STRENGTH PROPERTIES OF ALUMINIUM/ALUMINIUM AND ALUMINIUM/STEEL JOINTS FOR LIGHT WEIGHTING OF AUTOMOTIVE BODY

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1. INTRODUCTION

The main materials of automotive bodies is steel, and spot welding is mainly used in assembling them. In recent years, lightening bodies has been needed to reduce fuel consumption. Using aluminum in place of steel has been studied as an available lightening method. However, there are many difficulties in conventional spot welding of aluminum/aluminum or aluminum/steel. Investigation on new bonding methods for these materials is very important.

Firstly, we consulted some papers [1-6] on joint methods available for bonding aluminum/aluminum and aluminum/steel, and studied market researches. Further, we considered repeatability of joining actions, automation ability, cost and joint properties. Then we selected four methods to be tested as follows: (1) self piercing rivetting, (2) mechanical clinching, (3) hybrid of self piercing rivetting and adhesive bonding, (4) hybrid of mechanical clinching and adhesive bonding.

We have compared strength properties (shear strengths, tensile strengths, fatigue strengths) in four kinds of joining methods that we have selected on aluminum/aluminum, and aluminum/steel with conventional spot welding and weld-bonding.

2. EXAMINATION

2.1. Test methods

We tested (1) Henrob rivetting (Japan Driveit co. ltd.) as self piercing rivetting, (2) Tox clinching (Rix co. ltd) as mechanical clinching, (3) hybrid of Henrob rivetting and adhesive bonding (Henrob-bonding), (4) hybrid of Tox clinching and adhesive bonding (Tox-bonding) on aluminum/aluminum and aluminum/steel. We also tested (5)

![Fig. 1. Schematic illustration of the operational sequence of joining processes used for self-piercing rivetting (Henrob rivet) [1].](image-url)
spot welding and (6) hybrid of adhesive bonding and spot welding (weld-bonding) on steel/steel and aluminum/aluminum. We tested (7) adhesive bonding to examine hybrid effects on hybrid joining with adhesive bonding. Fig. 1 shows schematic illustration of Henrob rivet [1]. Fig. 2 shows schematic illustration of Tox clinching [6].

We tested strength properties in static strengths (tensile shear strengths and cross lap tensile strengths) and fatigue strengths (tensile shear test). Jointed materials used were 1.6 mm and 0.8 mm thick aluminum (A5182-0) and mild steel (SPCC). The lapped dimension was 25 mm x 25 mm scale on both single lapped tensile shear test specimens and cross lapped tensile test specimens. We made one joining point in the center of the area of each specimen by Henrob riveting, by Tox clinching and by spot welding. In the case of adhesive bonding, we bonded whole area lapped. In the hybrid joining, we made one joining in the center of lapped area by Henrob riveting, by Tox clinching and by spot welding, before curing of adhesives.

Under such conditions as recommended by makers, we used Henrob rivets of ©5 mm steel, and Dai ©8 mm (for 1.6 mm thick), ©6 mm (for 0.8 mm thick) for Tox clinching. Henrob rivets were pierced from the side of aluminum to steel. Tox clinching were punched from the side of steel. The adhesive used was E-6208 (Sunstar co.ltd.), one part heat curing epoxy, cured for 20 minutes at 170°C.

Shear strengths and tensile strengths were measured at room temperature by 5 mm/min. Fatigue strengths were measured at room temperature by 20 Hz.

2.2. Load-strain diagram

Fig. 3 shows Load-strain diagrams of tensile shear tests and cross lap tensile tests of hybrid joints. Both diagrams show that the peak P1 firstly appears when adhesive bonding begins to break at the edge of lapped area. Secondly peak P2 appears when rivets or clinchings break in the center of lapped area. In shear tests, strengths of P1 are always higher than those of P2. We adapted strengths of P1 as data. In tensile tests, strengths of P2 are always higher than those of strengths of P1. We adapted strengths of P2 as data.

As for mono-joints (Tox clinching, Henrob riveting, spot welding and adhesive bonding), only P1 appears in adhesive bonding, whereas only P2 appears in other joints.

3. RESULTS AND DISCUSSION

3.1. Static strengths

3.1.1. Strengths of mono-joints

Fig. 4 shows strengths of mono-joints of 1.6 mm Al/Al. From Fig. 4 we have known that the order of shear strengths is as follows:

Adhesive bonding > spot welding ≈ Henrob riveting > Tox clinching,

![Figure 4: Strengths of mono-joints](image)

and the order of tensile strengths is as follows:

Henrob riveting > spot welding > Tox clinching ≈ Adhesive bonding.

The order of adhesive bonding, spot welding and henrob riveting is opposite in shear test and tensile test, and Tox clinching is the lowest in both strengths. We think that weak strengths of adhesive bonding in tensile test is owing to peeling.

3.1.2. Strengths of hybrid joints

Fig. 5 shows strengths of hybrid joints of 1.6 mm Al/Al comparing with those of mono-joints. It shows that in shear test, strengths of hybrid joints are higher than those of mono-joints, being almost as high as strengths of adhesive bonding. So, strengths of hybrid joints can be said to depend on the strengths of adhesive bonding. Just for
your comparing reference, strengths of spot welding, Henrob rivetting and Tox clinching in hybrid joints are shown at the marks \( O \) in Fig. 5. In tensile test, the strengths of hybrid joints are almost equal to strengths of mono-joints. It seems to show that because the strengths of adhesive bonding are the smallest among the mono-joints. Marks of \( O \) in Fig. 5 show the breaking strengths of adhesive bonded area in hybrid joints.

### 3.1.3. Effects of jointed materials

Fig. 6 shows the ratio of Al/steel strengths to Al/Al strengths. In shear strengths, we found least margin or gap in the strengths between Al/Al and Al/steel. In tensile strengths, the strengths of Al/steel seems to be a little higher than that of Al/Al. Without clear distinctiveness, it seems to be valid that strengths of joints are depending on the materials strengths of aluminum.

### 3.1.4. Effects of thickness of jointed materials

Fig. 7 and Fig. 8 show effects of adherend's thickness on shear strengths and on tensile strengths. The strengths of spot welding and weld bonding on 0.8 mm steel/steel are also shown in Fig. 7 and Fig. 8. They can show that the effects of thickness of materials are very big in both shear strengths and tensile strengths. Fig. 7 shows that combining adhesive bonding with spot welding, Henrob rivetting and Tox clinching in case of 0.8 mm Al/Al will produce higher strengths than that on 0.8 mm steel/steel spot welding. When we combine these with adhesives on

#### 3.2. Fatigue properties

### 3.2.1. Fatigue properties of mono-joints

Fig. 9 shows fatigue strengths of mono-joints (1.6 mm Al/Al) compared with those of spot weldings on steel/steel (1.6 mm, 0.8 mm). The fatigue strengths of mono-joints on 1.6 mm Al/Al can be illustrated as follows:

Adhesive bonding > Henrob rivetting > Tox clinching > Spot welding.

The fatigue strengths of adhesive bonding on 1.6 mm Al/Al is almost the same as that of spot welding on 1.6 mm steel/steel. The fatigue strengths of Henrob rivetting or Tox clinching on 1.6 mm Al/Al are almost equal to that of spot welding on 0.8 mm steel/steel. Yet the spot welding on 1.6 mm Al/Al is weaker than that on 0.8 mm steel/steel.
of adhesive bonding. This will explain that fatigue strengths of hybrid joints will depend on adhesive bonding. Fig. 11 shows comparison of fatigue strengths of hybrid joints and adhesive bonded joints (1.6 mm Al/Al) with the strengths of spot welded steel/steel joints. This shows that fatigue strengths of 1.6 mm Al/Al hybrid joints and adhesive bonding are equal to those of 1.6 mm steel/steel spot welding.

### 3.2.3. Effects of thickness and materials jointed

Fig. 12 shows comparison of fatigue strengths of Henrob rivetting (shown in black scale) with Henrob bonding (shown in gray), on 1.6 mm Al/Al, 0.8 mm Al/Al, 1.6 mm Al/steel. What you can see in 1.6 mm, 0.8 mm Al/Al joints shows that effects of material thickness is quite big on Henrob rivetting. Between 1.6 mm Al/Al and 1.6 mm steel/steel there is not so big margin, Al/steel being a little superior. Fatigue strengths of mono-joints seem to depend on the strengths of aluminum which has smaller strengths than steel. On the other hand, in Henrob bonding, the fatigue strengths of 1.6 mm Al/Al, 0.8 mm Al/Al and 1.6 mm Al/steel are almost the same, showing no effects of materials and thickness. Joining in a surface with adhesives is thought to distribute the stress over the jointed area. We can also say that fatigue strengths of 0.8 mm Al/Al Henrob bonding and adhesive bonding are equal to those of 1.6 mm steel/steel spot welding from the results of Fig. 12 and Fig. 11.

### 3.2.2. Fatigue strengths of hybrid joints

Fig. 10 shows fatigue strengths of hybrid joints compared with those of mono-joints. [1.6 mm Al/Al].

Fig. 11. Comparison of fatigue strengths of hybrid joints and adhesive bonded joints [1.6 mm Al/Al] with the strengths of spot welded steel/steel joints.
3.2.4. Comparison of fatigue strengths at 10^6 cycles

Fig. 13 shows fatigue strengths on each joints at 10^6 cycles. For comparison, we too shows in Fig. 13 fatigue strengths of spot weldings on 0.8 mm and 1.6 mm steel/steel. From these results, you will find you can use about 1.2 mm Al/Al Henrob bonding to get the same fatigue strengths of 1.6 mm steel/steel spot welding, or about 1.5 mm Al/Al Henrob riveting for 0.8 mm steel/steel spot welding.

3.3. Availability to Al/Al joints

Table 1 shows thickness of aluminium sheet to get the equivalent strengths to 0.8 mm steel/steel spot welding or weld bonding. This also shows that strengths of Henrob rivetting on 1.6mm Al/Al joints and Henrob bonding on about 1.3 mm Al/Al joints are equal to those of spot welding on 0.8 mm steel/steel joints, or Henrob bonding on about 1.5 mm Al/Al joints are equal to those of weld bonding on 0.8 mm steel/steel joints.

Table 1. Thickness of aluminium sheet equivalent to 0.8 mm steel sheet.

<table>
<thead>
<tr>
<th>Joining method of 0.8 mm Steel/Steel</th>
<th>Joining method of aluminium/aluminium</th>
<th>Equivalent thickness of aluminium</th>
<th>Shear strength</th>
<th>Tensile strength</th>
<th>Fatigue strength</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spot-weld</td>
<td>Henrob-bond</td>
<td>&lt; 0.8 mm</td>
<td>&lt; 0.8 mm</td>
<td>1.3 mm</td>
<td>&lt; 0.8 mm</td>
</tr>
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<td></td>
<td>Tox-bond</td>
<td>&lt; 0.8 mm</td>
<td>&gt; 1.6 mm</td>
<td>1.3 mm</td>
<td>&lt; 1.6 mm</td>
</tr>
<tr>
<td></td>
<td>Henrob</td>
<td>1.6 mm</td>
<td>&lt; 1.6 mm</td>
<td>1.3 mm</td>
<td>1.5 mm</td>
</tr>
<tr>
<td></td>
<td>Tox</td>
<td>&gt; 1.6 mm</td>
<td>&gt; 1.6 mm</td>
<td>1.5 mm</td>
<td>&gt; 1.6 mm</td>
</tr>
<tr>
<td>Weld-bond</td>
<td>Henrob-bond</td>
<td>1.2 mm</td>
<td>&gt; 1.5 mm</td>
<td>1.2 mm</td>
<td>&gt; 1.5 mm</td>
</tr>
<tr>
<td></td>
<td>Tox-bond</td>
<td>1.2 mm</td>
<td>&gt; 1.6 mm</td>
<td>1.5 mm</td>
<td>&gt; 1.5 mm</td>
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<tr>
<td></td>
<td>Henrob</td>
<td>&gt; 1.5 mm</td>
<td>&gt; 1.5 mm</td>
<td>1.6 mm</td>
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<td>Tox</td>
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</table>

4. CONCLUSION

The results obtained are as follows:

1. Strength properties of aluminum/steel joints are about equal to those of aluminum/aluminum joints.

2. The strength properties of 1.6 mm aluminum/aluminum joints by Henrob rivetting and 1.3 mm aluminum/aluminum joints by Henrob-bonding are equivalent to those of 0.8 mm steel/steel joints by spot welding, and those of 1.5 mm aluminum/aluminum joints by Henrob-bonding are equivalent to those of 0.8 mm steel joints by weld-bonding.

3. In the case of Tox clinching and Tox-bonding, the strength properties of less than 1.6 mm aluminum/aluminum joints are less strong than those of 0.8 mm steel/steel joints by spot welding.

5. ACKNOWLEDGEMENTS

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6. REFERENCES