CHARACTERISTICS OF RECIPROCATING SLIDE ADHESION OF ALUMINUM METAL

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ABSTRACT Adhesive characteristics of aluminum metal to copper and carbon steel were examined by a reciprocating slide adhesive test and discussed in relation to the contact pressure, slide stroke and number of reciprocation times in order to develop a new metal joining method making use of strong adhesiveness of aluminum. Through the tests, the following features were revealed on the reciprocating slide adhesion: (1) Adhesive strengths of aluminum to copper and to carbon steel are both increased by increases of the contact pressure and of the slide stroke, (2) As regards the reciprocation times, it seems that there is an optimum amount depending on both the slide stroke and the contact pressure, and (3) Reciprocating slide brings about stronger adhesion than unidirectional slide. Results of trial joining showed not a little feasibility of the joining method.

Keywords: *Joining, Adhesion, Bond strength, Reciprocating slide, Aluminum insert*

1. INTRODUCTION

Through developing new cladding methods based on cold pressure welding, claddings of aluminum onto thin metal sheet by differential speed rolling[1,2] and onto metal rod or pipe by drawing[3], we recognized that sliding properly introduced into the mating surfaces to be joined has a good effect on joining. And in relation to the cladding processes, we investigated adhesive characteristics of aluminum by using a unidirectional slide adhesive test and it was confirmed that aluminum metal has strong adhesiveness to itself and to others[4]. In this study, we investigated the characteristics of aluminum's adhesion to copper and carbon steel by reciprocating sliding, with an aim at developing a new metal joining method based on the reciprocating slide adhesion of aluminum insert.

2. EXPERIMENTAL PROCEDURE

2.1 Experimental materials

Industrially pure aluminum(A1050) and copper(C1100) and carbon steel(S25C) rods were used for the experiments. Test pieces of two types A and B, whose shapes and sizes are shown in Figure 1, were prepared by machining and served to the test without any special treatment but dry cutting of the testing surface just before the testing. Table 1 gives Vickers hardness HV and the roughness R_{max} of the testing surface. In the test piece preparation, aluminum of relatively soft metal was machined into the type B so as not to be subjected to plastic deformation by the contact pressure by itself applied in the adhesive test.

Table 1 Materials used for the experiments

Materials	Vickers hardness HV	Roughness R_{max} / μm
Aluminum (A1050)	36	6.7
Copper (C1100)	97	2.3
Carbon steel (S25C)	155	15.2

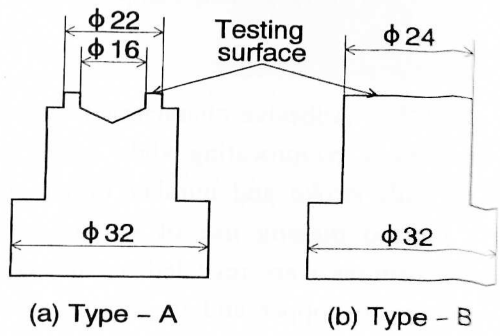

Fig.1 Shapes and sizes(mm) of test pieces

2.2 Reciprocating slide adhesive test

The test pieces A and B, each being held by a scroll chuck, were faced each other, and adhesion was caused in the mating surfaces by giving twist motion under the constant contact pressure, which was provided by using a hydraulic servo-press. The twist motion was given only to the test piece A against the fixed test piece B. Testing was all conducted at room temperature in the atomosphere, where the slide stroke S, contact pressure P an number of reciprocation times N were varied as a testing condition. The value of the sli stroke shown below was estimated at the mean diameter 19 mm of the ring-shaped testi area (see Fig.1). Slide velocity given in the test was about 3 mm/s, as measured at the me diameter.

2.3 Evaluation of adhesiveness

Adhesive strength or bonding strength was measured by tensile debonding test and evaluated as a maximum debonding force per a unit area. The strength shown below is a maximum value in 3 to 5 tests.

Adhesively joined area and debonded surfaces were observed by using a SEM and in part analized by using an EPMA in order to examine the condition of adhesion.

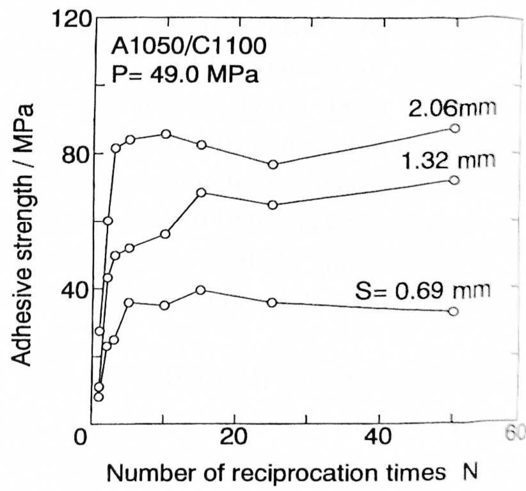

Fig.2 Adhesive strengths of aluminum to copper provided by reciprocating slide under various conditions.

3. RESULTS AND DISCUSSION

3.1 Adhesiveness to copper

Figure 2 shows the variation of

adhesive strength of aluminum to the copper with reciprocation times at different slide strokes under the contact pressure 49 MPa. In a range less than about 5 times of reciprocation, all the slide strokes shows a rapid increase in adhesive strength with increasing number of reciprocation times, but in a range more than 5 times, the strengths by the strokes 0.69 mm and 2.06 mm are almost maintained constant, while the strength by the stroke 1.32 mm still shows a gradual increase. It is seen from the figure that the adhesive strength is increased by an increase of the slide stroke.

Figure 3 shows the adhesive strengths by 10 times of reciprocation at different contact pressures 29.4 MPa and 49 MPa as a function of the slide stroke relating to the contact pressure. As seen in the figure, high adhesive strength is obtained in application of high contact pressure.

Figure 4 shows the adhesive strength plotted against total slide distance by arranging the results shown in Fig.2. Adhesive strengths observed in the unidirectional slide adhesive test conducted under the same contact pressure are given in the figure for comparison. It is worthy of note that adhesion generated by reciprocating slide is stronger than that by unidirectional slide. In a range of short slide distance, adhesive strengths behave in much the same way independently of the slide stroke, but in a range of long slide distance, they make a branch depending on their slide stroke. As is evident from the figure, the reciprocating slide is preferable to obtain strong adhesion.

3.2 Adhesiveness to carbon steel

Figure 5 shows the variation of adhesive strength of aluminum to the carbon steel under the same condition in Fig. 2. Adhesive strength by each slide stroke increases rapidly in a range less than about 3 times of reciprocation, and a peak is formed at

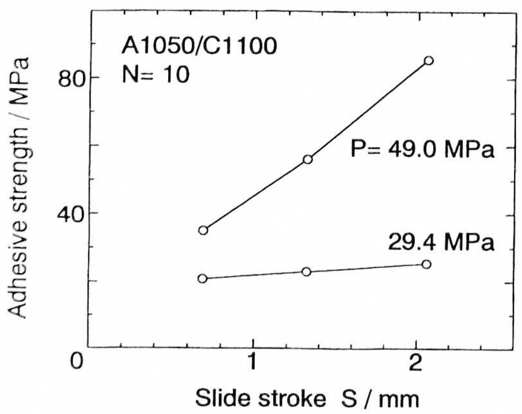

Fig.3 Effect of contact pressure upon adhesive strength of aluminum to copper.

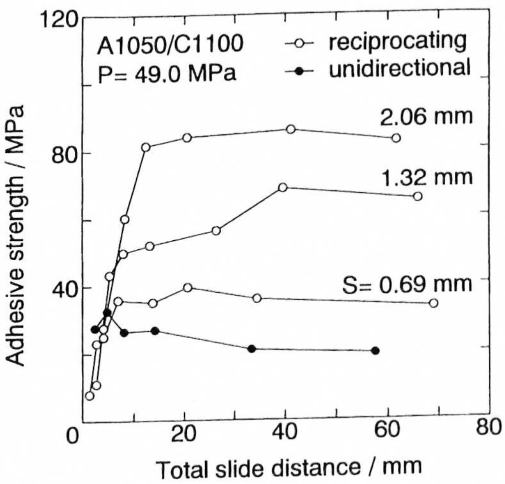

Fig.4 Variation of the adhesive strengths of aluminum to copper with total slide distance. Results by unidirectional slide at the same contact pressure are given for comparison.

15 times for the stroke 0.69 mm and at 25 times for 1.32 mm. The adhesive strength by the stroke 2.06 mm still increases in a range up to 50 times. A large slide stroke provides high adhesive strength as well as in the adhesion to the copper.

Figure 6 shows the adhesive strengths at the contact pressures 29.4 MPa and 49 MPa relating to the effect of the contact pressure upon the adhesive strength to the carbon steel. As is seen from the figure, high adhesive strength is obtained at high contact pressure as well as in the adhesion to the copper.

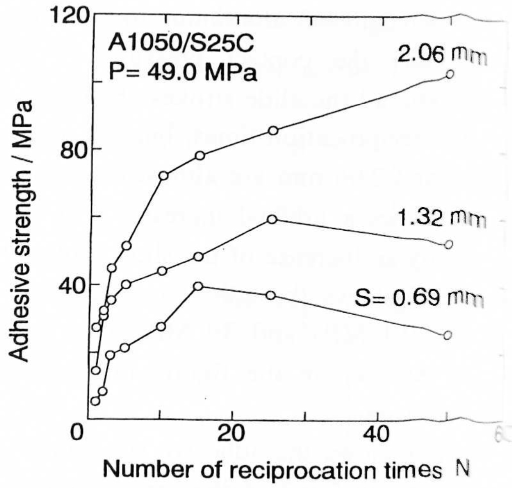

Fig.5 Adhesive strengths of aluminum to carbon steel provided by reciprocating slide under various conditions.

Figure 7 shows the adhesive strength plotted against total slide distance. The adhesive strength by unidirectional slide under the same contact pressure is also given in the figure for comparison. In a range of slide distance less than 10 mm, the unidirectional slide provides higher adhesive strength than the reciprocating slide. However, as the slide distance becomes large, the adhesive strength by the unidirectional slide decreases almost along the variation by the reciprocating slide at the stroke 0.69 mm. As seen in the figure, the reciprocating slide provides high adhesive strength. This is very favorable for the new metal joining method intended to develop.

As regards the condition of adhesively

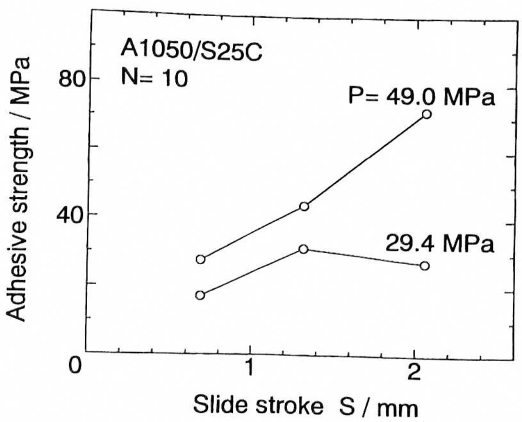

Fig.6 Effect of contact pressure upon adhesive strength of aluminum to carbon steel.

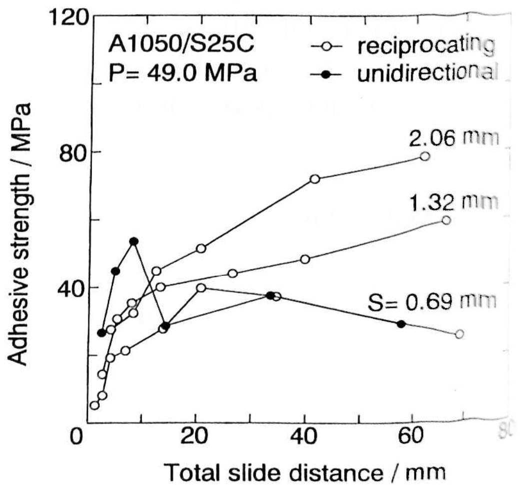

Fig.7 Variation of the adhesive strengths of aluminum to carbon steel with total slide distance. Results by unidirectional slide at the same contact pressure are given for comparison.

joined area, we observed debonded surfaces and found that the debonded surface on the carbon steel side was almost covered with soft metal of aluminum, and that the covering became strong by an increase of the contact pressure, reflecting increasing adhesive strength.

3.3 Trial joining using an aluminum sheet insert

Similar metal joinings of the copper and of the carbon steel were tentatively made by using an annealed aluminum sheet insert(thickness: 0.22mm, outer-diameter: 23mm, inner-diameter: 15mm). A pair of the test pieces used in the adhesive test were also used in the trial joinings.

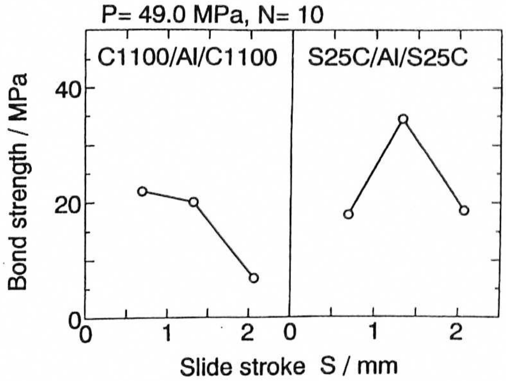

Fig.8 Bond strengths of copper/copper and steel/steel joints adhesively bonded by reciprocating slide with an aluminum sheet insert at room temperature.

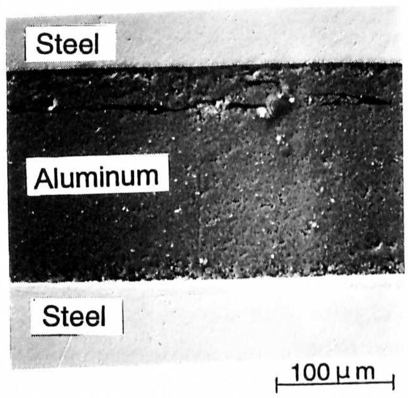

Fig.9 Cracks developed in the aluminum sheet insert by excessive shearing.

Figure 8 shows the bond strength obtained by 10 times reciprocating slide at the contact pressure 49MPa as a function of the slide stroke. In the joining, special surface treatment such as wire-brushing to remove oxide film was not given to the insert. The bond strengths are low as compared with the adhesive strengths in Figs. 3 and 6 and besides their slide stroke dependences differ from those in the figures. Existence of oxide film on the joining surfaces of the insert may be considered one of the main reasons for the low bond strengths. However, comparing with normal cold pressure welding without sliding, this reciprocating slide adhesive joining provides comparatively high bond strength. The breakage of the oxide film and the generation of a large amount of fresh surface on the mating surfaces by slide action are regarded as the reason. As for the difference in the slide stroke dependence between in the adhesive test and in the trial joining, it is explainable by the difference in the magnitude of shear strain developed in the aluminum metal by thinking as follows: In the adhesive test, shear deformation caused by the slide can spread deeply into the specimen, while in the trial joining it can not spread because of the limited thickness of the insert and hence concentrates, and this severe shearing, which is, in a sense, preferable to promoting the adhesion though, destroys already adhesively joined area in cooperation with work-hardening to reduce ductility. Thus thinking, it seems that even the shortest slide stroke

0.69 mm is too large for the insert whose thickness is 0.22 mm. In this relation, Figure 9 shows cracks developed in the aluminum insert by excessive shear.

Figure 10 shows the effect of heat treatment after joining. Adhesively joined specimens were heat-treated at 200 ° C for 2 hours. The joining strengths for the copper and for the carbon steel were both increased by 1.4 ~ 2.5 times as compared with those as-bonded. This shows that post-joining heat treatment is effective to increase joining strength. However, when the heat-treatment temperature is too high, brittle intermetallic compounds are formed at the interface. Therefore, attention should be paid to the heat-treatment temperature, especially in case iron and/or steel is involved in.

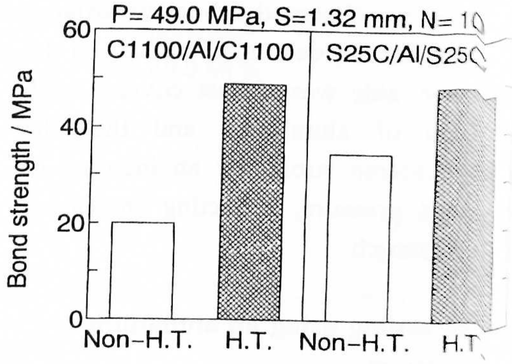

Fig.10 Effect of post-joining heat treatment on the bond strengths.

4. CONCLUSIONS

With a view to designing a new metal joining method based on the reciprocating slide adhesion, the characteristics of aluminum's adhesiveness to copper and carbon steel at room temperature were examined by a reciprocating slide adhesive test. Our findings were summarized as follows: (1) Adhesive strength was increased by an increase of the slide stroke in the extent we examined, (2) As for the contact pressure, it's increase promoted the adhesion, (3) The reciprocating slide provided higher adhesive strength than the unidirectional slide, and (4) Trial joining of similar metals using an aluminum sheet insert made at room temperature provided the bond strength of 20 MPa for the copper and 35 MPa for the carbon steel in 'as-bonded' condition, and the post-joining heat treatment at 200 ° C for two hours increased their bond strengths to 49 MPa and 48 MPa, respectively.

Finally the results of the trial joinings showed not a little feasibility of the new joining method but required more investigation into its optimum condition.

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