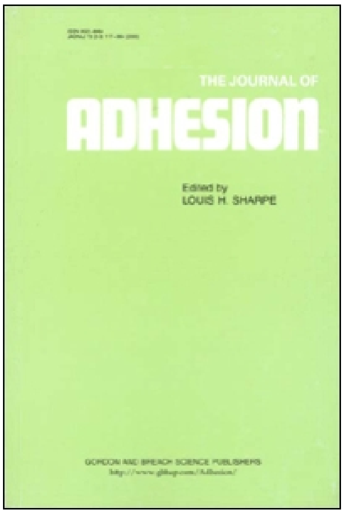

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Interfacial Contact and Bonding in Autohesion

IV—Experimental Verification of Theory

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ABSTRACT

A two-stage theory of autohesion, consisting of contact establishment as the first and bond formation as the second stage has been proposed previously. The shape of surfaces and their viscoelastic deformation are the controlling factors.

An experimental verification of the theory is obtained by performing bonding and tensile breaking tests on known cylindrical and "flat" surfaces. The test pieces are compression-molded polystyrene. Bonding is done at known temperatures, under known contact loads, and for known lengths of time. The experimental results agree well with those predicted by the theory.

INTRODUCTION

A TWO-STAGE-THEORY of autohesion has been proposed previously [1, 2, 3].In the first stage, the contact between surfaces at the interface is established. The surfaces deform under the contacting pressure. The shape of surfaces and viscoelastic properties of the material at bonding conditions are the controlling factors. In the second stage, a bond is established and, for polymers like polystyrene, intermolecular forces are the predominant ones.

The theory has been worked out for polystyrene where the relative bond strengths are calculated as functions of time, temperature, and load. Elastic-viscous-viscoelastic analogy developed by Alfrey and Gurnee[4] was used to calculate the contact and a 6-12 Lennard-Jones potential to calculate the intermolecular interfacial bonding. Specifically, the theory was applied to a polystyrene surface consisting of cylindrical segments.

An experimental verification of the theory is given here. Bonding and breaking tests are performed on the following two types of surfaces generated in the laboratory conveniently:

(i) Flat

(ii) Cylindrical.

It may be remarked that, in fact, it is not possible to generate a really flat surface since all surfaces are rough on a microscopic scale.

Compression-molded test pieces are bonded at known temperatures and pressures for varying lengths of time. The bonded assembly is then pulled apart in tension to obtain its bond strength. Measured bond strength values agree well with those predicted by the theory.

EXPERIMENTAL PROCEDURE

Test Piece:

The test pieces were designed so that they could be loaded in compression for bonding and pulled apart in tension for measuring the bond strength. Figure 1 shows the overall shape of the test piece. The bonding face of the piece could be either flat or have cylindrical serrations. As shown in Figure 2, the serrations are 0.02 inches in diameter and their center lines are 0.04 inches apart. Figure 3 is a photomicrograph of the section of the test piece taken perpendicular to serration direction. Figure 4 is a top view of the serrated bonding face.

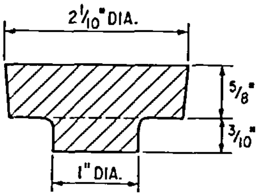

Figure 1. Cross-section of the compression-molded test piece designed for bonding and tensile breaking.

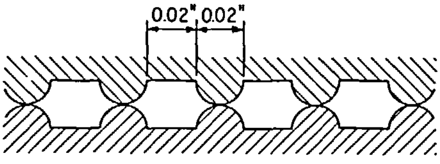

Figure 2. Contact of surfaces made up of cylindrical segments (serrations).

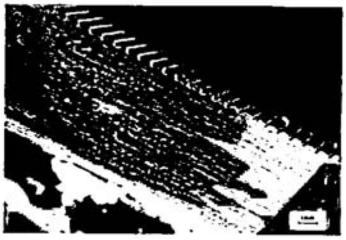

Figure 3. Photomicrograph of the cross-section of serrated test piece. The piece is cut normal to the serrations axes.

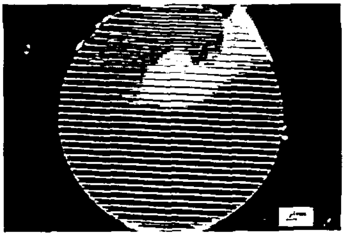

Figure 4. Photomicrograph showing top view of the serrated bonding face. The serrations are all parallel to each other.

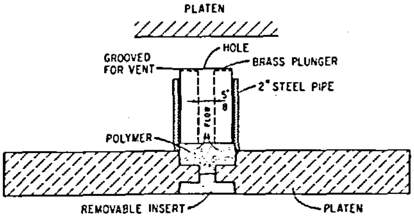

Figure 5. Arrangement used for compression molding of the test piece.

The test pieces are compression-molded from polystyrene pellets by an arrangement illustrated in Figure 5, The molding plate, with an insert carrying the impression of the surface (flat or cylindrical), is put between the hot platens of a compression molding machine. The plate has an arrangement of holes for carrying steam for heating and water for cooling. The samples are cooled gradually after molding to avoid introduction of internal stresses.

Bonding and Breaking:

Bonding is done at a constant temperature in an oven mounted on the Instron machine. A specially designed device attached to the upper crosshead is used for loading the autohesive assembly as illustrated in Figure 6. Before application of the load, the specimens are conditioned for some time to bring their temperature to that of the oven. The load is kept applied for varying lengths of time. After load removal, the assembly is allowed to cool slowly to room temperature. The assembly is then pulled apart by another Instron machine using C-clamps, specially designed to avoid misalignment.

Figures 7 and 8 show the cross-section and top view of the test piece after the assembly has been pulled apart. The cylindrical serrations are flattened out.

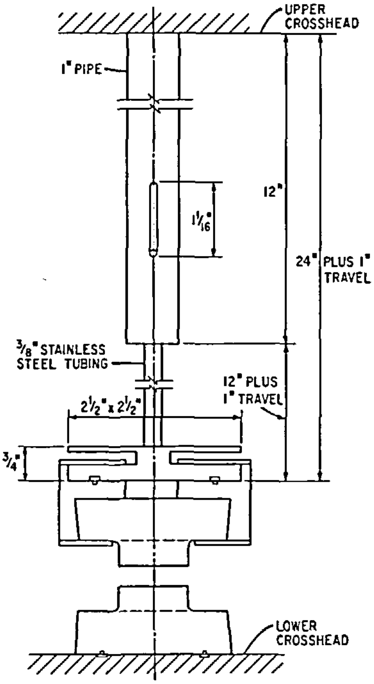

Figure 6. Arrangement used to load the autohesive assembly. The device is attached to the upper cross-head of the instron machine.

Figure 7. Photomicrograph showing the section of the test piece after bonding and breaking.

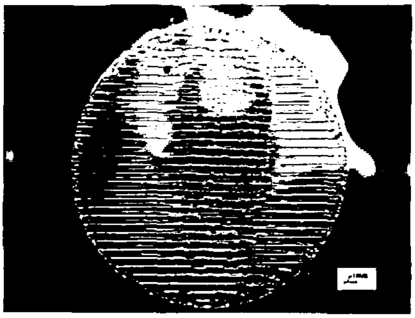

Figure 8. Photomicrograph showing top view of the test piece after bonding and breaking.

RESULTS

"Flat" Surfaces in Contact

Bonding for the so called "flat" surfaces is carried out at two different temperatures of 115°C and 120°C. The surfaces are one inch in diameter and the contact load employed in the two cases is 5.85 lbs. This load includes the weight of the assembly device in addition to the known weights added. The assembly device moves in a tube over roller bearings to reduce friction.

The assembly is allowed to remain in contact under the above conditions for varying lengths of time. The load is removed and the assembly cooled gradually to room temperature to avoid introduction of internal cooling stresses. The assembly is then pulled apart in an Instron machine to measure its strength. One or more runs are made for each time of loading, as necessitated by variation in the breaking load. The highest value determined is then assigned as the bond strength for each bond time.

Listed below are the results for the two temperatures:

Contact Load Employed = 5.85 lbs.
Temperature = 115°C

Time Minutes	Maximum Breaking Load Lbs.
1	890
10	1010
20	1270
30	1270

Temperature = 120°C

Time Minutes	Maximum Breaking Load Lbs.
1	1003
5	1000
10	1282
20	1300

The results are plotted in Figure 9 where the variation of Bond Strength with Time of Contact is shown for both these temperatures of 115°C and 120°C.

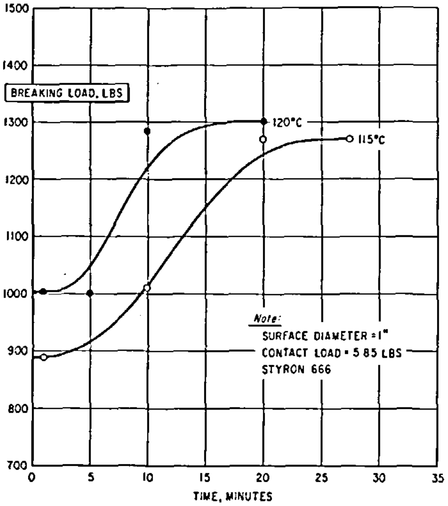

Figure 9. Plot showing variation of the bond strength with time for "flat" surfaces in contact. Curves are shown for two different temperatures.

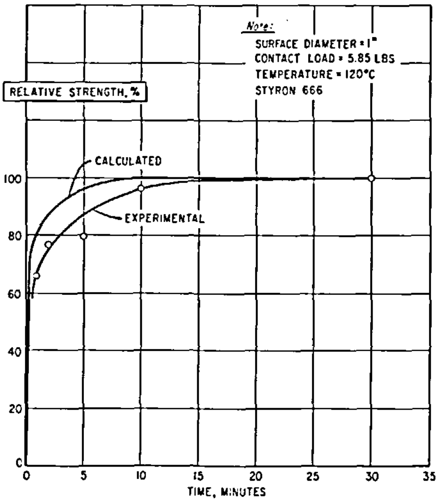

Figure 10. Plots showing variation of the relative bond strength with time for cylindrical serrated surfaces. Both calculated and experimental curves are shown.

Cylindrical "Serrated" Surfaces in Contact

The tests for these "serrated" surfaces of known shape are conducted for a temperature of 120°C only and for a contact load of 5.85 lbs., as described previously. Once again the maximum breaking load observed for each loading time is assigned as the bond strength for that time. The relative bond strength is obtained by considering the bond strength for 30 minutes loading time to be 100%.

The results are listed below as:

Contact Load Employed = 5.85 lb.
Temperature = 120°C

Time Minutes	Maximum Breaking Load Lbs.	Relative Bond Strength %
1	571	66.0
2	666	77.0
5	690	79.8
10	836	96.6
30	866	100

The relative bond strength is also calculated from the theory outlined previously. This requires the use of viscoelastic contact theory and the viscoelastic creep properties of the material. The calculated results are listed below:

Time Minutes	Relative Bond Strength %
1	81.07
2	87.34
3	91.16
4	93.94
5	96.14
6	97.97
7	99.55

Figure 10 shows the variation of relative bond strength with time of contact. Both calculated and experimental values are plotted for the sake of comparison.

DISCUSSION

The test pieces are carefully compression-molded from polystyrene pellets to avoid introduction of orientation in the surface. The molding plate and the insert for the surface are designed and carefully machined to eliminate eccentricities which could result in misalignment of test pieces in bonding and breaking test. For the same reason, the bonding assembly is designed to have alignment pins. A circular cross-section test piece was selected to avoid stress concentration effects resulting from corners.

It has been attempted to lower the effect of these factors but it cannot be eliminated entirely. Besides, additional error could be introduced in the breaking test if the bonded assembly is not aligned properly. Specially designed clamps are employed to reduce this effect. It is still possible, however, for the entire assembly to distort during the bonding process.

All these factors would tend to lower the breaking strength of the assembly. For this reason more than one test is performed for each time length of bonding. The highest value of the breaking load is taken as the representative bond strength. The number of tests to be performed is determined by the spread in values and their relative magnitude as compared to the neighboring time value.

For the so-called "flat" surfaces, the results are shown for two temperatures in Figure 9. The curves do not start from an initial zero bond strength value. This could be due to the fact that surfaces are partially flat to begin with. First of all, flat surfaces do not exist, in reality. Secondly, the surfaces change in shape due to thermal variations during the course of testing, such as cooling after molding, conditioning before bonding, and the following cooling.

The initial contact is, however, at the flat regions which results in a certain initial bond strength. As deformation of asperities takes place with time, the contact area changes, which results in an increased bond strength as indicated by the increasing slope of the curves. Finally, when no more deformation can take place, the bond strength has reached a maximum which results in a gradual flattening of the curves.

The curve for the higher temperature is higher than that for the lower temperature. This is to be expected since the polymer deforms at a faster rate at higher temperature. This also results in approaching the maximum bond strength value at faster rates at higher temperatures.

The so-called "flat" surface has been studied further. This study and further mathematical analysis from the contact theory point of view forms the subject of the next paper[5].

Figure 10 shows the variation of relative based strength with time for the cylindrical serrated surfaces. Both experimental and calculated curves are shown. Relative strength is based on the maximum value obtained for a test performed for a maximum length of time. The calculated curve is obtained from the theory outlined previously[1, 2, 3].

The experimental values are slightly lower than the calculated ones. This could be due to errors in our experimental procedures, such as the shape being not truly cylindrical and the specimens being not aligned properly—both of which would result in lower bond strength values. The other inaccuracies may be due to the temperature and variation of viscoelastic properties with heat treatment.

The general trend of the curves in the two cases is the same and, in spite of the fact that so many errors may be introduced, there seems to be a good agreement between the experimental and theoretical values.

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