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

Kosuke Haraga, Mitsubishi Electric Corp., Advanced Technology R & D Center, Ecomaterials & Material Analysis Dept.

The strength properties of four kinds of joining methods of aluminium to aluminium or aluminium to steel were investigated: selfpiercing riveting (Henrob rivetting), mechanical clinching (Tox clinching), hydrid of Henrob riveting and adhesive bonding (Henrob-bonding) and hybrid of Tox clinching and adhesive bonding (Tox bonding). The strength properties of aluminium/aluminium joints and aluminium/steel joints were compared with those of 0.8 mm steel/steel spot welded and weld-bonded joints. It was shown that the strength properties of aluminium/steel joints are about equal to those of aluminium/aluminium joints. The strength properties of 1.6 mm aluminium/aluminium joints by Henrob rivetting and 1.3 mm aluminium/aluminium joints by Henrob-bonding are equivalent to those of 0.8 mm steel/steel joints by spot welding and those of 1.5 mm aluminium/aluminium joints by Henrob-bonding are equivalent to those of 0.8 mm steel joints by weld bonding. In the case of Tox clinching and Tox bonding, the strength properties of less than 1.6 mm aluminium/aluminium joints are less strong than those of 0.8 mm steel/steel joints by spot welding.

Key words: Automobile engineering; Dissimilar materials; Aluminium; Steels; Resistance welding; Rivets; Adhesive bonding; Nonwelded joints; Shear strength; Ultimate tensile strength; Fatigue strength; Process variants

La résistance de quatre types d'assemblages aluminium/aluminium et aluminium/acier a été étudiée : rivetage autopoinçonneur (rivetage Henrob), clinchage (clinchage Tox), variante hybride de rivetage et de collage (assemblage Henrob) et variante hybride de clinchage Tox et de collage (procédé Tox). La résistance des assemblages aluminium/aluminium et aluminium/acier a été comparée à celle des soudures par résistance acier/acier (épaisseur 0,8 mm) et aux joints soudés par résistance et collés. On a montré que la résistance des assemblages aluminium/acier est sensiblement égale à celle des joints aluminium/aluminium. La résistance des assemblages aluminium/aluminium sur tôle de 1,6 mm d'épaisseur par rivetage selon le procédé Henrob et d'assemblages aluminium/aluminium par rivetage et collage est équivalente à celle obtenue en soudage par points de tôles en acier de 0,8 mm d'épaisseur ; la résistance d'assemblages de 1,5 mm d'épaisseur obtenue par le procédé Henrob est équivalente à celle obtenue sur des assemblages en acier de 0,8 mm d'épaisseur par soudo-collage. Dans le cas du clinchage et du procédé Tox la résistance d'assemblage aluminium/aluminium d'épaisseur inférieure à 1,6 mm est moins élevée que pour les assemblages acier/acier de 0,8 mm d'épaisseur assemblés par soudage par résistance.

Mots clés : Industrie automobile ; Matériaux dissemblables ; Aluminium ; Aciers ; Soudage par résistance ; Rivets ; Collage ; Fixations mécaniques ; Résistance au cisaillement ; Charge de rupture ; Résistance à la fatigue ; Variantes

IIS/IIW-1459-99 (ex. doc. III-1133-99) Class A, recommended for publication by IIW Commission III "Resistance welding and allied joining"

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)

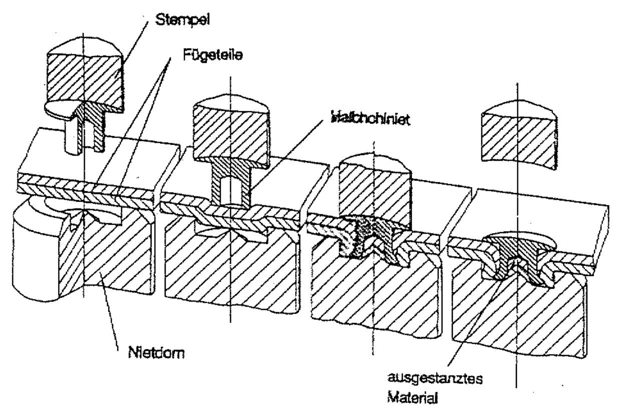

Fig. 1. Schematic illustration of the operational sequence of joining processes used for selfpiercing rivetting (Henrob rivet) [1].

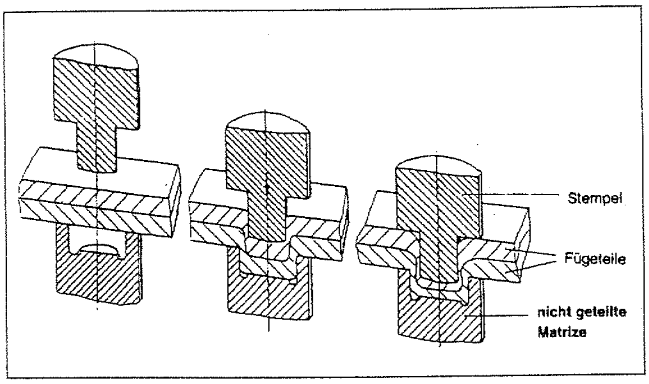

Fig. 2. Schematic illustration of the operational sequence of joining processes used for mechanical clinching (Tox clinching) [6].

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 dimention was 25 mm x 25 mm scale on both single lapped tensile shear test spesimens and cross lapped tensile test spesimens. We made one joining point in the center of lapped area of each specimens by Henrob rivetting, 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 rivetting, 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 20Hz.

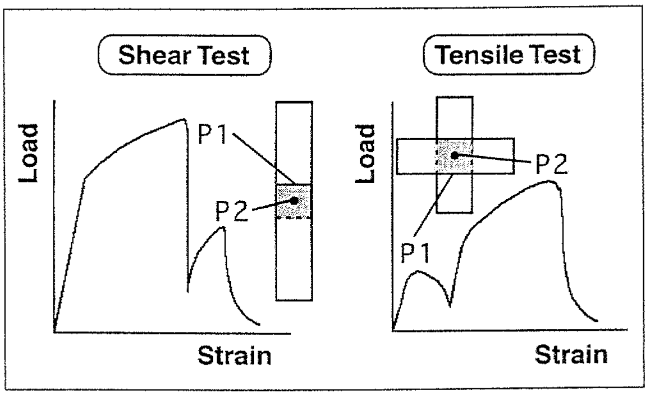

Fig. 3. Load-strain diagrams of tensile shear tests and cross lap tensile tests of hybrid joints (Tox-bonding, Henrob-bonding and weld-bonding).

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 stregths of P1. We adapted strengths of P2 as data.

As for mono-joints (Tox clinching, Henrob rivetting, 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 rivetting > Tox clinching,

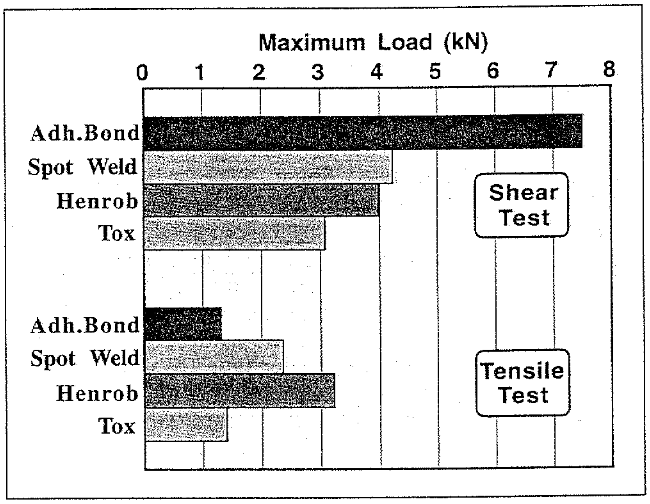

Fig. 4. Strengths of mono-joints (Tox clinching, Henrob rivetting, spot welding and adhesive bonding). [1.6 mm Al/Al].

and the order of tensile strengths is as follows:

Henrob rivetting > spot welding > Tox clinching ≑ Adhesive bonding.

The order of adhesive bonding, spot welding and henrob rivetting is opossite 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

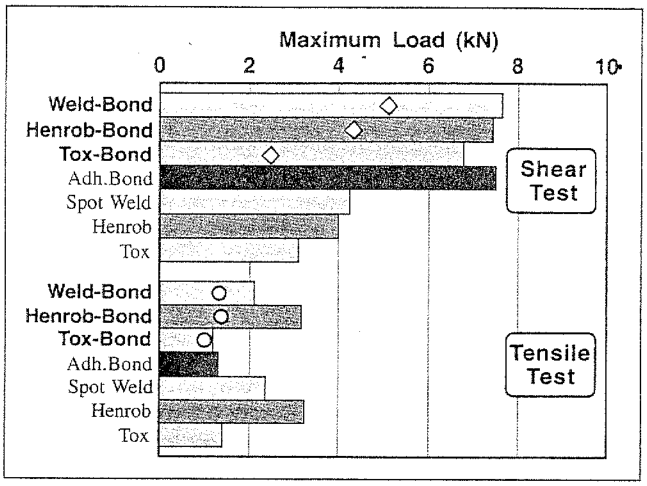

Fig. 5. Strengths of hybrid joints. [1.6 mm Al/Al].

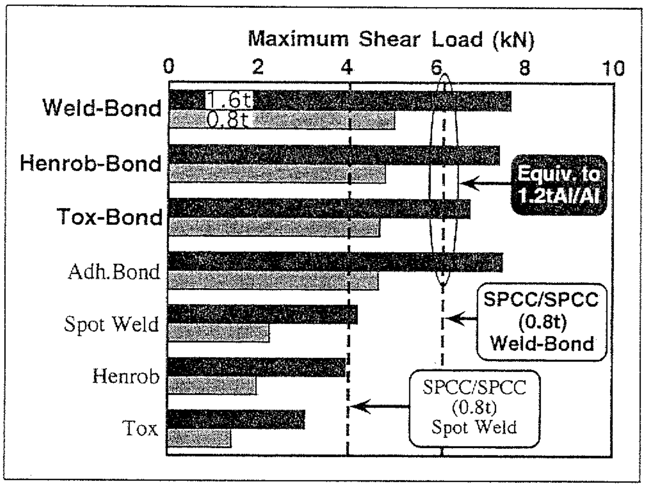

Fig. 7. Effects of adherend's thickness on shear strengths. [Al/Al].

your comparing reference, strengths of spot welding, Henrob rivetting and Tox clinching in hybrid joints are shown at the marks ◊ 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 ○ 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 btween 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 strenghts of joints are depending on the materials strengths of aluminum.

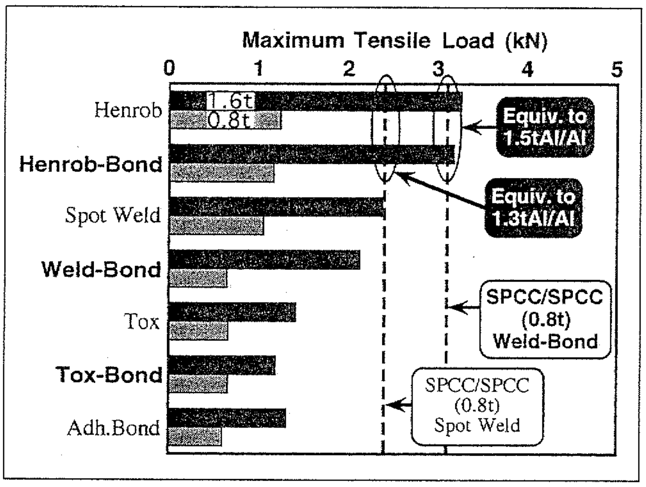

Fig. 8. Effects of adherend's thickness on tensile strengths. [Al/Al].

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 Al/Al(about 1.2 mm thick), we will get the strengths equal to that of weld bonding on 0.8 mm steel/steel. Further, spot welding and Henrob rivetting on 1.6 mm Al/Al can produce the same strengths as spot welding on 0.8 mm steel/steel. Fig. 8 will show that you can use Henrob rivetting on about 1.3 mm Al/Al to get the same strengths as spot welding on 0.8 mm steel/steel. To get the strengths equal to that on 0.8 mm steel/steel weld bonding, you can use Henrob rivetting on about 1.5 mm Al/Al.

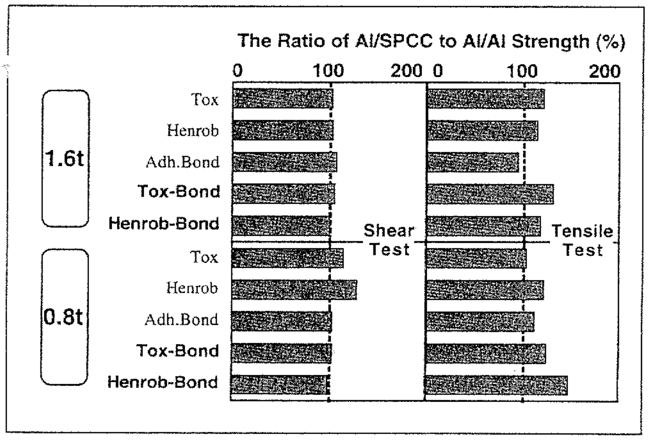

Fig. 6. The ratio of Al/steel strengths to Al/Al strengths.

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.

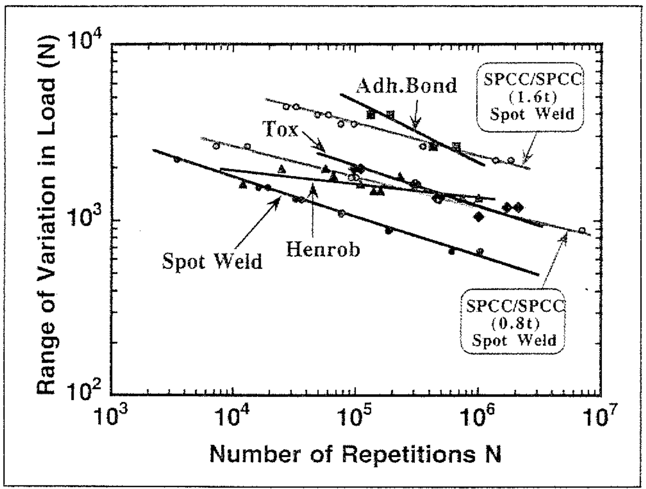

Fig. 9. Fatigue strengths of mono-joints [1.6 mm Al/Al] compared with those of spot welded steel/steel joints.

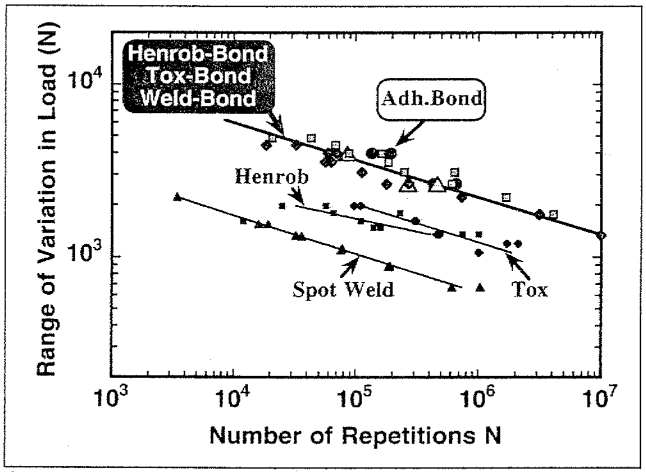

Fig. 10. Fatigue strengths of hybrid joints compared with those of mono-joints. [1.6 mm Al/Al].

3.2.2. Fatigue strengths of hybrid joints

Fig. 10 shows fatigue strengths of hybrid joints compared with those of mono-joints. It effectively shows that fatigue strengths of hybrid joints are much higher than those of mono-joints. In these three kinds of hybrid joining methods, fatigue properties are of the same, and equal to that

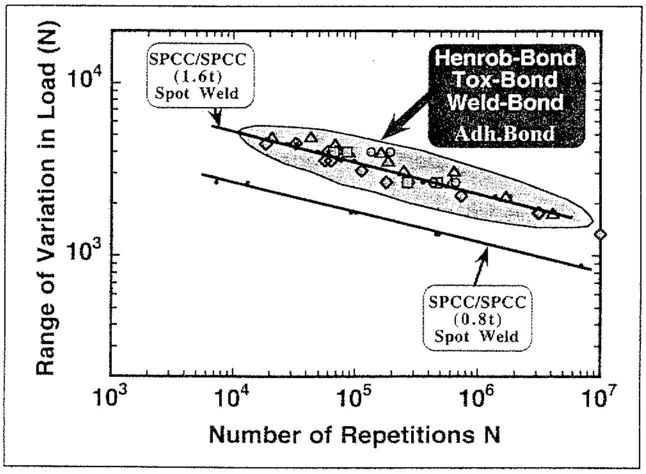

Fig. 11. Comparison of fatigue strengths of hybrid joints and adhesive bonded joints [1.6 mm Al/Al] with the strengths of spot welded steel/steel joints.

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 strenghts 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 mmAl/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 adehesive bonding are equal to those of 1.6 mm steel/steel spot welding from the results of Fig. 12 and Fig. 11.

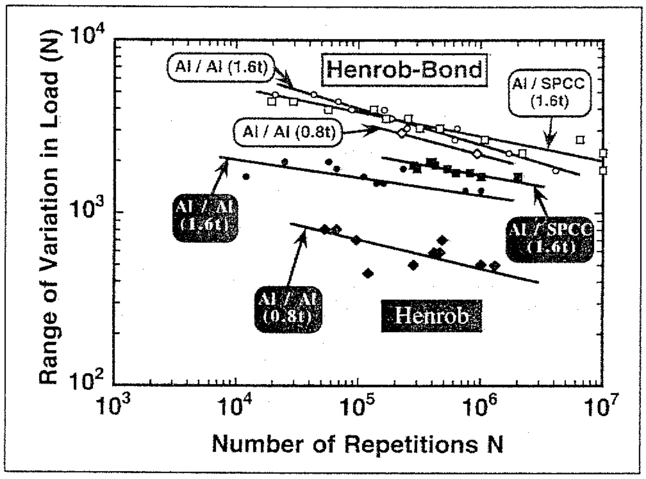

Fig. 12. Effects of the adherend's thickness and different kinds of metals on fatigue strengths.

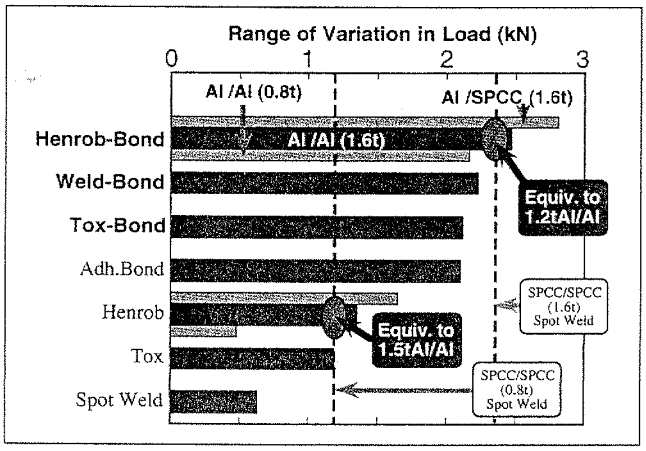

Fig. 13. Fatigue strengths at 10^6 cycles.

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 rivetting for 0.8 mm steel/steel spot welding.

3.3. Availability to Al/Al joints

Table1 shows thickness of aluminum 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 sopt 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.

Joining method of 0.8 mm Steel/Steel	Joining method of aluminium/ aluminium	Equivalent thickness of aluminium		
		Shear strength	Tensile strength	Fatigue strength
Spot-weld	Henrob-bond	< 0.8 mm	1.3 mm	< 0.8 mm
	Tox-bond	< 0.8 mm	> 1.6 mm	< 1.6 mm
	Henrob	1.6 mm	1.3 mm	1.5 mm
	Tox	> 1.6 mm	> 1.6 mm	1.6 mm
Weld-bond	Henrob-bond	1.2 mm	1.5 mm	1.2 mm
	Tox-bond	1.2 mm	> 1.6 mm	> 1.6 mm
	Henrob	> 1.6 mm	1.5 mm	> 1.6 mm
	Tox	> 1.6 mm	> 1.6 mm	> 1.6 mm

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 0.8mm 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 0.8mm steel/steel joints by spot welding.

5. ACKNOWLEDGEMENTS

This report was summarized some research results carried out by a technical committee on optimization of manufacturing process to reduce car body weight (Chairperson: Mr. Masao Fujimoto) founded in the Japanese SAE. The author is grateful to Mr. Toshiyuki Kanesaka (Isuzu Motors Ltd.) • Mr. Akira Mabuchi (Fuji Heavy Industries) • Mr. Atsushi Funasaki (Japan Automobile Research Institute, Inc.) • Mr. Naoki Takayama (Nissan Shatai Co., Ltd.) • Mr. Miyuki Yamamoto (Sumitomo Metal Industries Ltd.) • Mr. Shinichirou Takahashi (Kobe Steel,Ltd.), who supported the investigation with experimental works.

6. REFERENCES

1. Budde L., Lappe W., Boldt M. VDI Ber., No. 883, 333 (1991).
2. Budde L., Lappe W., Bander Bleche Rohre, Vol. 32, No. 5, 94 (1991).
3. Budde L., Lappe W., Liebrecht F., Suse D., Blech Rohre Profile, Vol. 39, No. 4, 310 (1992).
4. Gugisch K., Alum. Ind., Vol. 12, No. 6, 23 (1993).
5. Liebig H.P., Mutschler J. Bander Bleche Rohre, Vol. 34, No. 4, 46 (1993).
6. Kohstall T., Budde L., Blech Rohre Profile, Vol. 41, No. 2, 107 (1994).