Introduction

Mechanical behavior, strength and toughness of adhesive joints depend extremely on stress states and fracture resistance properties of the adhesive layer. In the literature, many works have been devoted on elucidating the mechanical and fracture behavior of sandwiched adhesive joints. These included investigations upon effect of joint geometry and crack propagation path, assessment of fracture initiation criteria and prediction of joint strength. Most of these investigations considered only joints with similar adherend, however, study on sandwiched dissimilar materials joints is hardly available thus motivated this work. It is predicted that the latter behaves slightly differ in comparison to the former due to the more complex elastic mismatches incorporated.

In this study, fracture tests of epoxy adhesively-bonded scarf joints of dissimilar metals were conducted under a remote tension load on several scarf angles and various adhesive bond thicknesses. Effect of joint geometry (i.e. bond thickness and scarf angle) upon strength and toughness of scarf joints will be qualitatively discussed.

Experimental procedures

The epoxy adhesive used in this study was Hi-Super 30 produced by Cemedine Co., Japan. This is a commercial brittle epoxy adhesive which can be cured at room temperature approximately in 30 minutes. The epoxy adhesive resin and hardener was mixed thoroughly prior to bonding by using the centrifugal mixer for 1 min: 3 min schedule of diffusion and de-foaming, respectively. The mechanical properties of the bulk epoxy adhesive have been reported in our previous study [1], and the pertinent results are tabulated in Table 1.

To study the effect of scarf angle upon performance of epoxy adhesive joints with different adherends, scarf joint specimens having the scarf angle of 45°, 60° and 75° were prepared. The dimensions of scarf joint are shown in Fig. 1. The adherents were consisted of SUS304 stainless steel and YH75 aluminium alloy. Prior to bonding, bonding surfaces were uniformly polished with #2000 waterproof abrasive paper and afterward degreased with acetone. Adhesive bond thickness, t inside a scarf joint was controlled by using a developed fixture and was varied between 0.1 mm to 1.2 mm. All specimens were cured at R.T. over 24 hours. After specimens were totally cured, four strain gages were mounted on bonding line; two in the longitudinal direction (i.e. side of plate) and another two perpendicular to bonding line. For specimens with interfacial crack, the pre-crack was introduced by pasting a strip of 0.05 mm thickness Tellon tape on the adherend surface prior to bonding. The a/W was fixed to 1/8, where a is the pre-crack length and W is the width of the specimen. Tensile fracture tests of scarf joints were carried out by a universal tensile test machine (INSTRON). All specimens were tested at R.T. with the crosshead speed held constant at 0.5 mm/min.

Table 1 Mechanical properties of materials

<table>
<thead>
<tr>
<th>Material</th>
<th>E (GPa)</th>
<th>σf(MPa)</th>
<th>ν</th>
</tr>
</thead>
<tbody>
<tr>
<td>Epoxy</td>
<td>3.4</td>
<td>36.5</td>
<td>0.396</td>
</tr>
<tr>
<td>SUS304</td>
<td>206</td>
<td>295</td>
<td>0.3</td>
</tr>
<tr>
<td>YH75 (ALU-alloy)</td>
<td>71</td>
<td>399</td>
<td>0.33</td>
</tr>
</tbody>
</table>

Fig. 1 Geometry of scarf joint
has experienced far greater stress triaxiality states in comparison to adhesive layer inside the 45° test specimens.

From calculation, the average values of fracture toughness, $J_c$, for scarf joints having 60° and 75° scarf angle are dependent on bond thickness. For 45° scarf joints, we can observe that there is a trend where $J_c$ increases with increasing bond thickness. It is noted from fracture surface observations that a high $J_c$ value is related to the cohesive failure. In contrast, interfacial failure always demonstrates a relatively constant value of $J_c$ regardless of bond thickness. From Fig. 5, it can be seen that, despite variance in data, $J_c$ values for scarf joints having 45°, 60° and 75° scarf angle are independent of bond thickness. For $t < 0.5$ mm, $J_c$ values of 60° and 75° scarf joints are almost identical while for 45° are higher than 60° and 75° about a factor of two. All of scarf joints of AES failed interfacially.

In overall, the $J_c$ values for cohesively fractured joints are higher than $J_c$ values of the interfacially fractured joint. This is not surprising since the sufficiently bonded scarf joints are likely to fracture within the adhesive layer (i.e. bond strength > adhesive force). Therefore, it may be concluded that the quality of the bonding surface strongly affects the adhesive joint toughness. In other words, any defects on the bonding surface or insufficient bonding achieved may reduce the $J_c$ values dramatically.

Now, we will discuss the fracture toughness of scarf joints with an interfacial crack. Fracture toughness, $J_c$ of scarf joints with an interfacial crack was evaluated by a path-independent integral, $J$ integral calculation in FE analysis. The relationship between fracture toughness, $J_c$ and bond thickness, $t$ is shown in Fig. 4 and Fig. 5. Here, SEA and AES represent the scarf joint specimens with an interfacial crack at the steel/adhesive interface and aluminium/adhesive interface, respectively.

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5. Conclusions

From analytical solutions, stress singularity exists most pronouncedly at steel/adhesive interface corner of joint having 45° to 75° scarf angle and this is in agreement with the fracture observations wherein the fracture always initiated at this point. $J_c$ values for cohesively fractured scarf joint are higher than $J_c$ values of the interfacially fractured scarf joint.

6. References