DECHEMA e.V.

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4th European
Conference
on Adhesion

WCARP-1
1st World Congress
on Adhesion and
Related Phenomena

September 6-11, 1998
Kongreßhaus Garmisch-Partenkirchen/Germany

Tuesday, September 8, 1998, 10.30 - 12.30 h

1.1 A. Hartwig, K. Albinsky, U. Diekmann, O.-D. Hennemann, Bremen/D
Analysis of the surface composition of pretreated polymers by dye reactions

1.2 A.D. Crocombe, H.O. Hambly, J. Pan, S. Hadidimoud, Guildford/UK
Measurement and prediction of the strength of bonded joints exposed to moisture

1.3 H.-J. Kim, Stony Brook, NY/USA; S. Hayashi, Shizuoka/J; H. Mizumachi, Tokyo/J
Miscibility and fracture energy of probe tack for acrylic pressure sensitive adhesives

1.4 Z. Li, G. Li, H. He, M. Yu, Shenyang/PRC
The whiskers of calcium sulfate´s strengthening effect on the epoxy resin adhesives

1.5 V.V. Shibanov, I.J. Marshalok, Lviv/Ukraine
The photocuring adhesives

1.6 G. Richardson, A.D. Crocombe, S. Hadidimoud, Guildford/UK
Time dependant constitutive data and enhanced material models for adhesives

1.7 H. Kleinert, J. Gehrke, G. Hadlich, Dresden/D
Properties of bonded joints under typical conditions of use for media in mechanical engineering

1.8 M. Pröbster, Heidelberg/D
New elastic adhesives based on MS-Polymer-Technology

1.9 R. Häßler, Dresden/D
Modulated DSC (MDSC) for adhesives

1.10 R. Häßler, K. Mai, Dresden/D
Interphase characterization of joints by AFM

1.11 P.E. Dubois, C. Vittoz, J.C. Joud, Saint-Martin d´Hères/F;
M. Mantel, Ugine/F;
Wettability of metallic oxides and passive films. Application to stainless steels

1.12 J.C. Joud, P.E. Dubois, C. Vittoz, S. Roger, Saint-Martin d´Hères/F
Effect of carbon contamination on the metallic oxide wettability

1.13 J.P. Jeandrau, Saint-Etienne/F
Corona-discharge treatment of low surface-energy substrates for adhesive bonding: optimisation of parameters

1.14 D. Dengler, Landsberg/D
Fast curing adhesives answering the demands of modern production technologies

Time dependant constitutive data and enhanced material models for adhesives

G. Richardson, A.D. Crocombe, S Hadidimoud; University of Surrey UK.

Introduction

Adhesive bonding is being used increasingly across a wide spectrum of engineering industries. To facilitate this process good tools for adhesive joint design are required. Such tools may take the form of design guidelines or may be computer based failure prediction systems but in both cases their development will require detailed understanding of the adhesive behaviour.

New material models for adhesive behaviour are currently being developed at the University of Surrey. The basis for these models is extensive material test data some of which are presented here. This paper is divided into two, firstly experimental data is presented and a number of observations are made about bulk adhesive behaviour, secondly the requirement for an accurate material model are discussed.

Experimental results

Here we present results from three adhesive systems E04, E27 and E32, although we focus on the behaviour of E27. All of the adhesive discussed are two-part cold-cure epoxies supplied by Permabond. E27 is a basic epoxy, being neither filled nor toughened. E04 and E32 are both are filled systems (>10%) and E04 is rubber-toughened (6% by volume).

Constant strain/displacement rate loading

Figure 1 and Figure 2 show stress - strain responses for E27 and E32 respectively. Figure 2 also shows the transverse strain vs. longitudinal strain a single E32 flat tensile specimen. The results presented were obtained from two forms of test, flat tensile and four point bend. For the flat tensile tests clip on extensometers were used to record strain and provide a feedback signal to enable the tests to be carried out at a constant strain rate. The four point bend tests were carried out using a constant crosshead speed and strain gauges were used to measure the compressive and tensile surface strain. The reconstruction of the tensile and compressive stress - strain curves from the experimental data followed the procedure presented by Crocombe et al (1993). For all bend tests the loading rate was adjusted to give a tensile surface strain rate of around 0.1 to 1 %/min. Tensile stress - strain responses have also been obtained for E04 using flat tensile specimens tested at constant rate of

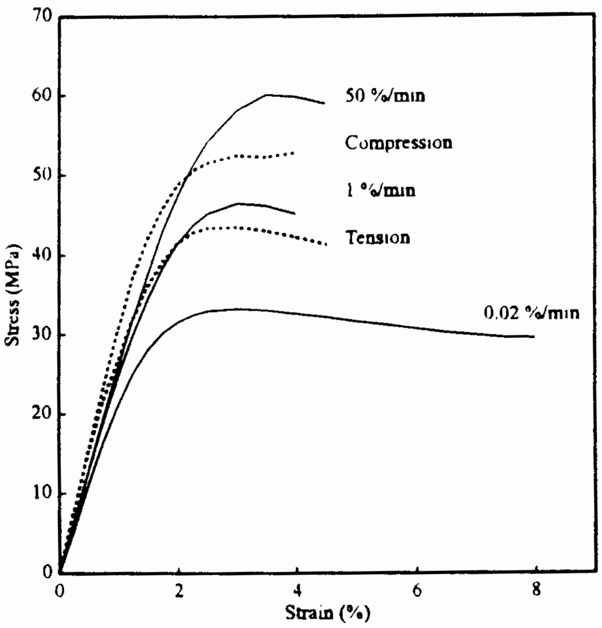

Figure 1: E27, stress - strain response

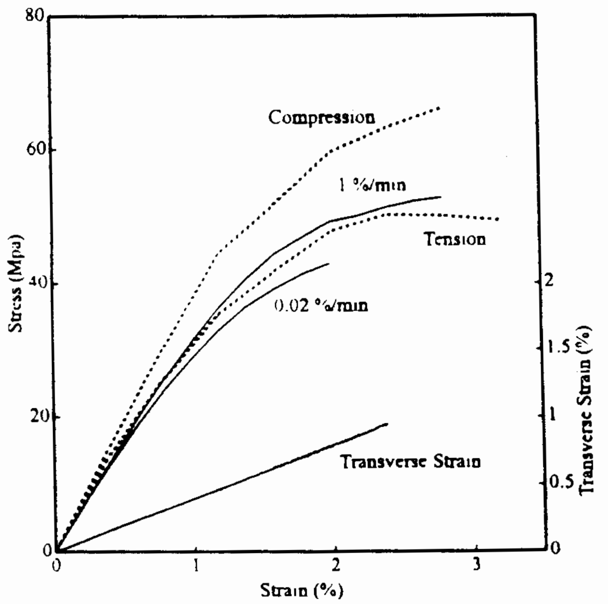

Figure 2: E32, stress - strain response

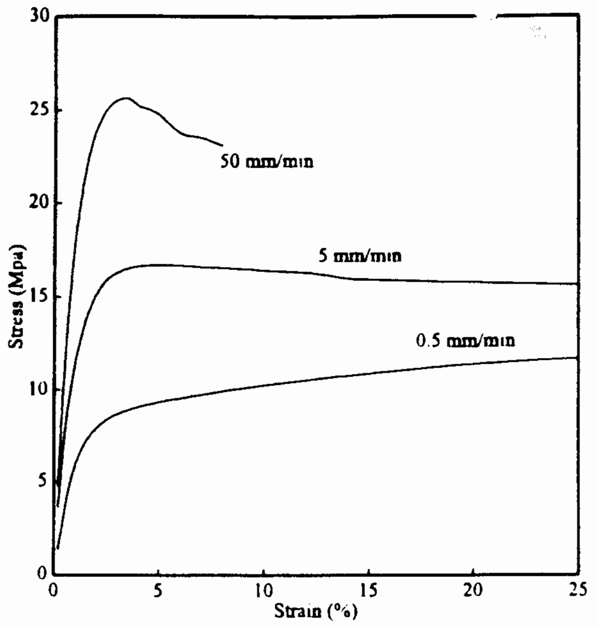

Figure 3: E04, stress - strain response

displacement. These are shown in Figure 3.

From these results is can be seen that adhesive systems can show considerable rate dependency, particularly for the unfilled and/or rubber modified systems, however for an adhesive such as E32 which is filled but contains no rubber, rate effects may be negligible. Comparing the tensile and compressive stress - strain curves in Figure 1 and Figure 2 it can be seen that the non-linear deformation of these systems is sensitive to the level of hydrostatic stress. The plot of transverse strain vs. longitudinal strain in Figure 2 demonstrates that the ratio of these strains remains constant at about 0.4 throughout a test. This is particularly interesting as it is generally stated that plastic deformation occurs under constant volume conditions and thus as non-linear deformation occurs the ratio of transverse to longitudinal strain should tend to 0.5. The deformation of the E32 specimens is only partially recoverable. The conclusion is therefore that the irrecoverable deformation is not a constant volume process.

Both the E04 and E27 results demonstrate a stress peak then a reduction in stress before failure. This could arise for a number of reasons, for example the elastic modulus may reduce as a result of damage or the material's resistance to flow may reduce, which could also be a result of damage mechanisms.

Creep loading

Figure 4 and Figure 5 show the creep response of E04 and E27 flat tensile specimens. Figure 6 shows a typical curve from each of the figures plotted on logarithmic axis.

From Figure 6 it can be seen that at a given load the creep response of E04 is of a power law form

$$\varepsilon(t) = A.t^b$$

which is typical of primary creep behaviour. The creep response of E27 is not of this form but tends

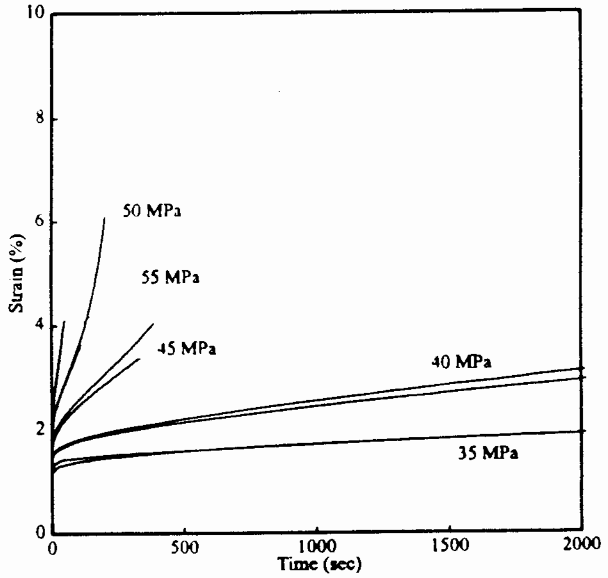

Figure 4: E27, Creep response

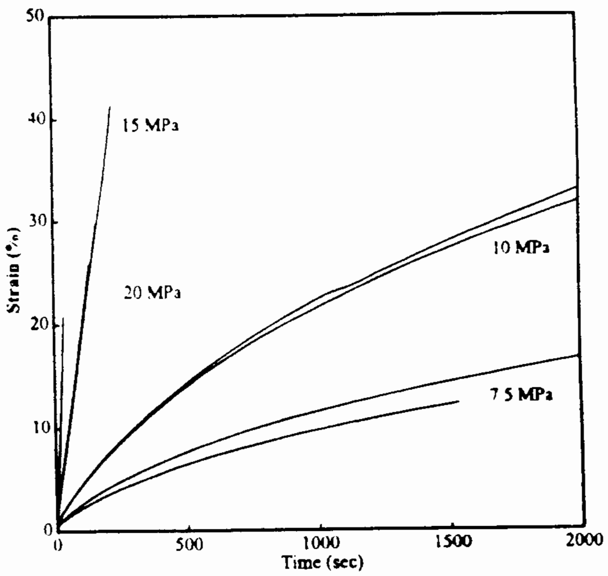

Figure 5: E04, Creep response

to have a large region where the creep strain rate is constant, see Figure 4. The creep behaviour of E27 is thus dominated by secondary creep.

As with the constant rate experimental result the creep results show a strong dependence between the stress applied to the specimen and the strain rate. Figure 7 compares the applied load and strain rate under constant strain/displacement rate and creep loading for both E04 and E27 specimens. For the constant rate tests the stress plotted is the peak stress obtained. The strain rate used for the E04 constant displacement rate tests is the instantaneous value, calculated from the measured strains, corresponding to the peak stress. The strain rates for the creep tests time averaged values over the middle of the test for E27 specimens and over the last two thirds of the test for E04 specimens. Figure 7 shows that there is a exponential relationship between the applied stress and the strain rate. This is consistent with a viscous flow theory for deformation and is typical of activated energy processes. This is diferent from the behaviour of metals where the strain rate is a power law of the applied stress.

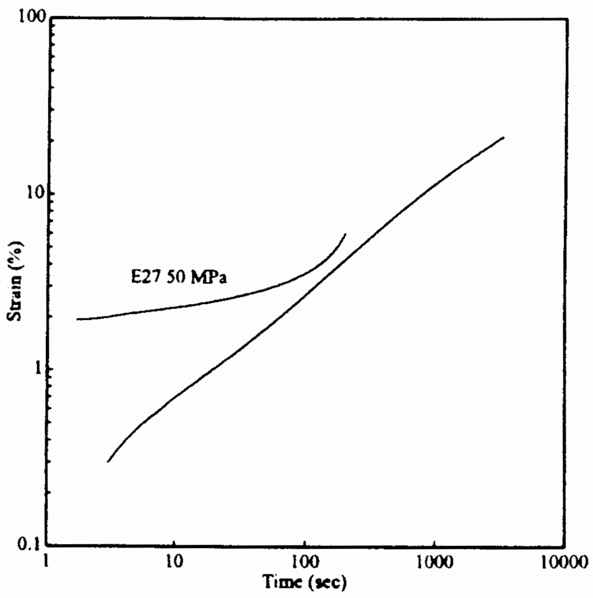

Figure 6: E04 & E27, Creep response

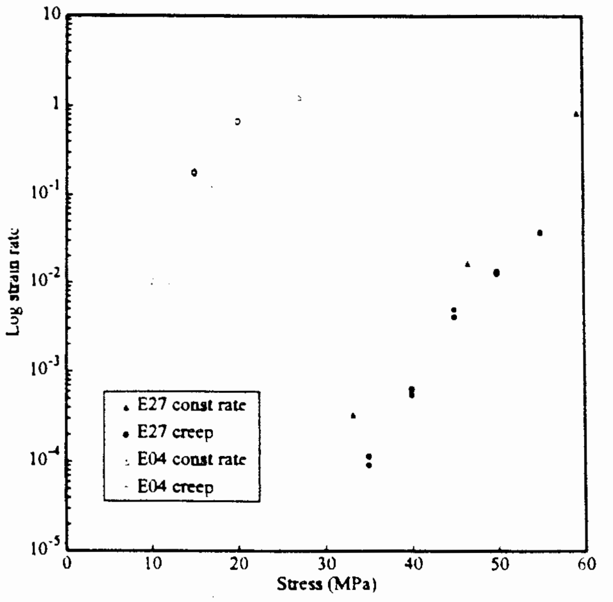

Figure 7: E04 & E27, Strain rate effects

Figure 7 also shows that there is good correlation between the constant rate tests and in the creep tests.

Cyclic loading a recovery

Cyclic loading and recovery tests have been carried out on E04, E32 and E27 specimens although the results are not presented here. These tests have indicated that a large fraction of the non-linear deformation in adhesive specimens is recoverable, typically 50 % to 80 %. It has also been observed that the elastic modulus reduces both when the adhesive is strained and when it is allowed to recover. These changes in the elastic modulus maybe related to the reduction in stress level observed in the latter stages of the constant rate tests.

Formulating a material model

From the experimental data presented above it is possible to define some characteristic of an accurate material model, as stated below.

An accurate material model requires

- An exponential flow rule
- A flow rule which is sensitive to the hydrostatic stress
- Non-constant volume non-linear deformation
- A state dependant elastic modulus
- Partially recoverable non-linear deformation

A new material model which satisfies these requirements is currently being developed at the University of Surrey.

Crocombe AD, Richardson G and Smith PA, J. Adhesion, Vol. 42, pp 209-223, 1993