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How to obtain the adhesive strength for double lap joint by using single lap joint

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Abstract. The testing method of adhesive strength of lap joint is prescribed in Japanese Industrial Standard (JIS K6850). However, it has been reported that the strength of double lap joint (DLJ) is about two times larger than the one of single lap joint (SLJ). Therefore, suitable testing method has been required from industries. In this study, the equivalent conditions of strength for SLJ and DLJ are investigated in terms of the intensity of singular stress field (ISSF) appearing at the interface end. First, in order to minimize the bend effect for SLJ, the effect of the specimen geometry on ISSF and deformation angle at the interface corner is considered under the same adhesive geometry and load P. It is found that the minimum ISSF of SLJ can be obtained when the adherend thickness t_1 is large enough, and the deformation angle at interface corner is also smallest when adherend thickness t_1 is large enough. Therefore, it is necessary to use the specimen with thicker adherend thickness. Then, the equivalent conditions of strength for SLJ and DLJ is investigated by changing adherend thickness. The results show that the strength of the DLJ in JIS (t_1 =1.5mm) can be obtained by using the SLJ with adherend thickness t_1 =7mm. When the adherend thickness t_1 ≥25mm, the strength of SLJ is nearly equal to that of DLJ.

1. Introduction

Since adhesively joints are economical, practical and easy to be used, they have been widely used in a variety of industries and a number of studies of adhesive joints have been made so far[1-4]. The authors investigated the adhesive butt joint strength in Figure 1 by changing the adhesive thickness and material combination [5]. It is found that the adhesive strength of butt joint can be expressed as the critical intensity of singular stress field (ISSF) $K_{\sigma c}$ =const [5]. The adhesive strength of single lap joint (SLJ) also can be expressed as $K_{\sigma c}$ =const [6],[7].

The testing methods for the adhesive strength of lap joints are standardized by Japanese Industrial standard (JIS) [8]. Compared with double lap joint (DLJ), SLJ can be used conveniently. However, the shear strength of DLJ in Figure 2(a) is about two times larger than the one of SLJ in Figure 2(b) (see Figure 3) [9]. Therefore, in this study, the equivalent conditions of strength for SLJ and DLJ are investigated in terms of the ISSF.

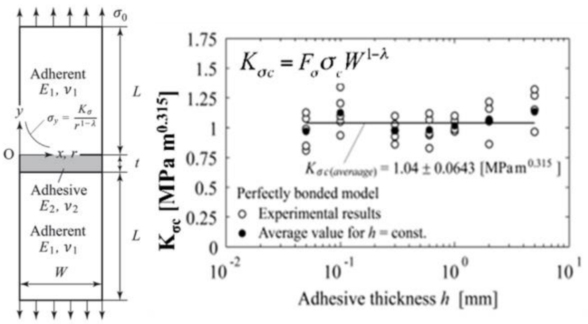
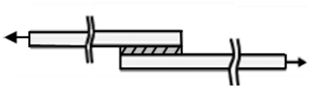
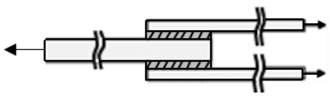


Figure 1. Adhesive strength expressed as $K_{\sigma c}$ =const for butt joint.



(a) Single lap joint (SLJ)



(b) Double lap joint (DLJ)

Figure 2. Two kinds of lap joint specimens.

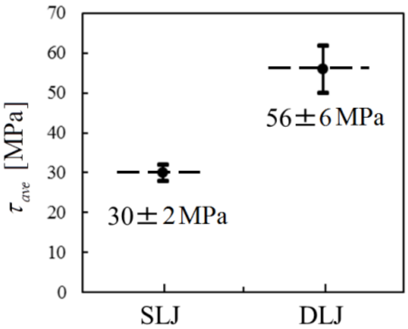


Figure 3. Adhesive shear strength for SLJ and DLJ (Adherend: S45C, Adhesive: Epoxy).

2. Pure shear testing to minimize K_{σ,λ_1}

Figure 4 shows the schematic illustration of the analysis models. It has been reported that the singularity exists near the interface corner, and the singularity depending on the singular indexes λ_1 and λ_2 at the interface. In this paper, λ_1=0.6062, λ_2=0.9989. The stress σ_θ at r direction (θ=0) can be expressed as follows. The notation r denotes the radial distance away from the corner singular point O_1.

$$\sigma_\theta = \frac{K_{\sigma,\lambda_1}}{r^{1-\lambda_1}} + \frac{K_{\sigma,\lambda_2}}{r^{1-\lambda_2}} \cong \frac{K_{\sigma,\lambda_1}}{r^{1-\lambda_1}}\left(1 + C_\sigma\, r^{\lambda_2-\lambda_1}\right) \quad (1)$$

Here, K_{σ,λ_1} and K_{σ,λ_2} are ISSFs. The values of K_{σ,λ_1} and K_{σ,λ_2} can be obtained by using the method presented in [6-7]. The ISSF can be represented with only K_{σ,λ_1} since C_σ is almost constant expressed as $C_\sigma = -5.321 \pm 0.338$.

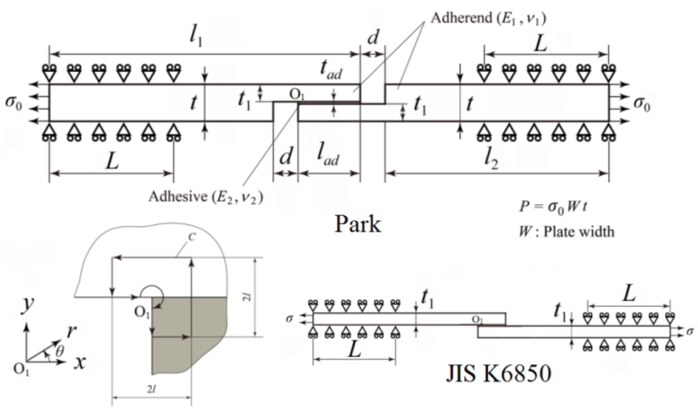


Figure 4. Analysis model and boundary condition.

The butt joint in Figure 1 is used to obtain the adhesive strength under pure tension [5] and the SLJ in Figure 2 is used to obtain the adhesive strength under pure shear. However, due to the deformation of SLJ during testing, the peeling force is applied to the adhesive region. Then the K_{σ,λ_1} at the interface corner is affected by the peeling force. Since the single lap joint testing should be done under pure shear loading, smaller K_{σ,λ_1} is desirable. Therefore, in order to minimize the K_{σ,λ_1}, the effect of the specimen geometry is considered under the same adhesive geometry and load P based on the specimen used by Park [10] in Figure 4 (Adherend: Aluminum alloy 6061-T6, Adhesive: FM73M epoxy). The total length of the specimen is 225mm, adhesive length l_{ad} =25mm, adhesive thickness t_{ad} =0.15mm, d =10mm, P =14.15N. L is fixed boundary length, t_1 is adherend thickness.

Figure 5 shows the deformation near the interface corner. In this study, the deformation angle at interface corner C will be considered to explain the deformation. Here, the deformation angle θ_C is considered by using the maximum θ_C since the value of maximum θ_C is almost constant independent of element sizes.

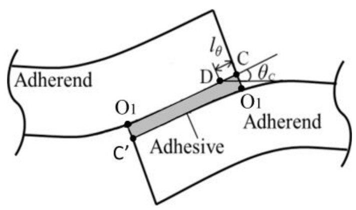


Figure 5. Deformation angle at corner edge C.

The relationship between the ISSF K_{σ,λ_1} and deformation angle θ_C for three types of models is shown in Figure 6. It is found that the K_{σ,λ_1} decreases with decreasing θ_C. This means that the changing of the ISSF can be explained by the deformation angle at the interface corner. Here, the minimum ISSF of SLJ can be obtained when t_1 is large enough($t_1 \geq$25mm), and the deformation angle at interface corner is also smallest when t_1 is large enough($t_1 \geq$ 25mm). The possible reason of minimum $K_{\sigma,\lambda_1} \neq 0$ is the existence of local surface deformation at the interface corner even for very large thickness. Therefore, it is necessary to use thick adherend.

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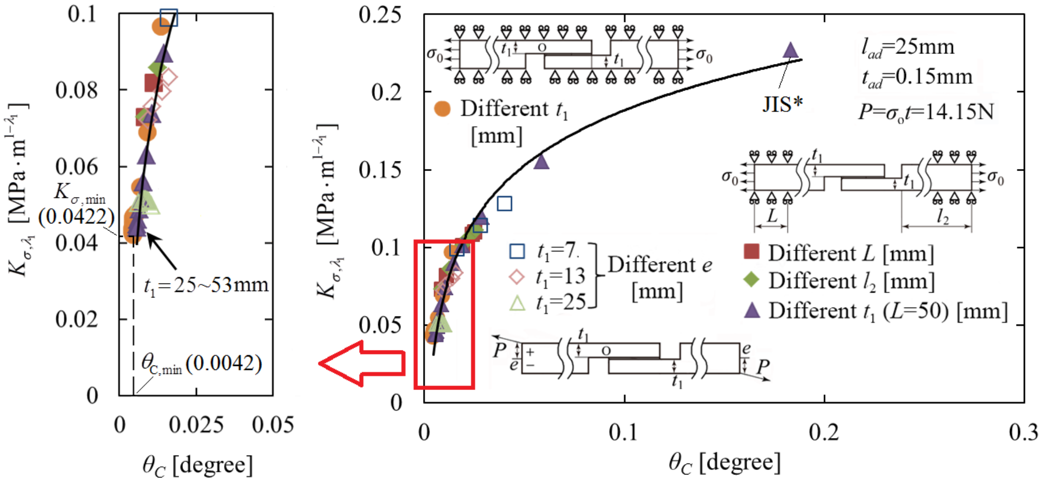


Figure 6. Relationship between K_{σ,λ_1} and θ_C.

3. Equivalent conditions of strength for lap joints in terms of ISSF

The experimental results show that the strength of DLJ is about two times larger than the one of SLJ (see Figure 7(a)) [9]. However, the critical ISSF $K_{\sigma c}$ of SLJ is almost the same as the $K_{\sigma c}$ of DLJ (see Figure 7(b)). Therefore, in this chapter, the equivalent conditions of strength for the DLJ and SLJ in Figure 8 are investigated in terms of the ISSF K_{σ,λ_1}. Here, based on the conclusions in chapter 2, the effect of the adherend thickness on the K_{σ,λ_1} is considered. Since end tab is often bonded at the ends of experimental specimens to reduce bend effect when loaded, the influence of the tab on K_{σ,λ_1} is also considered in this chapter. The same material as adherend is used for tab. The total length of the specimen is 225mm, tab length is 90mm, adhesive length l_{ad} =25mm, adhesive thickness t_{ad} =0.15mm, P =14.15N.

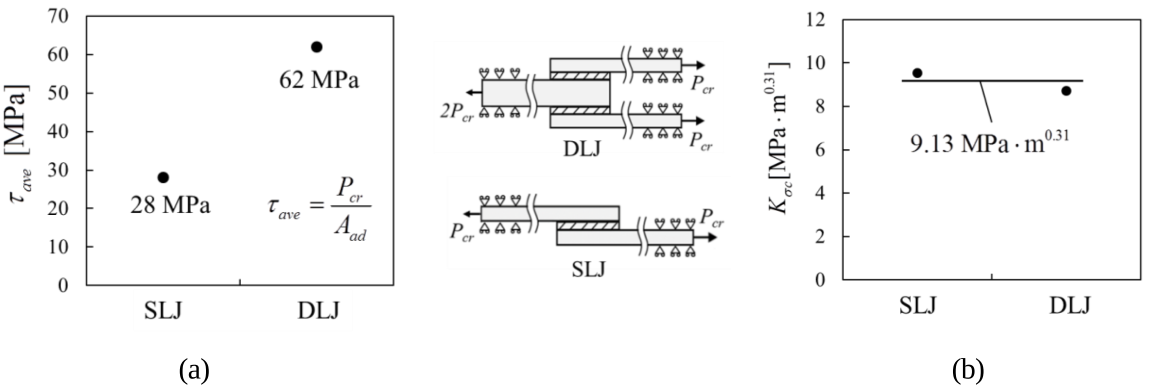
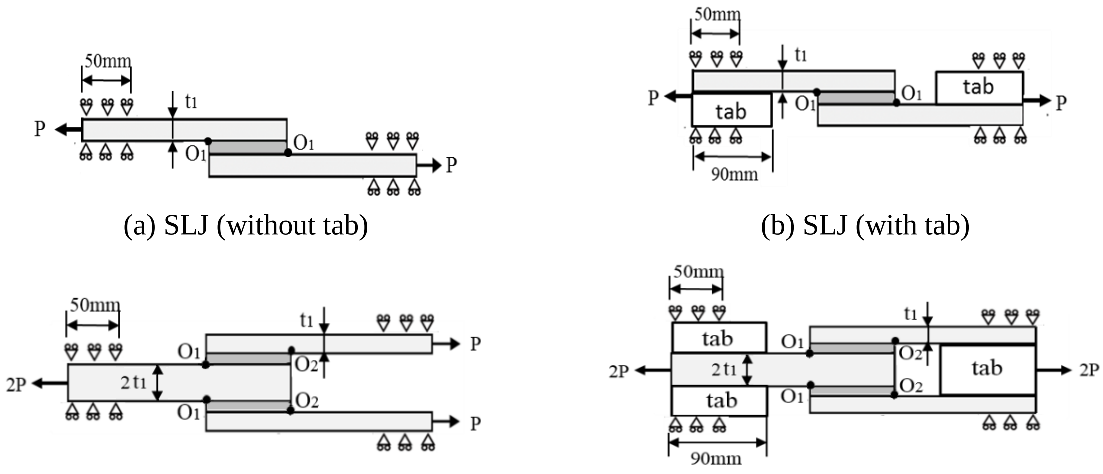


Figure 7. (a) Average shear strengths of SLJ and DLJ, (b) $K_{\sigma c}$ of SLJ and DLJ (Adherend: S45C, Adhesive: Epoxy B).



(a) SLJ (without tab) (b) SLJ (with tab)

(c) DLJ (without tab) (d) DLJ (with tab)

Figure 8. Models of SLJ and DLJ.

For DLJ, the K_{σ,λ_1} at interface corner O_1 is not equal to the K_{σ,λ_1} at interface corner O_2. Figure 9 shows the results of K_{σ,λ_1} at interface corners O_1 and O_2. It is found that the K_{σ,λ_1} for the specimen with tab is nearly equal to the K_{σ,λ_1} for the specimen without tab, the K_{σ,λ_1} at corner O_1 is large than that at corner O_2. Therefore, the fracture may occur at corner O_1 during testing. For this reason, the equivalent conditions of strength for SLJ and DLJ will be considered by using the K_{σ,λ_1} at corner O_1.

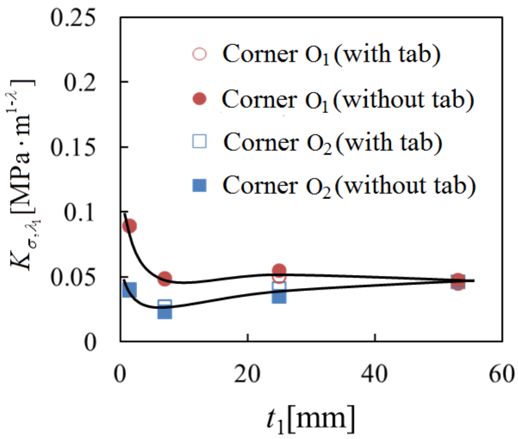


Figure 9. Results of DLJ (see Figure 8(c),(d)).

Figure 10 shows the results of K_{σ,λ_1} at interface corner O_1 with different adherend thickness t_1 for SLJ and DLJ. It is found that the K_{σ,λ_1} for the specimen with tab is nearly equal to the K_{σ,λ_1} for the specimen without tab, the K_{σ,λ_1} decreases with increasing t_1. When $t_1 \geq 25$mm, the minimum K_{σ,λ_1} can be obtained and the minimum $K_{\sigma,\lambda_1} \approx 0$. At that time, the bend effect is minimized, the possible reason of minimum $K_{\sigma,\lambda_1} \neq 0$ is the existence of local surface deformation at the interface corner even for very large thickness. In JIS, the adherend thickness t_1=1.5mm (see Figure 4). The strength of DLJ with t_1=7mm is nearly equal to that of DLJ with t_1=1.5mm (JIS) since the K_{σ,λ_1} of SLJ and DLJ are nearly the same. For the same reason, the strength of SLJ is nearly equal to that of DLJ when $t_1 \geq 25$mm .

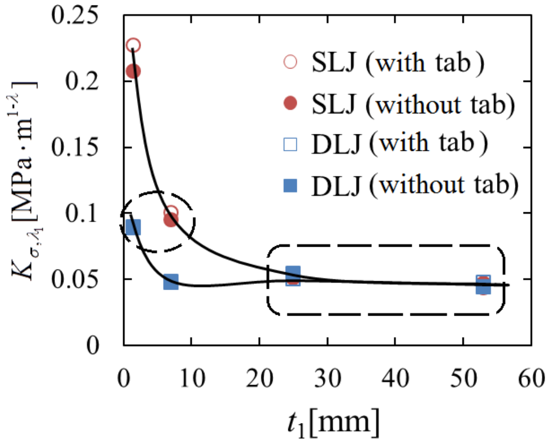


Figure 10. Comparison of SLJ and DLJ at corner O_1(see Figure 8(a)-(d)).

4. Conclusion

(1) The minimum ISSF of SLJ can be obtained when t_1 is large enough, and the deformation angle at interface corner is also smallest when t_1 is large enough.

(2) The strength of SLJ with t_1 =7mm is nearly equal to that of DLJ with t_1 =1.5mm (JIS) since the ISSFs of SLJ and DLJ are nearly the same. For the same reason, the strength of SLJ is nearly equal to that of DLJ when $t_1 \geq 25$mm .

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