FRACTURE CONTROL OF ENGINEERING STRUCTURES – ECF 6

FRACTURE STRENGTH OF AN ADHESIVE JOINT

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ABSTRACT

The F.E.M. was applied for the nonlinear analysis of a symmetrical adhesively bonded lap joint. The selected fracture criterion has predicted the fracture strength of a joint which was within 10% of the experimental results. The analysis has shown that the fracture is not caused, as it is generally believed, by shear stresses but it is initiated at the front end of a joint by the biaxial normal stresses. The strength capacity of a joint increases with its length assymptotically to its maximum value beyond which it remains constant.

INTRODUCTION

A large number of papers have been published on the distribution of stresses in the adhesive joints, but only a few of them have discussed strength of the joints. Motsumoto et al. (1) carried out experiments on three different types of joints: simple nonsymmetrical lap joints, tapered nonsymmetrical lap joints, and scarf joints. In his paper, the variation of the strength with the length depended on the configurations of the joints. For tapered and scarf joints the relationship was linear. The scarf joints were the strongest and displayed the highest rate of increase of strength with length.

Ikegami et al. (2) investigated strength of simple nonsymmetrical lap joints numerically (F.E.M.). For prediction of fracture two different criteria were applied: von Mises criterion for adhesive and adherends and an experimentally obtained "strength law" for the strength of interfaces. Good correlation was reported with the experimental results.

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According to Raevskii (3), when the adherends are properly treated failure occurs in the adhesive. Various fracture criteria for adhesive were considered (4,5), but none of them had sufficient experimental verification. For this reason the biaxial tensile tests of the adhesive EA93920 were performed, and the criterion predicting the best results was chosen.

Simplification of the geometry of an adhesive layer which neglects spew fillets and models it with square ends predicts nonrealistic, very high concentration of stresses and leads to the underestimation of the strength of a joint.

To avoid this, a number of joints were made and typical geometry of the spew fillets was used (Fig.4) in designing the finite element model.

Strength Analysis

The geometry of the joint considered is shown in Fig.1. The adherends were made of aluminum alloy T2004, (E ≅ 70000MPa), and glued together with the adhesive EA9320. True stress-strain relationship for this adhesive is shown in Fig.2.

The analysis was performed for the range of length varied between 5 and 100 mm. To determine distribution of stresses in the adhesive layer an iterative method similar to that described by Gali et al. (6) was applied. The calculations were performed with the use of the finite element program "ABAQUS", capable of stress analysis for large strains. On the basis of the failure criterion given by Eq. 4, the failing load for each length was determined.

Four different fracture criteria were considered (Fig.3):

1. Maximum normal stress criterion

$$\sigma_{max} \leqslant \sigma_{uts} \tag{1}$$

2. Modified distortion energy criterion, suggested by Bronfman et al (4), which for tension quadrant returned to

$$\left(\frac{\sigma_1}{\sigma_{uts}}\right)^2 - \frac{\sigma_1\sigma_2}{\sigma_{uts}^2} + \left(\frac{\sigma_2}{\sigma_{uts}}\right)^2 \leqslant 1 \tag{2}$$

3. Two criteria suggested for polymers by Kusenko et al (5) which for biaxial state of stress reduced to

$$A_1\sigma_1 + C_1(\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 \leqslant 1 \tag{3}$$

and

$$A_2\sigma_1^2 - C_2\ (\sigma_1^2 - \sigma_1\sigma_2 + \sigma_2^2 < 1 \tag{4}$$

where

$$A_1 = \frac{1}{\sigma_{uts}} - \frac{1}{\sigma_{ucs}} \qquad (\sigma_{ucs} = \text{ultimate compressive strength}$$

$$C_1 = \frac{1}{\sigma_{ucs}\,\sigma_{uts}} \qquad \sigma_{utc} = \text{ultimate tensile strength})$$

and

$$A_2 = \frac{1}{\sigma_{uts}^2} - \frac{1}{\sigma_{ucs}^2}$$

$$C_2 = \frac{1}{\sigma_{ucs}^2}$$

To choose the criterion providing the best results the biaxial tensile tests were performed with the use of pressurized tubular specimens (Fig.5). Five specimens were tested. It was possible to produce only one ratio of stresses $\sigma_{Hoop}/\sigma_{Axial} \cong 2/1$. However, for this particular problem it was considered sufficient.

Results and Discussion

The experimental results of the biaxial tensile test carried out for the adhesive EA9320 and graphical representation of the fracture criteria considered (Eqs. 1,2,3 and 4) are shown in Fig.3. Numerical analysis of stresses indicated that failure will occur at the free edge of an adhesive layer, (regardless of the fracture criterion applied), where biaxial state of normal stress exists. The applied adhesive near fracture has Poisson's ratio, $\gamma \cong .5$, therefore the ratio of principal stress, σ_1/σ_2, is approximately the same as in the tests. It should be clearly stated that the tests performed have not verified application of any of the criteria considered in general, but only have indicated which of them is the most applicable for the problem considered.

Fig.4 depicts end region of the adhesive layer with the localization of the origin of failure as predicted. Fig.6 shows determined experimentally strength of 15 and 30 mm long joints superimposed on the curve predicting variation of the strength with lengths ranging between 5 and 100 mm. Initially, for short joints the strength increased approximately linearly with increasing length, similarly to the predictions made by Motsumoto et al (1) for the nonsymmetrical joints. For joints longer than 15 mm the strength increased assymptotically to its maximum value and for the joints longer than 100 mm it was practically constant.

The experimental results were within 10% of the predicted value, which was generally lower.

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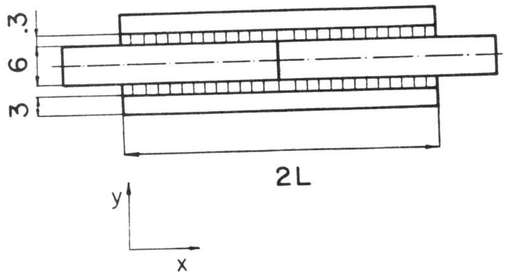

L mm
5
15
30
50
100
200
300

Figure 1. Symmetrical lap joint

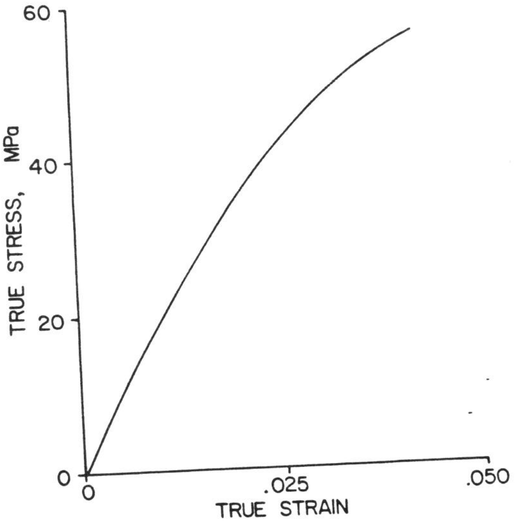

Figure 2. True stress-strain curve for the adhesive under tension

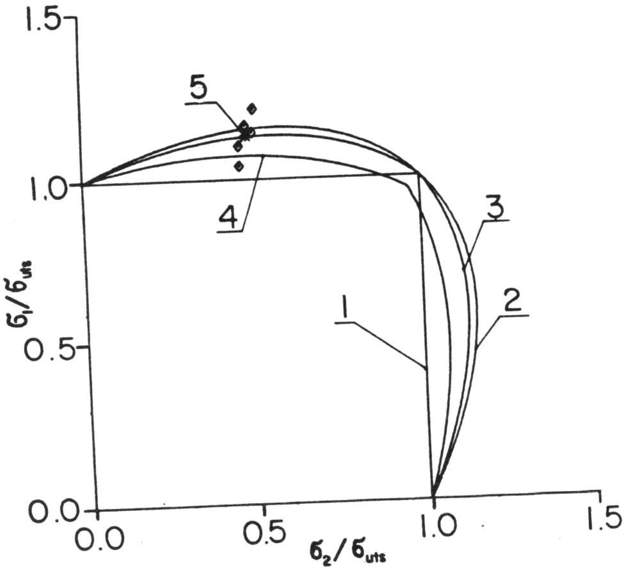

Figure 3. Fracture criteria (eqs.1-4, experimental)

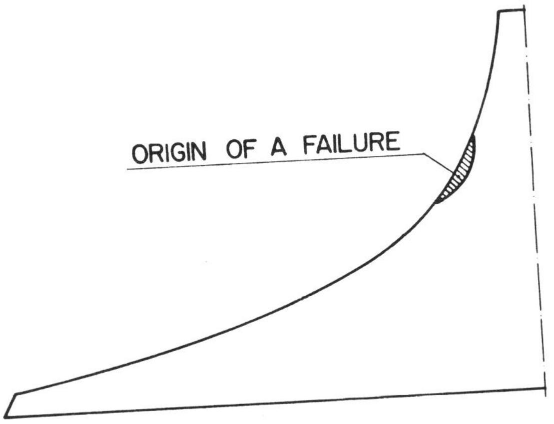

Figure 4. Typical profile of a spew fillet

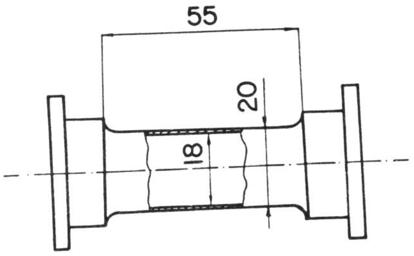

Figure 5. Specimen of the adhesive for the biaxial test

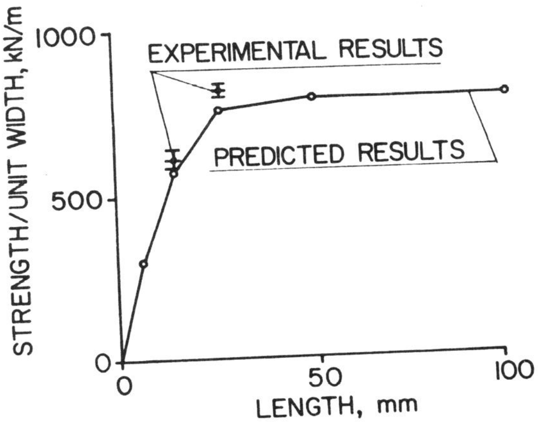

Figure 6. Strength of the joints vs. length and experimental results