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# Stress Intensity Factors of a Crack on the Interface of Adhesive and Adherents

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**Key words:** Elasticity, Interface Crack, Stress Intensity Factor, Adhesive

**Abstract.** Adhesive joints are widely used as the joints with the same or different adherents, such as in engineering and electric devices. However, because of mismatch of different materials properties, failures due to crack initiation and propagation are often observed on the interface between adhesive and adherents. Therefore, it is important to analyze stress intensity factor of crack on the interface. In this paper, the effect of material combination of adhesive and adherents on stress intensity factor and effect of the thickness of adhesive $t$ on stress intensity factor are discussed. A useful method to calculate the stress intensity factor of interface crack is presented with focusing on the stresses at the crack tip calculated by finite element method. The stress intensity factors are indicated in charts under different thickness of adhesive $t$. It is found that the intensity of singular stress $F_I$ first increases with increasing $t/W$, then decreases from about $t/W = 0.1$, and keeps constant from about $t/W = 1$, when $W$ is the width of adhesive. These results are helpful to design dimensions of devices and choose appropriate materials when adhesives are used inside of them.

## Introduction

Adhesive joints are most frequently used in numerous industrial sectors such as automobile, shipbuilding, aeronautical, etc., replacing or supplementing traditional joining technologies, such as welding or riveting. From previous experimental results, it is found that the joint strength decreases with increasing of adhesive thickness [1]. However, the reason why the joint strength decreases with increasing of adhesive thickness has not been explained explicitly. Therefore, in this paper, to explain the reason by simulation, stress distributions on the interface of adhesive and adherents have been obtained, and the effect of adhesive thickness on the intensity of singular stress will be analyzed by the finite element method (see Fig.1(a)).

Because of the mismatch of different materials between adhesive and adherents, the crack often happens on the interface. The effect of adhesive thickness on stress intensity factors has been discussed (see Fig.1(b)) .

## The effect of adhesive thickness on stress distributions along the interface

First of all the stress distribution on the interface between adhesive and adherents are studied. For adherent, SUS304 is considered , and resin is assumed for the adhesive. Figure 2 gives the stress

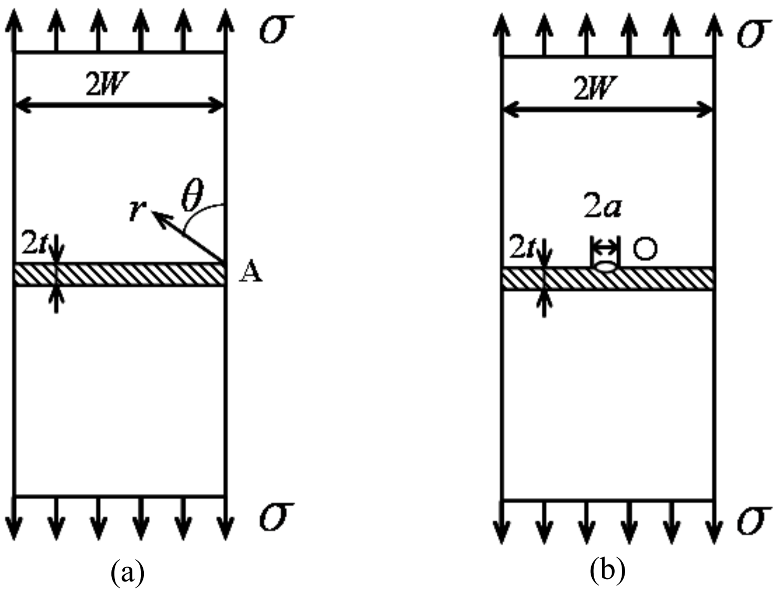


Fig.1 The adhesive joint with adherents. (a) without crack; (b) with crack

distributions when $t/W = 0.001, 0.01, 0.1, 0.5, 1, 2, 4$. It is should be noted that the stress goes to infinity at the edge of interface. It is known that the singular stress appears at the edge of interface when $\alpha(\alpha - 2\beta) > 0$, where, $\alpha$, $\beta$ are Dunders' parameters. The singular stress becomes small when adhesive thickness becomes small, and it becomes large when adhesive thickness becomes large. The stress distribution is almost the same when $t/W = 1, 2, 4$.

**The effect of adhesive thickness on the intensity of singular stress at the corner A**

As confirmed above, the singular stress appears at the edge of interface when $\alpha(\alpha - 2\beta) > 0$. To understand the effect of adhesive thickness on the singular stress, the definition of intensity of singular stress $K_\sigma$ is expressed as the following:

$$F_\sigma = \frac{K_\sigma}{\sigma W^{1-\lambda}} = \frac{\lim\limits_{r\to 0}[r^{1-\lambda}\sigma_{\theta|\theta=\pi/2}(r)]}{\sigma W^{1-\lambda}} \quad (1)$$

Here, $F_\sigma$ is the dimensionless of intensity of singular stress and $\lambda$ is the singular index.

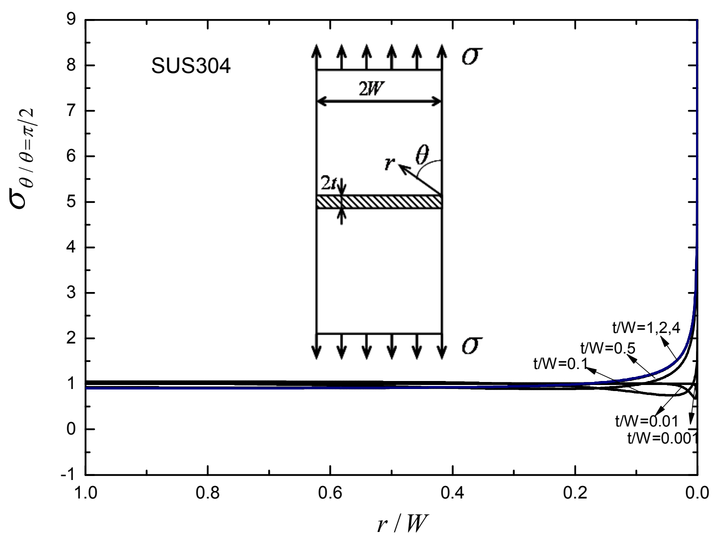


Fig.2 Stress distribution $\sigma_{\theta/\theta=\pi/2}$ along the interface with different adhesive thickness for SUS304.

SUS304 stainless, YH75 aluminum alloys, Silicon and substrate FR-4.5 are considered for adherents, and resin is assumed for adhesive. Table 1 shows the material properties of adherents and adhesive. Chen[2] has obtained the intensity of singular stress when $t/W=1$. Using the FEM, the ratio $F_\sigma / F_{\sigma/t/W=1}$ has been obtained, and Fig.3 shows the ratio $F_\sigma / F_{\sigma/t/W=1}$ with varying the adhesive thickness $t/W$. It is found that $F_\sigma / F_{\sigma/t/W=1}$ increases with increasing $t/W$ and keeps constant which is equal to 1.0, whatever the material combination is.

**The effect of adhesive thickness on stress intensity factors of the central crack on the interface**

Here, we consider an interface crack appearing at the interface. Then, the effect of adhesive thickness on the stress intensity factor will be discussed. The stress intensity factor for a very small crack at the center of interface can be estimated exactly from the stress $\sigma_y$ without interface crack [3]. Figure 4 shows the stress intensity factors $F_I$ for $a/W \to 0$ with varying $t/W$. It should be noted that $F_I$ first increases with increasing t/W, then decreases from about $t/W=0.1$, and becomes constant from about $t/W=1$.

Using the FEM method [4], stress intensity factors are calculated for $a/W=1/1620$ and $a/W=0.1$ when SUS304 is adherent. Figure 5 shows the results $F_I$ with varying t/W. The value of $F_I$ has the similar tendency when $a/W=1/1620$ and $a/W=0.1$ with $F_I$ when $a/W \to 0$. It is should be noted that $F_I$ has larger variation when $a/W$ is large.

Table 1 Material property

| | Material | Elastic Modulus/Gpa | Poissons' ratio |
|---|---|---|---|
| Adherent | SUS304 | 206 | 0.3 |
| | YH75(A7075) | 71 | 0.33 |
| | Silicon | 166 | 0.26 |
| | FR-4.5 | 15.34 | 0.15 |
| Adhesive | Resin | 2.74 | 0.38 |

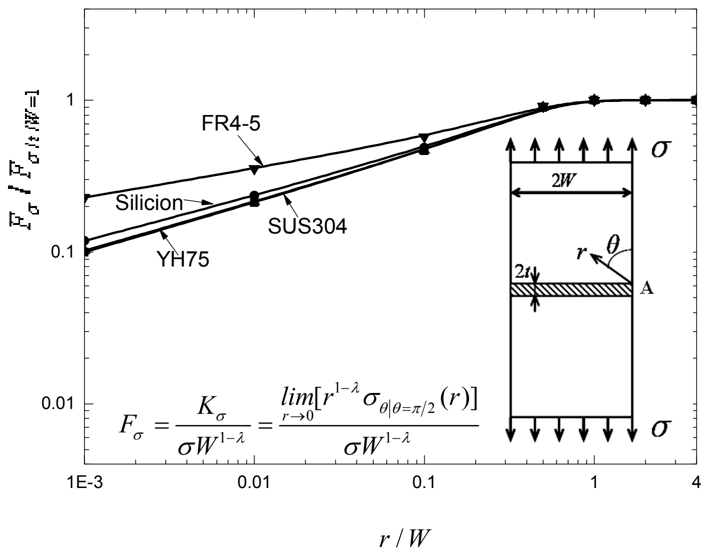


Fig. 3 The intensity of singular stress at the corner A with varying adhesive thickness

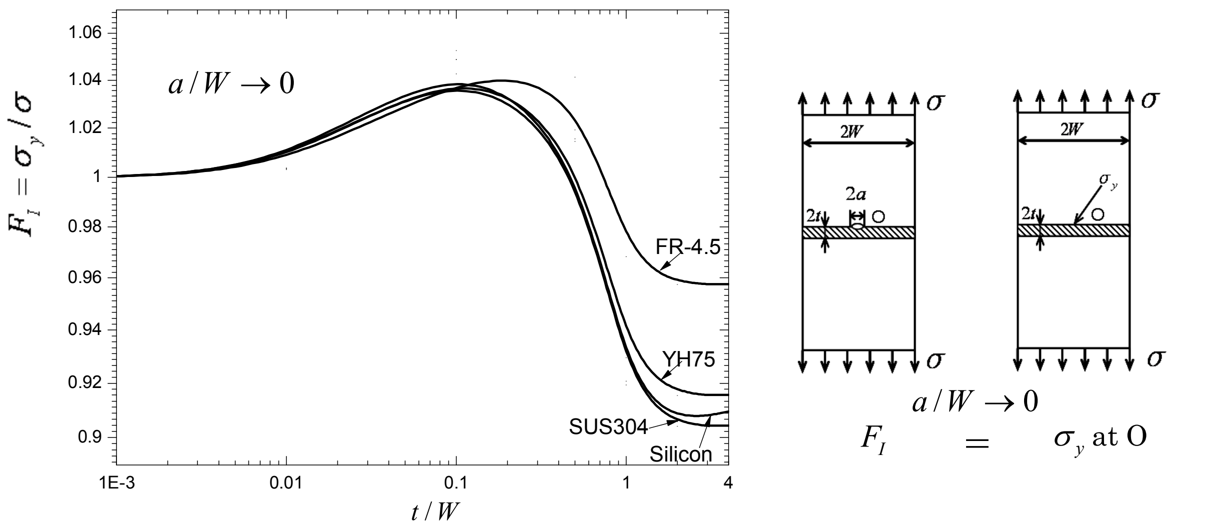


Fig.4 Stress intensity factors $F_I$ for a small central interface crack at O with varying adhesive thickness.

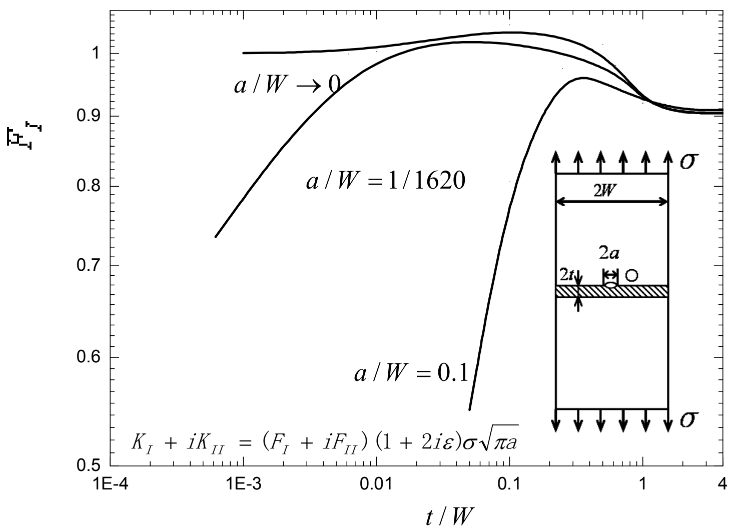


Fig.5 Stress intensity factors $F_I$ at O with varying adhesive thickness when resin is used for joining SUS304.

$$\varepsilon = \frac{1}{2\pi}\ln\left\{(G_2\kappa_1 + G_1)/(G_1\kappa_2 + G_2)\right\} \tag{2}$$

$$\kappa_m = \begin{cases} (3-\nu_m)/(1+\nu_m) & \text{(Plane stress)} \\ 3-4\nu_m & \text{(Plane strain)} \end{cases}$$

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