Vacuum Brazing of Aluminum (Report-I)†

—Effect of Surface Treatment—

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Abstract

Vacuum brazing tests on aluminum were carried out to find out a suitable pretreatment. Specimens were brazed into tee type joint using Al-12% Si filler alloy. The alloy sheet was pre-inserted between vertical and horizontal members. The results indicate that inserted type brazing enables sound fillet formation when the surface treatment is pertinent. Chemical treatments were not recommended as a pretreatment for vacuum brazing of aluminum, however, emery paper grinding was guaranteed satisfactory fillet formation. The effect of emery paper roughness was also studied. It was found that rougher papers than 1000 grades were preferable but grinding by fine papers of 1200 and 1500 grades were not adequate.

1. Introduction

Aluminum brazing has been developed in recent years with the manufacture of aluminized heat exchangers. Fluxless brazing techniques[1)~3)] are also widely used as well as dip and furnace brazing methods. Excellent wetting guaranteed by fluxes, but they cause the troublesome problems such as removal of them, corrosion by residues, treatment of washing water after residues were removed, and damages of brazing jigs. Fluxless brazing eliminates these problems. Of cource, the brazability depends on the degree of removal of surface oxide films as same as flux methods.

Terill et al.[4)] added various third elements to Al-Si binary filler alloys and investigated their effects on brazability. They revealed that magnesium is the most effective additional element for promoting aluminum vacuum brazing. Therefore almost recent brazing sheets consist of core material and claddings containing a few percent magnesium. But vaporized magnesium during brazing contaminates the interior wall of a furnace. Cleaning of contaminated furnace is considerably dangerous because of metallic magnesium included in the adhered materials on the wall. To avoid this problem and costs for cleaning, it is desirable that the vacuum brazing can be performed with filler alloys not containing magnesium.

This work is based on the ground so as to braze aluminum with commercial filler alloys not contaning magnesium. An inserted type brazing method that the filler alloy is preset between vertical and horizontal members is suitable for this purpose and makes well brazed tee joint.

2. Materials and Procedures Used

The materials used in this study are commercially pure aluminum (1100) as base plate and Al-12%Si alloy (BA 4047) as filler metal. Chemical compositions of both alloys were given in previous report[5)]. Specimens were brazed into a tee joint shown in **Fig. 1**.

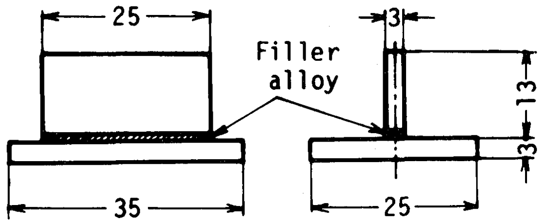

Fig. 1 Shape and size of tee joint.

Filler alloy (2.4 ϕ mm) was cold rolled to 1.35 mm thickness and set between the vertical and horizontal members. Pressure was applied by a heat resistant spring to the filler alloy for about 20 g/mm^2 at room temperature. The proof stress of the spring alloy was reported to be scarcely changed up to about 600 °C[6)].

Prior to brazing, specimens were degreased by acetone and then pretreated in chemicals, electropolished or ground with emery papers. Treated ones

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were rinsed in water and acetone and dried by air. They were set in a furnace and evacuated to 2×10^{-5} torr pressure. Typical heating and cooling curves are shown in **Fig. 2**. Curve (A) represents the temperature 1 cm away from vertical and horizontal members, and curve (B) shows the temperature of the bottom of horizontal member. As shown in Fig. 2, temperature (A) increased rapidly, therefore the temperature of furnace is controlled by thermocouple (A). After the melt of filler alloy was recognized from curve (B) and direct observation through a window equipped to the furnace, the electric source was cut off. Curve (A) begins to decrease but curve (B) still rises to a maximum temperature and then decreases. Curve (B) clearly shows the melting and solidification of filler alloy. After solidification of filler alloy, specimens were cooled to 100 °C in introduced argon. In this study, brazing temperature is designated by the maximum of curve (B). The time required to melting of filler alloy and the holding time above the melting point is dependent on the peak temperature of curve (A), however, they were about 11~12 min and 4~7 min respectively in the range of experimental conditions.

Brazability was evaluated mainly by the appearance of fillet, sectional fillet area (S_F), fillet leg length ratio (L_V/L_H, L_V: vertical leg length, L_H: horizontal leg length) and erroded area of base plate by melted filler alloy (S_M: sectional melted area).

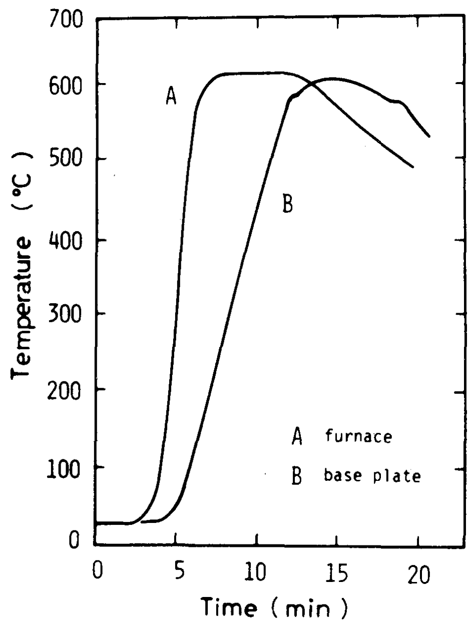

Fig. 2 Representative heating and cooling curves.

3. Results and Discussions

3.1 Effect of temperature

The melting temperature of this filler alloy was 577~8 °C. Then brazing temperature was varried between the melting point and 620 °C. Prior to brazing, specimens were ground with 600 grade emery paper, this process enables sound fillet formation. Grinding direction by emery paper is parallel to the rolling direction of base plate, i.e., longitudinal direction for the horizontal member, and the direction is also parallel to the climbing direction of melted filler alloy against the vertical member. The relation between the fillet area of central section of specimen (S_F) and brazing temperature is shown in **Fig. 3**. S_F is about

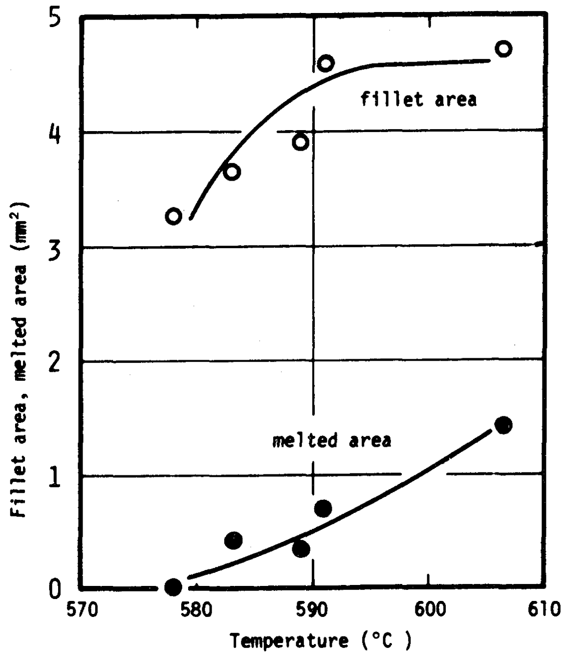

Fig. 3 Effect of brazing temperature on melted area and fillet area.

3.5 mm² at brazing temperature of 580 °C, but 4.6~4.7 mm² when exceeded 590 °C and scarcely changed with temperature up to 607 °C. On the other hand, melted area (S_M) increased with the rise of temperature. **Figure 4** shows the relation between L_V/L_H and brazing temperature. The value of L_V/L_H increases to 0.86 at 590 °C and is almost constant up to 606 °C, and is extremely small below 580 °C, at which the form of fillet is not tolerable. **Photograph 1** is the appearance of fillet.

Photograph 2 is micrographs of fillet. The used Al-12.1wt%Si alloy is hypereutectic composition[7], therefore the primary Si crystal appeared when the errosion of base plate by melted filler alloy was small, because

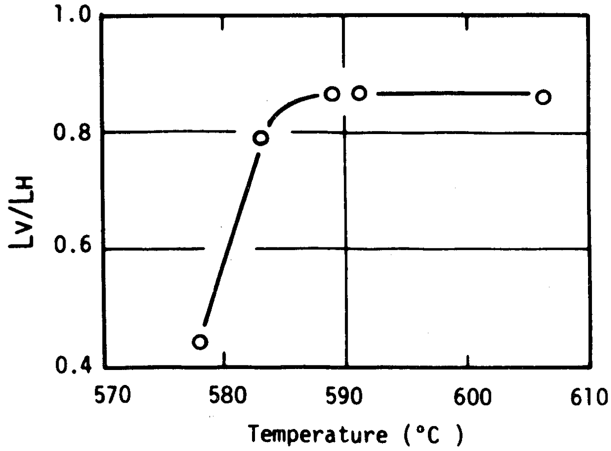

Fig. 4 Effect of brazing temperature on L_V/L_H.

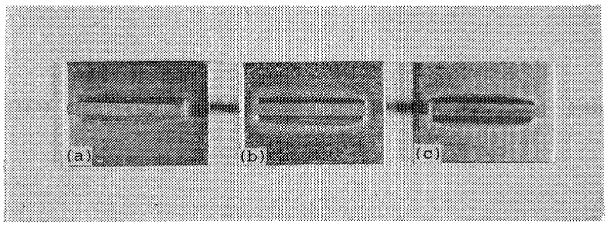

Photo. 1 Appearances of specimens brazed at (a) 585°C, (b) 590°C and (c) 603°C. Both vertical and horizontal members are ground by 600 grade emery paper.

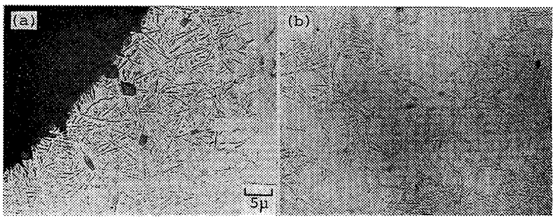

Photo. 2 Microstructure of fillet brazed at (a) 586°C and (b) 606°C.

of the low brazing temperature (Photo. 2(a)). The amount of primary Si decreases and relative increase of α-aluminum takes place with the rise of brazing temperature owing to the mutual dissolution reaction of base plate with filler alloy. Photograph 2(b) shows the cellular networks of eutectic structure around the primary α-aluminum. From these observations, it is known that brazing temperature more than 590°C enables sound fillet formation.

3.2 Effect of surface treatment

To investigate the effect of surface treatment on brazability, vertical and horizontal members were treated in sulphuric acid or in sodium hydroxide solutions. Brazing were done at 605~610°C, at which sound fillet was obtained by emery paper grinding. The results shows that satisfactory sound fillet was not formed in these chemically treated specimens, indicating poor climb of melted filler alloy against vertical member. On the other hand, as mentioned above, sound fillet was formed by emery paper grinding. Then, vertical member was ground by 600 grade emery paper, and horizontal member was chemically treated. Brazing of these treated members showed the existence of close relation between the treatment method of horizontal member and the brazability. The relations were investigated at various brazing temperatures. Chemical treatments were as follows: H_2SO_4=(33% H_2SO_4, 60°C, 5 min), NaOH=(10% NaOH, 60°C, 3 min→rinsed in water→50% HNO_3, R.T., 1 min), HNO_3-HCl=(HNO_3:HCl:H_2O=3:1:2, R.T., 5 min).

S_F and L_V/L_H increased with temperature up to a certain temperature but became constant at higher temperature. The temperature, at which S_F and/or L_V/L_H became constant, is definable as minimum brazable temperature (MBT). **Table 1** shows the MBT of each surface treatment. Other treatments for horizontal members such as electropolished and as received are also shown in the table. As indicated in the table, MBT by emery paper grinding and electropolishing is lower than 600°C. But in chemically treated and as received specimens, they were higher than 600°C. The maximum L_V/L_H is obtained in the specimen ground with 600 grade emery paper, and this treatment is superior to others.

Table 1 Relations between various surface pretreatments and the minimum brazable temperature.

Treatments *	Minimum brazable temperature (MBT),(°C)	L_V/L_H
Emery paper(600grade)	590	0.85
NaOH	615	0.80
HNO_3-HCl	610	0.70
H_2SO_4	605	0.75
Electropolished	595	0.65
As received	610	0.70

* Treatments of horizontal members, vertical members were ground with 600 grade emery paper.

Photographs 3~5 are the appearance of tee joint with various treatments. The appearance of electropolished specimen was sound at the brazing temperature of 585°C, however, L_V/L_H was extremely low (0.3), therefore the temperature was considered to be lower than MBT. Fillet surface of specimens treated in H_2SO_4 or as received were not smooth even at 600

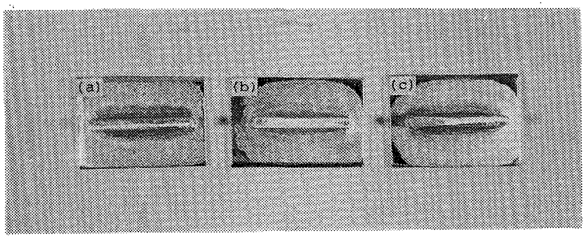

Photo. 3 Appearances of tee joints brazed at (a) 585°C, (b) 593°C and (c) 603°C. Horizontal members are electropolished.

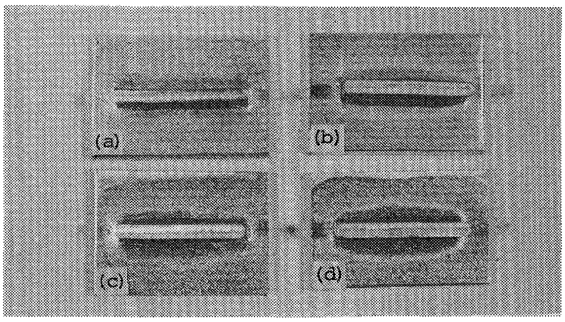

Photo. 4 Appearances of tee joints brazed at (a) 600°C, (b) 606°C, (c) 613°C and (d) 620°C. Horizontal members are treated in H_2SO_4.

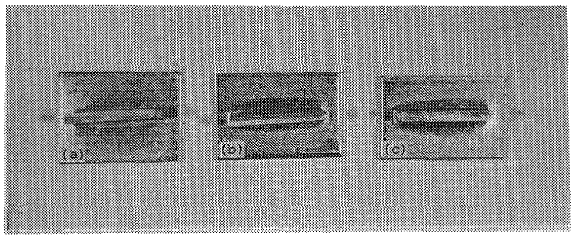

Photo. 5 Appearances of specimens brazed at (a) 604°C, (b) 610°C and (c) 617°C. Horizontal members are only rinsed by acetone (as received surface).

and 604°C respectively (Photos. 4 and 5).

Kawase et al.[8] pointed out that chemical cleaning for brazing sheet containing magnesium is not favourable to the pretreatment for vacuum brazing. They observed inhomogeneous filler alloy flow as a result of chemical cleaning, and suggested that the cause of inhomogeneity may be attributed to the precipitated surface impurity due to chemical treatment or adherent moisture. Similar effects may not be considered as the cause of poor brazability in chemical treated specimens of this work, because of no magnesium in filler alloy used, but moisture may responsible to poor brazability.

3.3 Effect of emery paper number

The results obtained in former section show that the most suitable pretreatment for vacuum brazing with Al-12%Si filler alloy is emery paper grinding. Then the effect of emery paper number on brazability was investigated. **Figure 5** shows the relation between fillet area (S_F) and emery paper number (grade) for specimens brazed at about 607°C. S_F is 4.5 mm² for 220~1000 grades, 2.5 mm² for 1200 and 1500, and 3.5 mm² for 80. Melted area shown in the

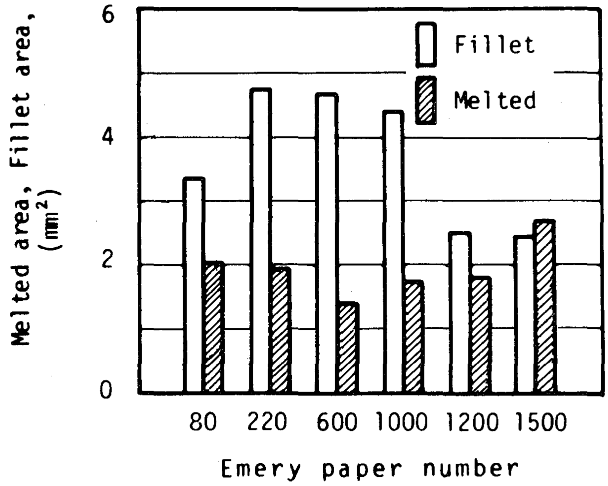

Fig. 5 Relations between emery paper number and melted area and fillet area.

figure is the greatest for 1500. The relation between L_V/L_H and emery paper number is shown in **Fig. 6**. The values of L_V/L_H were more than 0.8 for 80~1000 grades, forming good fillets. But for 1200 and 1500, L_V/L_H is extremely low (0.2~0.35). In these specimens the climb of melted filler alloy against the vertical members was small and the amount of spread on horizontal members was large. Appearance of joints shown in Photo. 5 indicates that the sound fillet was obtaind for 80~1000 grades but satisfactory fillet was not formed for 1200 and 1500 grades. The results

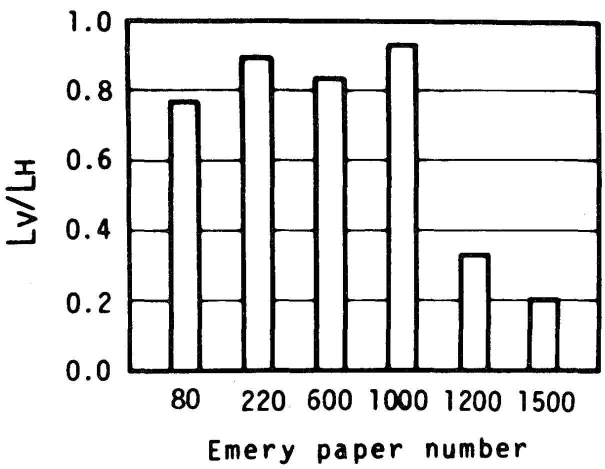

Fig. 6 Relation between emery paper number and L_V/L_H.

show that good brazability was obtained by grinding with rough or medium rough emery papers of 80～1000 grades.

As mentioned in section 3.2, the climb of melted filler alloy against vertical member was small when specimens were treated by chemicals, resulting unsatisfactory fillet formation. Sound fillets were obtained by grinding the vertical members with emery papers of 80～1000 grades, however, sound fillet was not formed by grinding with fine papers of 1200 and 1500 grades. **Photograph** 7 is scanning electron micrographs of specimen surface ground with various emery papers. Ground direction is distinguished and grooves caused by grinding are clearly observed in 80～600 grades. Fine asperity exists on the surface ground with 1000～1500 grades. The grooves shown in Photo. 6 (a)～(c) may have capillary effect for the climb of melted filler alloy. Then, vertical member was ground to perpendicular direction against the climb of molten alloy. Horizontal member was ground parallel to longitudinal direction. This treatment eliminates the possibility of capillary effect due to grooves caused by grinding. This test revealed that sound fillet was formed by grinding with 80～1000 grades emery papers and L_V/L_H was great enough (0.85～0.9). Good fillet was not obtained by 1500 grade. These results are quite independent of grinding direction of vertical member. Therefore, the grooves shown in Photo. 6 (a)～(c) are not so effective for the climb of filler alloy.

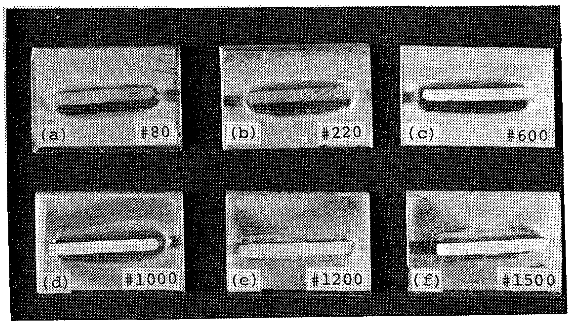

Photo. 6 Appearances of specimens ground by various grades of emery papers.

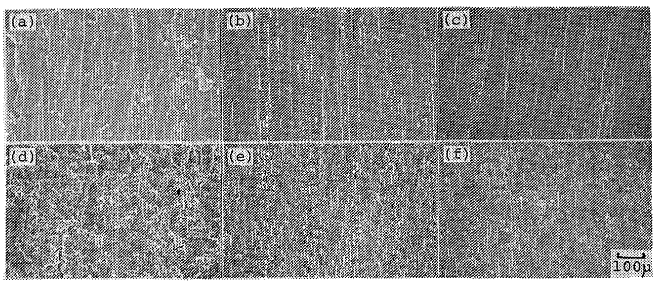

Photo. 7 Scanning electron micrographs of 1100 aluminum ground with various emery papers, emery paper numbers are (a) 80, (b) 220, (c) 600, (d) 1000, (e) 1200 and (f) 1500.

Photograph 6 (d)～(f) show similar surfaces irrespective of the grades from 1000 to 1500, however, brazability is quite different from surface conditions such as the surface of 1000 grade to the surface of a group of 1200 and 1500 grades. Surface condition is slightly rough in the former than the latters, but this small difference may not be considered as the cause of the difference in brazability. The component of the emery paper (Si) was fairly included in specimens ground with 1000～1500 grades. The qualitative analysis of included species may be important for the precise discussion of the effect of emery paper number on brazability.

4. Summary

An inserted brazing method, in which a filler alloy sheet (BA 4047) was preset between vertical and horizontal member, enabled the vacuum brazing of aluminum under suitable surface pretreatment. The obtained results are summarized as follows.

(1) Emery paper grinding is adequate for the pretreatment of aluminum vacuum brazing compared with chemical methods. Specimens ground with 600 grade emery paper can be well brazed at 590°C.

(2) Satisfactory fillet was not obtained in the specimens ground with 1200 and 1500 grades, however, sound fillet was formed at 607°C by grinding with rougher papers than 1000 grade.

(3) Sound fillet was not formed when both vertical and horizontal members are treated by chemicals, but grinding of vertical member with emery paper makes the fillet formation possible to some extent. However, the brazability of these specimens was not so good as those of both members ground with emery paper. In the specimen with chemically treated horizontal member, higher brazing temperature (605～615°C) was required to make the value of L_V/L_H high, in addition to this, the maximum value is lower than that of emery paper grinding.

References

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