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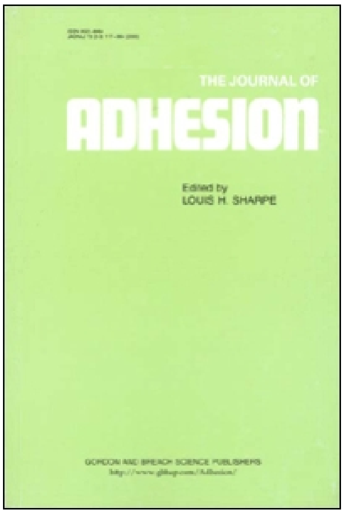

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Interfacial Contact and Bonding in Autohesion

V—Bonding of "Flat" Surfaces

by

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ABSTRACT

All surfaces, when viewed under the microscope, are found to be rough. When the so-called "flat" surfaces are bonded together, the initial contact is only at the high points in the surface. This contact increases with time and the rate of contact establishment is a function of surface roughness and the viscoelastic properties of the material.

A surface study of the "flat" compression-molded surface is made. The profiles are generated by tracing the surface with a stylus. The Interference Microscope is used to study the region in the vicinity of an asperity.

The surfaces are approximated to be composed of simple spherical segments. The deformation is conceived of as a two-stage process. The first stage of easy deformation controls the initial bond strength. The initial bond strength predicted by theory agrees well with experiment.

INTRODUCTION

THE PRECEDING PAPER in this series[1] gave an experimental verification of the viscoelastic contact theory of autohesion[2]. Bonding and tensile breaking tests on flat polystyrene surfaces are described there. The plots of bond strength vs. time are given in Figure 1 for temperatures of 115 and 120°C. The initial bond strength is found, by extrapolating the curves to zero time, to be 890 and 1000 lbs., respectively, as compared to a maximum bond strength of 1300 lbs. It was suggested that the so-called "flat" surfaces may be partially curved. The initial high bond strength is, then, due to the initial contact being at the flat portions. The gradual increase in bond strength with time is due to viscoelastic deformation of the curved portion. It was, therefore, decided to look at the surface of the test piece before bonding and analyze the problem mathematically from the viscoelastic contact theory.

The so-called "flat" surface of the bonding face of several compression-molded test pieces is studied by the stylus method and the interference microscopy technique. The surfaces are found to be curved, usually with one or more hills and valleys.

J. ADHESION, Vol. 2 (January 1970), p. 23

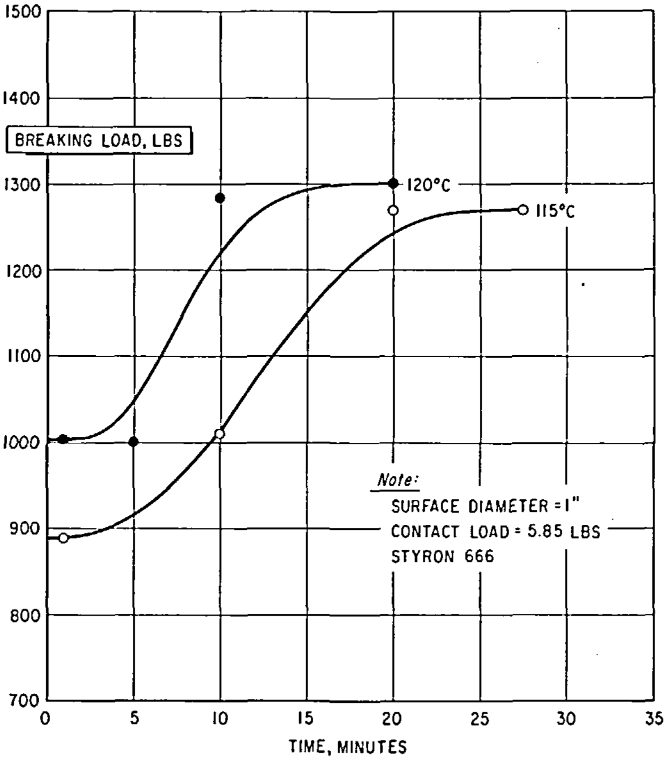

Figure 1. Plot showing variation of the bond strength with time for "flat" surfaces in contact. Curves are shown for two different temperatures.

By approximating the surface to be composed of several spherical segments, the autohesion problem is analyzed mathematically. These segments would gradually deform into cylinders passing through the stages of truncated sphere and truncated cone, respectively. It is found that at the temperature of bonding of 120°C for polystyrene, spherical surfaces deform into cylinders in less than 1/100 of a second. Since this deformation is very fast, it appears as if the surfaces are partially flat, resulting in a high initial bond strength. The calculated value of this bond strength at this stage is very close to the observed initial bond strength. This stage of easy deformation, where the individual asperities deform independently, may be called the first stage of deformation. At the end of this stage, the resulting surface consists of cylinders in contact with each other. Deformation of these contacting cylinders under compressive load is confined and would be rather slow. The cylinders have to flatten out and fill the void space between them. It is also possible that air may be trapped in these spaces which will make complete contact virtually impossible. This stage of difficult deformation may be called the second stage of deformation. This is a very complicated problem and is being analyzed currently.

SURFACE STUDIES

1. Stylus Method

Here the sample is mounted on a stage which moves horizontally under a diamond needle stylus. The stylus is attached to the vertical iron core which moves in the coil of a linear variable differential transformer. The output of the transformer coil is amplified before feeding into a recorder. Figure 2 shows three of the typical profiles generated. The profiles have been corrected for level difference between the two ends of the test piece due to variation in thickness.

2. Interference Microscopy Technique

This method is described in detail in another paper[3]. For a general reference, the reader is referred to the book by Tolansky[4]. The bonding surface and an optical flat are coated simultaneously with aluminum to give the same reflecting properties. The coating thickness is such that the optical flat is still partially transmitting.

The arrangement used for producing interference fringe is sketched in Figure 3. Monochromatic green light of 5500Å wavelength is employed. The surface and the optical flat are placed together such that the reflecting surfaces face each other. The light coming from the top is partially reflected from the optical flat coating and is partially transmitted. This

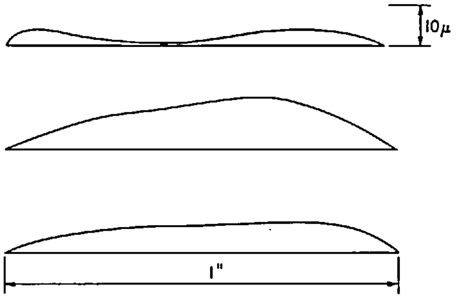

Figure 2. Three of the typical profiles generated by the stylus method. The profiles have been corrected for level difference between the two ends of the test piece.

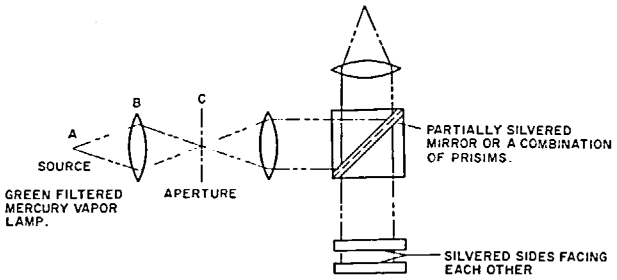

Figure 3. Schematic sketch of the arrangement used for interference microscopy. Wavelength of light used is 5500Å.

transmitted light is then reflected back from the surface and, depending on the difference in levels of the two, will interfere with the light reflected from the optical flat. This results in interference fringes where all the points at the same level are marked by a single fringe. The difference of level between two consecutive fringes is equal to half the wavelength of light.

Figure 4 shows the interference topograph of the surface in the region of a hill on the test piece. The picture is made by superimposing several topographs.

MATHEMATICAL ANALYSIS AND RESULTS

As pointed out previously, the surface may have more than one asperity. The average height of these asperities is about 10 microns. For the sake of simplicity in mathematics, it will be assumed that asperities are in fact spherical segments. Thus, a typical compression molded surface about one inch in diameter may be conceived to consist of 3, 4, or 7 spherical segments, as shown in Figure 5. A single spherical segment is shown in Figure 6. From this figure, the radius of the sphere may be calculated. Thus,

$$R^2 = b^2 + \rho^2 \qquad (1)$$

where:

$$b \doteq R - a \qquad (2)$$

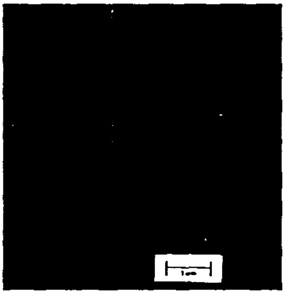

Figure 4. Interference fringe micrograph of the surface region in the vicinity of an asperity. The picture is made by superimposing several individual micrographs.

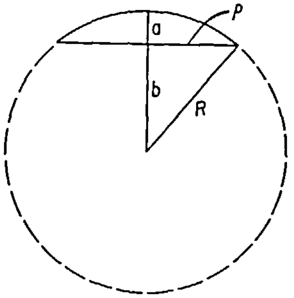

Figure 6. A single spherical segment showing its dimensions.

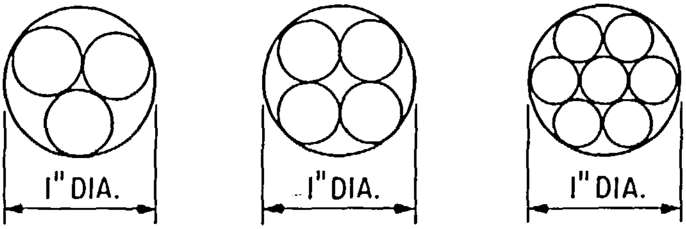

Figure 5. Illustration of the model used for mathematical analysis. Figure shows three, four, and seven spherical segments composing the surface.

Substituting (2) in (1), we get

$$R^2 = (R - a)^2 + \rho^2 \tag{3}$$

which yields

$$R = \frac{a^2 + \rho^2}{2a} \tag{4}$$

For $a = 10\,\mu$

and

$$\rho = 0.5 \text{ inch.}$$

the value of R is calculated to be $= 810$ cm., approximately.

When two surfaces of the type shown in Figure 5 are brought together at a certain temperature and under a certain load, the spheres will deform to become cylinders. Assuming that the volumes remain constant, the time to deform may be calculated from the theory outlined previously[2]. Length of the equivalent cylinder may be obtained by referring to Figure 7.

$$\text{Volume of the spherical segment} = \frac{\pi}{6} a\,(a^2 + 3\rho^2) \tag{5}$$

$$\text{Volume of the Cylinder} = \pi\rho^2 l$$

Equating (5) and (6) yields the length l of the cylinder to be (6)

$$l = \frac{a}{2} + \frac{a^3}{6\rho^2} \tag{7}$$

The bond strength may, then, be calculated from the area of contact and the tensile strength of polystyrene. Figure 8 shows the plots of bond strengths vs. time for 3, 4, and 7 spherical segments. The maximum bond strength in the three cases is 570, 620, and 1270 lbs., respectively.

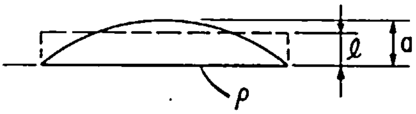

Figure 7. Equivalence of a spherical segment and the resulting cylinder after deformation.

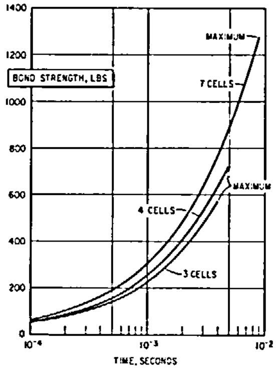

Figure 8. Plots of calculated bond strength vs. time for a temperature of 120°C. Plots are given for 3, 4, and 7 spherical segments.

DISCUSSION

Compression-molded "flat" surfaces are found to be curved. The stylus method reveals that there may be one or more hills and valleys in the one-inch diameter bonding surface of the test piece. The interference microscopy technique gives a topograph from which one may obtain the entire profile of the surface. Such a method has been developed and has been described in another place[3].

The viscoelastic contact theory developed previously is employed to analyze the autohesion of such "flat" surfaces. It is assumed that the surface may be approximated by simple spherical segments. This facilitates mathematical analysis of the problem.

The deformation, in itself, is a two-stage process. The first stage involves easy deformation of spherical segments until they become contacting cylinders. During this stage, the segments successively pass through geometric shapes of truncated spheres and truncated cones. The second stage should be slow due to confined deformation by compression of contacting cylinders. This problem is very complicated and is being tackled at the present time.

The first stage of deformation of polystyrene at 120°C, under a contact load of 5.85 pounds, takes about 1/100th of a second (Figure 8). The calculated bond strength value is very close to the measured initial bond strength for a time of one minute. Since the first stage of deformation is so fast, it appears that initial high bond strength value is due to an apparent, initially flat portion of the surfaces.

The gradual rise in bond strength at longer times involves the second stage of deformation. This is a confined type of deformation and requires filling up of the void space. Since compression of an assembly of contacting cylinders is a slow process, the overall operation is naturally slow. Moreover, there is a possibility of trapping air in pockets between the cylinders, which will make the achievement of complete contact impossible.

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