Yielding of adhesives

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For the stress analysis of adhesive lap joints it is necessary to know accurate values of the yield strength of an adhesive in tension, compression and torsion. Tension and compression tests for the three types of adhesives were performed. Yield strength for compression was determined by the recovery tests for which the irreversible deformation did not set in. For tension it was proposed that the change of Poisson's ratio with strain should give an accurate indication of the yield strength.

1. Introduction

In the design of an adhesively bonded lap joint, as shown, for example, in Fig. 1, the designer has to calculate its load capacity before irreversible deformation sets in in an adhesive or adherents. Assuming that the weakest component in such a joint is the adhesive, stress analysis of such a system was made by the authors [1]. It was found that the failure of a joint is not initiated, as is generally assumed by shear stresses, but by the biaxial normal stresses at the centre of the leading edge of an adhesive. The enlarged section of the spew of an adhesive, showing the area with the highest concentration of stresses, in shown in Fig. 2.

There are many other designs of adhesive joints in which a complex state of stress occurs [2], and for such cases an accurate yield criterion should be applied [3]. For a symmetrical lap joint shown in Fig. 1, a yield criterion for a complex state of stress was considered and for the verification in one quandrant, tension and compression tests of the adhesives were performed.

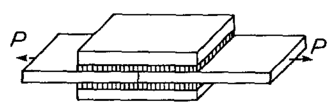

Figure 1 Adhesively bonded symmetrical lap joint.

2. Experimental procedure

Three types of commercially available adhesives were used representing: (a) high strength and low ductility (EA9320); (b) low strength and high ductility (Multron R-221-75/Mondur CB-75); (c) moderate strength and moderate ductility (EC2216 B/A).

Specimens for tension and compression were made by mixing the adhesives in an airless mixer, in order to avoid formation of bubbles, and then poured into open moulds. The tension specimen had a dog-bone shape with a gauge length measuring 35 mm × 3 mm. The compression specimens were of a square cross-section 10 mm × 10 mm and 35 mm long. The tests were conducted at room temperature and at the highest speed of the cross head of an Instron testing machine which produced a strain rate of $0.0283\ \text{sec}^{-1}$. Tension specimens were also used for the measurement of Poisson's ratio against strain. Strain was measured with strain gauges on specimens made from adhesive a, and an extensometer was used for the other adhesives. Adhesive c was used in addition to determine the effect of strain rate on the shape of the stress–strain curves and on the variation of Poisson's ratio. Both tension and compression specimens were allowed an arbitrary three days' relaxation and the load, after this period, when the irrecoverable strain has set in, was marked for the determination of the yield stress.

3. Results

A typical curve, showing change of Poisson's ratio with strain for Adhesive c, is shown in Fig. 3.

Fig. 4 shows stress–strain curves for three adhesives in tension. All adhesives displayed similar behaviour of Poisson's ratio with strain, i.e. all three curves had a maximum where the value of Poisson's ratio was closest to 0.5. Crosses on the stress–strain curves are marked for those values. In compression the Poisson's ratio did not display a maximum; it increased almost to the point of failure of the specimen.

Fig. 5 shows the stress–strain curves of three adhesives in compression. Crosses this time mark the yield stress determined by the strain recovery experiments.

Finally, Fig. 6 shows three stress–strain curves for Adhesive c at three different strain rates. Crosses on the curves mark the maxima of Poisson's ratios.

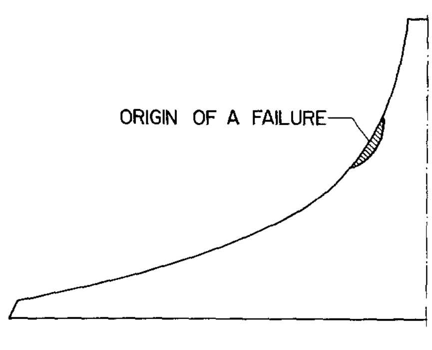

Figure 2 Spew of the adhesive showing origin of a failure.

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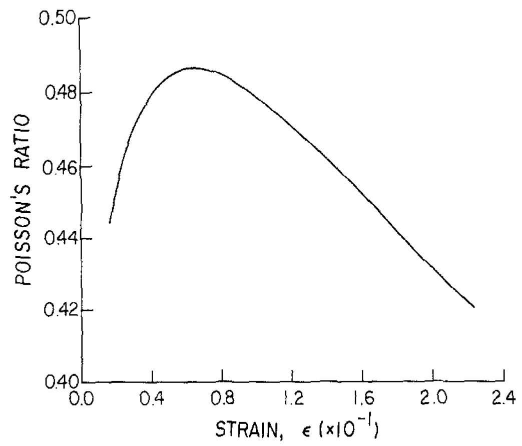

Figure 3 Variation of Poisson's ratio with strain for Adhesive c (EC2216B/A).

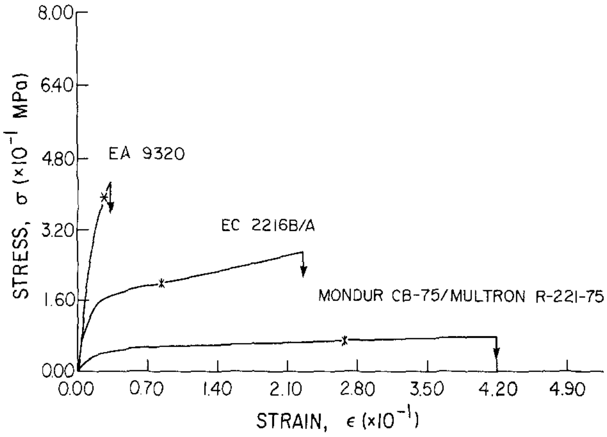

Figure 4 Stress–strain curves for three adhesives in tension. Yield and fracture points marked.

4. Discussion

The determination of the yield strength from the non-Hookean stress–strain curves presents some difficulty. Two methods generally used are: yield strength determined by the point of the intersection of lines approximating the two distinctly different slopes of the curve and the 0.3% offset method. A more accurate method, used in this investigation and recommended by others [4], is the measurement of the strain recovery and the assumption that the yield strength is at the onset of unrecoverable deformation. Compression curves in Fig. 5 show the yield strength determined by this method and it is quite clear that the values are much higher than those obtained by conventional methods.

Fig. 4 shows tension curves on which crosses mark the strains at which the Poisson's ratio peaked to its maximum. It is interesting to note that when the strain recovery experiments were performed for determination of yielding, the values were within the experimental error of the same crosses. Thus, it may be postulated that a faster and equally accurate method for determining yield strength is the measurement of the variation of Poisson's ratio. From the fact that the Poisson's ratio reaches its maximum and then it starts to decline again, it is reasonable to postulate that at its maximum point, irreversible deformation starts to occur. The reason for this assumption is that the Poisson's ratio is the measurement of a materials compressibility or expandability, i.e. the lower the Poisson's ratio, the higher the compressibility or expandability of a material. Thus, following the curve in Fig. 5, it is possible to reason that the volume of the specimen tested was increasing up to the point where Poisson's ratio was at its maximum; at about that range the rate of change in the volume decreased almost to zero, and deformation occurred at an approximately constant volume. On further deformation the volume started to increase again and kept increasing until fracture. Similar change of Poisson's ratio was observed by Whitney and Andrews [5].

Based on the fundamentals of microstructure of polymers [6], possible microscopic explanation may be offered that, during the recoverable deformation, i.e. the ascending part of the curve, primary and secondary molecular bonds were stretched similarly to metallic bonds in metals. The maximum of the curve may indicate the limit to which those bonds may be stretched, past which molecules would slide past each other producing nonrecoverable deformation similar to the

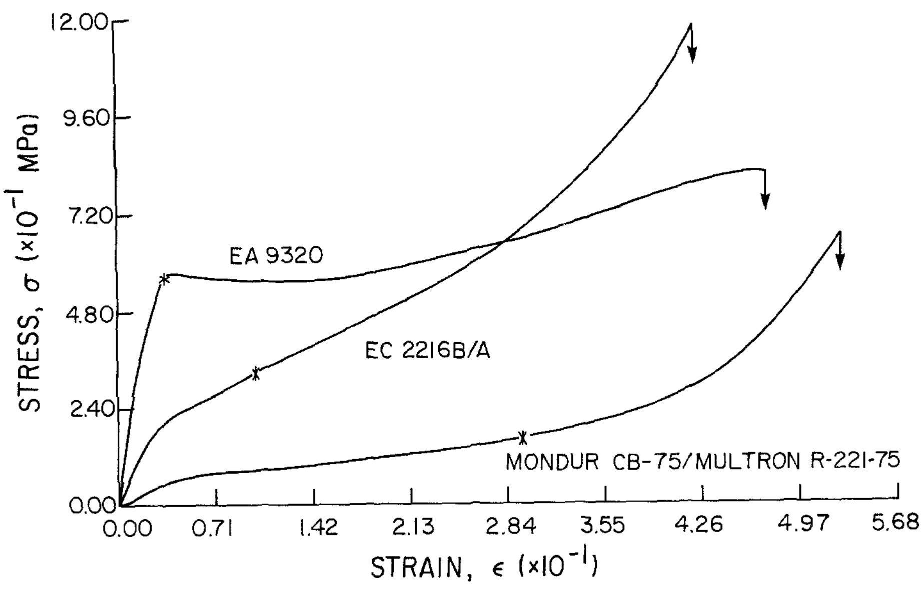

Figure 5 Stress–strain curves for three adhesions in compression. Yield and fracture points marked.

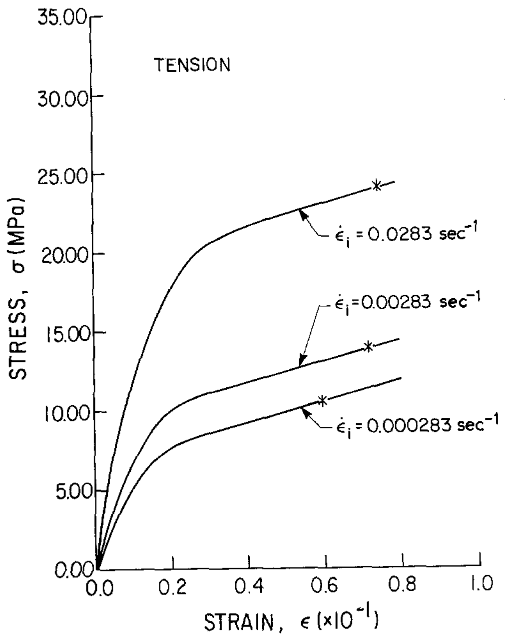

Figure 6 Stress–strain curves for the Adhesive c in tension at different strain rates. Yield points marked. (Adhesive EC2216B/A.)

irreversible motion of dislocations in metals. On further stretching, fracture of the molecular chains may occur accompanied by the formation of microvoids, coalescence of the microvoids and finally macroscopic fracture. There is also similarity with the migration of vacancies and formation of microvoids before fracture of metallic materials.

It may also be pointed out that the phenomenon of whitening on the surface of the tested specimen, as reported by Kusenko and Tamuzs [7] and Bowens [8] resembled quite closely the yield strength determined by the change of Poisson's ratio.

It is a well known fact that for any stress analysis of polymers their strain rate sensitivity should be taken into consideration [9]. Fig. 6 illustrates this dependence quite adequately but it also shows another characteristic of an adhesive, that the strain at yield strength is almost strain rate independent.

5. Conclusions

1. Change of Poisson's ratio with strain may be used for the determination of the yield strength of an adhesive in tension.

2. Irreversible deformation of adhesives does not occur at constant volume, as is generally believed.

3. Strain at yielding of adhesives is almost strain rate independent.

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