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Tack performance of pressure-sensitive adhesive tapes under tensile loading

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ABSTRACT

An important property of adhesive tapes is their tack performance, which relates to the adhesive force generated by a small short-term pressure on the tapes. Tack performance declines when an adhesive tape experiences tensile loading, but this influence has not been characterized well, especially for thin adhesive tapes. A testing apparatus is developed to quantitatively evaluate the influence of applied tensile loading on the tack performance of various thicknesses adhesive tapes. The apparatus allows microscopic observation of the adhered area during separation. The separation force of 15 μm and 5 μm thick adhesive tapes exhibit ductile behavior, while that of 1 μm thick adhesive exhibits brittle behavior. These separation behaviors relate to the generation of cavities in the adhesive, whose expansion is affected by adhesive thickness. Microscopic images show that the adhered area becomes smaller with increasing tensile loadings. The unified separation energy is defined and calculated for adhesive tapes, to simultaneously evaluate the tack performance for different adhesive thicknesses and applied tensile loadings. The separation energy decreases with increasing tensile loading, but the separation energy per unit area remains largely constant, regardless of the applied tension. The effect of separation speed on separation behavior is investigated, with a change from ductile to brittle separation observed with increasing separation speed. Separation speed is also reflected in the unified separation energy.

1. Introduction

Tack is the adhesive force generated by a small short-term pressure (called the initial adhesive force), and is an important property of pressure-sensitive adhesives (PSAs), which are made from viscoelastic polymers. A light contact with a PSA generates a peel resistance because of wetting and surface interactions, but without any chemical reaction occurring. Tack is usually characterized by the standard ASTM D2979, but it is difficult to quantitatively evaluate because of large viscoelastic deformation [1]. The probe-tack test is a common way of investigating tack performance, in which a probe approaches and contacts an adhesive tape, followed by retraction to obtain load–displacement curves (tack curves) until complete separation. This test is designed to control the contact pressure, contact time and separation speed, and allows the separation behavior to be observed with an optical microscope [2,3].

Tack performance depends on the adhesive material properties (e.g. elastic modulus, viscosity and surface tension) [4] and on geometric conditions (e.g. surface roughness [5] and adhesive thickness [6]). Separation proceeds by deformation of the adhesive, nucleation of cavities, growth of cavities to form fibrils, and finally separation of fibrils from the probe [7,8]. Each step of this process can be correlated to a region of the tack curve, which generally shows an increase in adhesive force in the early cavity nucleation stage. The behavior of cavities depends on their size and the elastic modulus of the adhesive [9]. When cavities stop nucleating and start growing, the adhesive force drops and then plateaus while forming fibrils, and finally gradually decreases during the separation of fibrils [10].

Tack has Industrial importance in the labeling and lamination of thin films requiring instant and stable adhesion. Adhesive coating weights have significantly decreased in recent years, making products more compact and saving material costs. However, tack performance decreases for thinner adhesive tapes, at least from an empirical perspective. Tack performance has been analytically modeled [11] and characterized [12], but most examples are limited to adhesive film thicknesses of hundreds of micrometers. It is uncertain whether similar phenomena occur in adhesives with thickness of up to 1 μm. Another factor that may decrease tack performance is the tension applied to adhesive tapes to prevent them from wrinkling. The influence of tensile stress on

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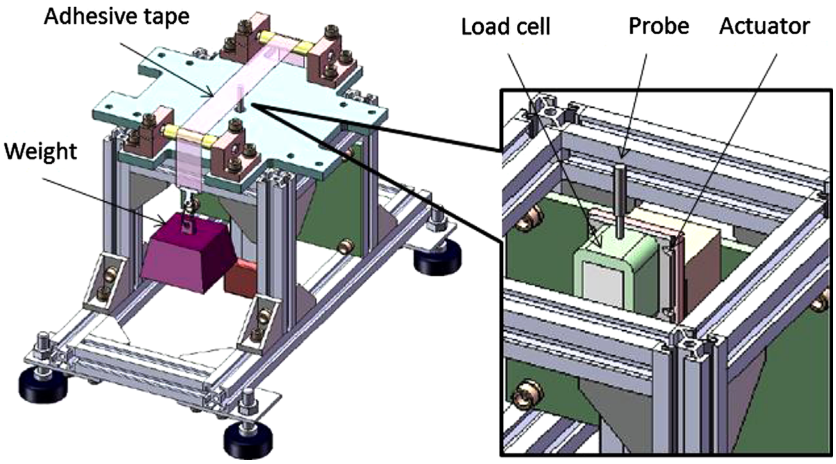

Fig. 1. Probe-tack testing machine for evaluating tensile loading on an adhesive tape.

the tack performance has not been well evaluated, because the conventional probe tack test apparatus is not suitable for this purpose.

In this study, the correlation between tack performance, adhesive thickness and tensile stress is investigated. An original probe-tack test machine is modified by incorporating a function to apply tensile loading. As in the conventional probe-tack test, tack curves are obtained for various adhesive thicknesses and tensile stress levels, and are correlated to images of the adhered area recorded with a high speed camera.

2. Materials and methods

2.1. Probe-tack testing machine

The modified testing machine controls the tensile loading to the adhesive tape, and records images of the adhered area during separation. Fig. 1 shows a probe connected to the load cell (KYOWA: LTS-200GA), and this probe moves up and down by an actuator (Maicom: PMS35L-02-050L). Conventional probe-tack tests use cylindrical probes, while the machine in this study uses a steel sphere attached to the probe tip. A cylindrical probe is useful for characterizing adhesive behavior because the adhered area deforms uniformly, but it is difficult to control the alignment to make a flat contact, especially for thin adhesives. A spherical probe always maintains the same contact conditions, and is still able to quantitatively evaluate the tack performance [13,14]. An adhesive tape is positioned above the probe, and tensile loading is applied by weights attached at each end of the tape through rollers, as shown in Fig. 1. Predefined weights of 0, 60, 120, 360, 720 and 1000 g are employed. The corresponding levels of stress are located within the elastic region of the tape substrates. After applying tension, the adhesive tape is held by a fixture, to ensure a stable contact with the probe. Images of the adhered area during separation are recorded from above using a high speed camera (KEYENCE: VW-9000).

2.2. Specimens

The adhesive tapes tested are composed of three layers; an acrylic adhesive layer sandwiched between polyethylene terephthalate (PET) base materials. The thicknesses of the upper and lower PET layers are 25 and 38 μm, respectively. Part of the lower PET layer is removed to expose the adhesive layer, and allow the spherical probe to make contact. Three adhesive tape layer thicknesses are investigated; 1, 5 and 15 μm. The spherical probe approaches the adhesive tape at 0.2 mm/s, stops at the position of maximum probe displacement for 3 s, and then retracts at 0.2 mm/s to commence separation.

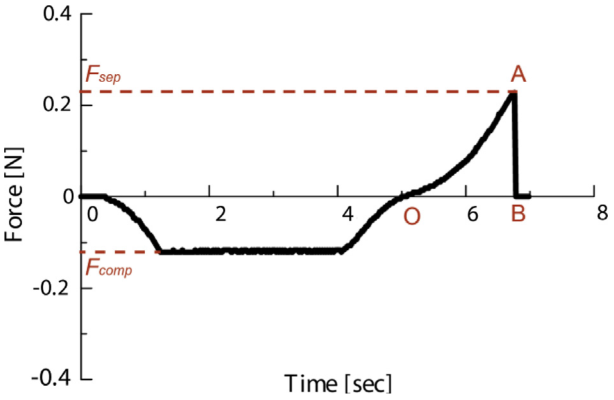

Fig. 2. Load–displacement relationship during probe-tack testing of 1 μm thick adhesive layer under 360 g tensile loading.

3. Results and discussion

3.1. Tack Curves

The load–displacement relationship was measured, from the initial contact of the probe to the adhesive tape until complete separation. Fig. 2 shows probe force vs. time, from which the relationship between the probe force and displacement can be ascertained. This is an example of an adhesive tape containing a 1 μm thick adhesive layer, under 360 g tensile loading. The spherical probe experiences a negative force when it is initially compressed against the adhesive tape. When the probe reaches the desired displacement, it stops for 3 s before retracting. The probe returns to its original position and continues retracting, causing positive adhesive force. The probe eventually releases from the adhesive tape, causing the sharp drop seen in Fig. 2.

The brittle separating behavior exhibited by the tape containing the 1 μm thick adhesive layer differs from typical tack curves, which show a plateau before complete separation. The test was repeated under various tensile loadings, and all results show similar brittle behavior with differing separation forces. The maximum separation force F_{sep} obtained in Fig. 2 is plotted in Fig. 3, in terms of compressive force F_{comp} during initial contacting of the probe. Regardless of the applied tension, larger compressive