 28 (2008) 192–198

International Journal of Adhesion & Adhesives

www.elsevier.com/locate/ijadhadh

Application of the bulk properties of a silicone PSA to peeling

John A. Williams[a,*], James J. Kauzlarich[b]

[a]*Engineering Department, Cambridge University, Cambridge CB2 1PZ, UK*
[b]*University of Virginia, Charlottesville, VA 22904-4746, USA*

Accepted 19 June 2007
Available online 25 September 2007

Abstract

Finite element analysis of peeling of a pressure sensitive flexible adhesive requires a knowledge of the mechanical performance of the adhesive layer. The bulk tensile properties of a silicone pressure sensitive adhesive (PSA) can be related to its behaviour when used as a thin adhesive layer in a commercial PTFE tape. A finite element analysis for fixed arm peeling of this tape predicts the strain energy density of the adhesive and these values are consistent with the measured data using a mandrel peel test. The effect of local constraint, the extent of the deformation, and distribution of stresses while during the peel test are demonstrated.

Keywords: Peeling; Pressure sensitive adhesive; Silicone adhesive; Finite element analysis

1. Introduction

Modern silicones have come to occupy a special niche within the range of pressure sensitive adhesives (PSAs) available in the commercial adhesive tape market. Although expensive, silicone adhesives have the advantage of low glass transition temperatures (typically about −120 °C) and generally generate fewer skin sensitivity problems in medical applications [1]. This paper is intended to expand the understanding of the peel performance of a silicone PSA by using the bulk properties of the adhesive as an input to a finite element (FE)model of peeling a specific PTFE-backed commercial tape.

A number of papers have been published in which FE models have been used to examine the mechanics of peeling. Crocombe and Adams [2,3] demonstrated the value of finite element analysis (FEA) when applied to the plastic behaviour of an aluminium alloy backing with a rubber modified epoxy adhesive. A more recent FEA for peel of an aluminium backing with a toughened epoxy was carried out by Cui et al. [4] using a critical von Mises strain as the criterion of separation. These authors found it possible to predict the steady-state peel force and the backing root curvature at three peel angles.

In the case of 'flexible' tapes using a PSA the stress–strain characteristics for the tape components are essential for constructing an operational FE model. Du et al. [5] used a two-dimensional (2-D) large strain FEA model to examine the 180° peeling of a tape with a flexible backing of thickness 300 μm and modulus 2.7 GPa (a stiffness which is typical of a cellulose material) secured by a PSA of thickness 25 μm to an effectively rigid substrate of modulus 195 GPa. The linear visco-elastic response of the adhesive was described in terms of shear relaxation modulus represented by a generalized Maxwell series with time periods from 10^{-8} to 10^{6} s. Interfacial de-bonding was simulated using a failure criterion based on the level of stored elastic energy in the PSA layer. Although the FEA predicted the general features of the PSA, it consistently underestimated the values of the peel forces.

2. Effect of specimen dimensions on measured properties

The apparent tensile modulus of a flexible material in the form of a very thin layer sandwiched between two effectively stiff plates and measured in the direction normal to its plane is much enhanced by the constraint of the surrounding material [6]. This increase in effective modulus

*Corresponding author. Tel.: +44 1223 765237; fax: +44 1223 332662.
E-mail address: jaw1000@hermes.cam.ac.uk (J.A. Williams).

0143-7496/$ - see front matter
doi:10.1016/j.ijadhadh.2007.06.007

Nomenclature

b	width of tape	h_a	adhesive thickness
D	mandrel alignment load	P	peel force
E	elastic modulus	ε	strain
E_a	apparent elastic modulus	S	shape factor
E_∞	constrained elastic modulus	σ	stress
K	bulk modulus	σ_y	yield stress
G_a	de-adhesion energy per unit area	ν	Poisson's ratio
G_p	deformation energy per unit area	L	dimension
h	backing thickness	ℓ	dimension
		F	detachment force

is well established—for example in the case of a thin rubber sheet bonded to a pair of parallel metallic plates [7] and will apply in the case of an adhesive securing a tape backing to a solid substrate. In what follows we describe a simple FEA of tape peeling—since this simulation is essentially 2-D it is important to incorporate the effects of the constraint offered by the surrounding material in the model. This can be achieved by adjusting the value of the modulus of the layer which represents the adhesive in the numerical input to the model.

Previous authors, see Ref. [8], have shown that the stiffness of such flexible sandwiched blocks depends on a 'shape factor' S defined as the ratio of the area of one of the loaded faces of the material to the area of the stress-free faces of the block. In the peeling situation, illustrated in Fig. 1, the adhesive in advance of the peel front is constrained and thus exhibits an enhanced stiffness, while that in its wake, which may well be drawn out into characteristic fibrils, is comparatively unconstrained and therefore of a much lower effective modulus. In such an example an appropriate value of S can be given by ratio of the area $b \times L$ to area $h_a \times (2L + b)$. Since in general $b \gg L$ this approximates to the ratio L/h_a where dimension L represents the length over which significant stresses act in the adhesive layer. Although this is not known explicitly in peeling, it is typically of the order of several millimetres, while h_a is perhaps 50–100 μm: it follows that in this region $10 < S < 100$. Conversely, downstream of the peel front, in the area of fibril formation, where each fibril or strand acts essentially independently of the others, there is little modulus enhancement: because of its elongation each fibril has a large length to diameter ratio so that $S < 1$. Gent and Lindley [7] and Gent and Meinecke [8] have derived approximate relations for compression and extension showing how the apparent or effective Young's modulus of constrained material E_a is related to the value E measured in a bulk or unconstrained specimen together with the influence of a quantity E_∞, a constrained Young's modulus which is closely related to the bulk modulus K and Poisson's ratio ν (see the Appendix). These references examine two geometries, viz. when the material is either in the form of a rectangular block of infinite length or a thin cylindrical disc, and express the increase in apparent modulus as a function of S. Eqs. (1) and (3) of Ref. [7] provide the relation

$$\frac{E_a}{E} = \left\{ \frac{E}{E_\infty} + \frac{1}{1 + 2S^2} \right\}^{-1}. \quad (1)$$

Fig. 2 shows a plot of the way in which the ratio E_a/E varies with shape factor S for a material in which the ratio E_∞/E has the value 20.5.

The prediction of the compliance of a deformable layer sandwiched between two flat (most commonly circular) platens has been more latterly investigated by a number of workers both analytically and numerically [9–13]. The formulation of the last of these can be readily rearranged to provide the following equation:

$$\frac{E_a}{E} = \frac{1 - \nu}{(1 + \nu)(1 - 2\nu)} f(\lambda), \quad (2a)$$

where

$$\lambda = S \times \sqrt{\frac{6(1 - 2\nu)}{1 - \nu}} \quad (2b)$$

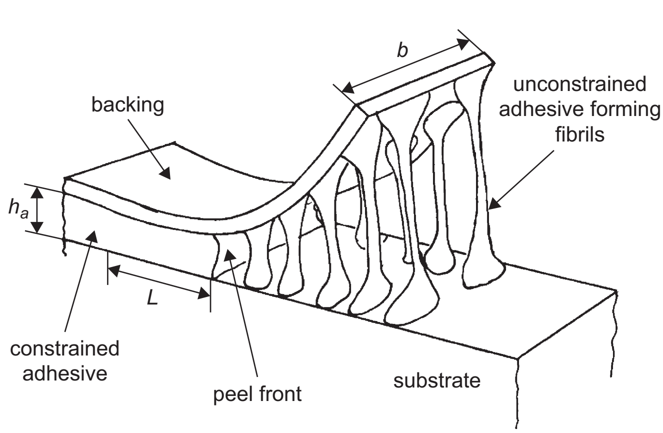

Fig. 1. Diagrammatic view of the zone of separation in peeling: the breadth b of the tape is large compared to the thickness h_a of the adhesive. Where the adhesive forms a continuous film between the backing and the substrate it is severely constrained, i.e. the value of the 'shape factor' $S \gg 1$. Once separation occurs and the adhesive is drawn out into fibrils the degree of constraint is greatly reduced so that the value of S rapidly falls away.