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TENSILE AND TORSIONAL STRENGTH OF METAL SHAFT JOINT CONNECTED ADHESIVELY WITH CYLINDRICAL COUPLING

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1. INTRODUCTION

A traditional method of connecting two shafts is to use mechanical fastening with flanges. The method needs large space comparing with the diameter of connected shafts. Adhesive bonding is one of useful way of joining two shafts. There are a few papers on adhesive shaft joints [1]-[3]. A method of joining two metal shafts with adhesive coupling is proposed. Two carbon steel shafts with the same diameter are connected by bonding through a cylindrical coupling with epoxy resin. The method has an advantage of reducing space for joining. This paper presents the analytical and experimental results on the strength of the adhesive shaft joints with a coupling under combined tensile and torsional loads.

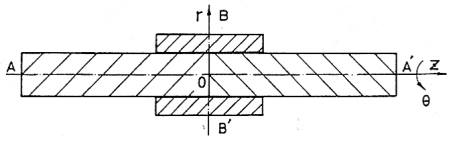
2. JOINT MODEL

Figure 1 shows a model of shaft joint with adhesive coupling. The joint consists of two metal shafts and a metal coupling. The Shafts are adhesively connected with the coupling. The materials of shaft and coupling are carbon steel, and the adhesive material is epoxy resin. The coordinate of the joint is defined as shown in Fig. 1(a). The dimension of the joint is given in Fig. 1(b). The figure is illustrated by the quarter of the joint due to the symmetry. The shaft joint is subjected to tensile load and torsional load.

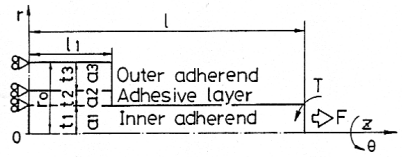
The boundary condition of the joint for the analysis is defined in Fig. 1 (b). The outer adherend and inner adherend correspond to the coupling and the shaft, respectively. The outer adherend and adhesive layer are fixed at the directions z and θ, and free at the direction r. The inner adherend is free at the directions z, r and θ. The inner adherend is subjected to tensile load and torsional load at the edge.

3. STRAIN ANALYSIS

The stress and strain distributions are computed by the elastic finite clement method under the assumption of symmetric three-dimensional condition. The material constants used in the analysis are given in Table I. The analyzed results are shown by use of the non-dimensional values of $Z = z/l_1$ and $R = r/r_0$ for the ordinates, and the non-dimensional values of $L_0 = l_1 / t_1$ for the overlapped length and $R_a = a_3 / a_1$ for the cross sectional area between shaft and coupling. Figure 2 shows the normal strain distributions in the outer and inner adherends. For the outer adherend, the strain variations on the outer surface and inner adhesive side are illustrated. For the inner adherend the strain variations on the free surface are given. The strain values increase near at Z = 1.0 in the inner adherend and the stress concentration is expected at the point. In the outer adherend, the strain values on the adhesive side and the free surface are illustrated in the figure. The strain on the adhesive side distributes uniformly in the inner region and decreases to zero at the adhesive edge. The strain on the free surface also decreases to zero at the adhesive edge approximately in linear manner. The marks in Fig. 3 are the experimental strain values, which are measured by strain gauges.



(a) Coordinate



t : Thickness
l : Length
a: Sectional area
F: Tensile load
T: Torsion

(b) Boundary condition and dimension

Fig. 1. Model of adhesive shaft joint

4. STRENGTH EVALUATION

The joint strength is evaluated by applying the strength laws of the adherend, the adhesive layer and the adhesive interfaces to the stress distributions in the joint [4]. Mises conditions are applied to the outer and inner adherends and to the adhesive layer. The adhesive strength law is applied to the adhesive interface. This strength law is experimentally determined by using butt joints of thin-walled tubes subjected to combined axial and torsional loads. The condition is represented by the following expression,

$$\left|\sigma_r / \sigma_0\right|^m + \left|\left(\tau^2_\theta + \tau^2_{rz}\right)^{1/2} / \tau_0\right|^m = 1 \qquad (1)$$

where the notations σ_0 and τ_0 are tensile and torsional adhesive strength, and m is the material constant.

The failure stress values of the adherends, the adhesive layer and the adhesive interface are estimated by applying their strength laws to the stress distributions. The minimum failure value among the adherends, the adhesive layer and the adhesive interface is defined as the initial failure strength of the joint.

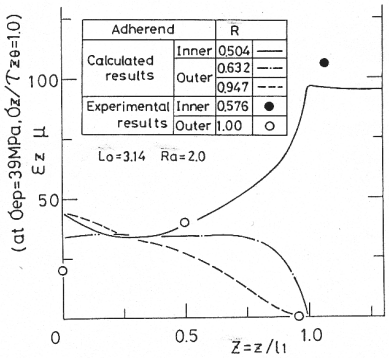


Fig. 2. Strain distributions of shaft and coupling

5. JOINT STRENGTH

Figures 3 are the joint strength under combined axial and torsional loads for different overlapped length. The stress values in the figures are the tensile and torsional stress at the initial failure in the joint. The tensile stress values are calculated by dividing the axial load at the initial failure with the cross sectional area of the shaft. The torsional stress values are the shear stress at the outer diameter of the shaft at the initial failure. The solid and broken lines are the initial failure stress in the adhesive interface. The position of the initial failure is different according to the loading condition as shown the positions A and B in the insert figure.

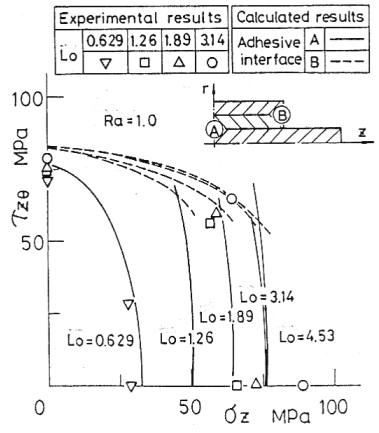


Fig. 3. Joint strength under combined loads

For short overlapped length the adhesive interface of the shaft, denoted by the position A, is the initial failure position. But, with increase of overlapped length, the critical position for the initial failure is changed according to the stress state. When the shear stress is dominant, the position B on the adhesive surface of the coupling is the initial failure position. When the dominant stress is tensile component, the critical position is the adhesive interface A on the shaft. The overlapped length is effective to increase the joint strength for the case when tensile stress is dominant. But when shear stress is dominant, the increase of overlapped length dose not effectively contribute to the increase of the joint strength. The strength is easily saturated with increase of the overlapped length. It is known that the adhesive interface in the joint is critical position for the initial failure. The joint strength will be estimated by the interfacial strength between the shaft and coupling.

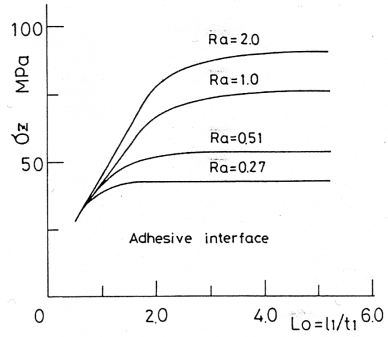


Fig. 4. Joint shear strength estimated by interfacial strength

Figure 4 is the estimated tensile strength of the joint against the overlapped length for different cross sectional areas, respectively. The effect of cross sectional ratio on the joint strength is significant as seen in Fig.4. With increase of the cross sectional ratio the joint strength increases. The strength is saturated above the overlapped length of L_0 = 2.0. The saturated strength depends on the cross sectional ratio. Large cross sectional ratio gives large saturated strength.

6. CONCLUSIONS

The strength of adhesive shaft joints is investigated analytically and experimentally under tensile and torsional loading condition. The joint consists of two steel shafts and a coupling bonded with adhesive. The materials of the shafts and the coupling are mild steel and the adhesive is epoxy resin. The stress and strain distributions in the joint are analyzed by the finite elastic method. The joint strength is estimated by applying the strength laws of shafts, coupling, adhesive layer and adhesive in terrace between shaft and adhesive coupling.

1) For combined axial and torsional loads the adhesive interface face is the critical position for the initial failure.

2) The adhesive interface of shaft surface is critical position for small cross sectional ratio. For large cross sectional ratio, the adhesive interface of shaft is critical position for dominant tensile stress and the adhesive interface for coupling is critical for dominant shear stress.

3) The joint strength for torsional load is saturated by a certain overlapped length. The saturated strength depends on the ratio of cross sectional area of shaft joint and coupling.

4) The joint strength for tensile load is also saturated by a certain overlapped length. But the overlapped length at the saturated joint strength is longer for tensile load than for torsional load.

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