Vacuum Brazing of Aluminum Using Al-12%Si System Filler Alloy†

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Abstract

Aluminum vacuum brazing using Al-Si filler alloy is carried out in relation to the surface roughness of base plate. The results indicate that the medium rough paper grinding is adequate for the pretreatment of aluminum vacuum brazing. Surface film of filler alloy seems to act as an obstacle to the sound fillet formation. Insert type brazing method, in which filler alloy plate is pre-set between the vertical and the horizontal members, enables excellent fillet formation and is recommended for this system.

1. Introduction

Vacuum brazing of aluminum is receiving wide attention as one of the fluxless method[1)–5)]. It permits excellent brazability without the use of very aggressive fluxes and eliminates the problems caused by flux residues such as corrosion and expensive process of its removal. The mechanism for vacuum brazing of aluminum is proposed by Terill et al.[6)] who used numerous metals as possible activators. Their experiments showed that successful brazing in vacuum was possible only if the following reaction occurred, where M represents the metal and MO the oxide.

$$M + \frac{1}{3}Al_2O_3 \rightarrow MO + \frac{2}{3}Al$$

And they stated that there appeared to be no relationship between metal vapor pressures and ability to promote vacuum brazing. Magnesium was regarded as the best metal for a braze promotor. Therefore in recent years, claddings containing small amount of magnesium are used for vacuum brazing of aluminum.

Although such brazing sheets enhanced the component reliability and working efficiency, the metal promotors which scavenge remaining oxygen and moisture in the vacuum contaminate the furnace interior bacause of its high vapor pressure. Then it is desirable that the claddings contain non-volatile metal promotor or none.

In the first stage of the work, to find out the fundamentals in vacuum brazing of aluminum using Al-Si filler alloy, commercial pure aluminum (1100) was vacuum brazed after various surface treatments.

2. Experimental

2.1 Materials

Commercial pure aluminum plate (1100) was used as base plate and Al–12%Si alloy (1.6^{ϕ}x 20^{l} mm, BA 4047) as a filler alloy. Chemical compositions of the alloys are shown in Table 1. As indicated in previous work[7)], shape and size of the brazed joint are as follows: horizontal member; $25^{w}x35^{l}x3^{t}$ mm, vertical member; $12^{h}x25^{l}x3^{t}$ mm. Specimens are brazed into tee type joint by setting the filler alloy closely at the both sides of the vertical member. Members are bound by molybdenum wire (0.3^{ϕ} mm) for the purpose of fixture, and then set hori-

Table 1 Chemical compositions of alloys (wt%)

	Si	Fe	Cu	Mn	Al
1100	0.08	0.23	0.03	0.02	bal.
BA 4047	12.1	0.34	<0.01	<0.01	bal.

Mg, Cr, Zn, Ti, < 0.01

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zontally in a furnace. Brazability was evaluated by the appearance after brazing, fillet area and the shape of fillet. Figure 1 shows the designations used to compare the brazability. S_F, S_M, L_V and L_H are the mean value of the both sides of the fillets respectively.

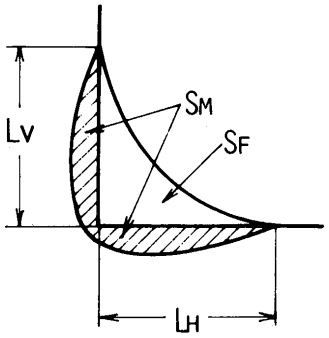

Fig. 1 Symbol of fillet size
S_F: fillet area, S_M: melted area, L_H: horizontal leg length of fillet, Lv:vertical leg length of fillet

2.2 Brazing method

The laboratory vacuum furnace is a cold wall type electric resistance furnace. Before vacuum brazing, specimens were ground with emery papers of various roughness and then washed and dried with acetone. They were set in the furnace and then heated after the chamber achieved to 2×10^{-5} torr pressure. Brazing temperature was controlled by the thermocouple located 1 cm away from the specimen in the furnace. Therefore in the following interpretation, brazing temperature means the temperature of the thermocouple. The temperature of the specimen is presumed slightly lower than the brazing temperature. After heating for the periods of 18–20 min, filler alloy flows to form fillets. Having observed the filler alloy to flow, heating was stopped and the specimens are cooled in introduced argon.

3. Results and discussions

3.1 Brazing temperature

Previous work[7] revealed that the adequate brazing temperature of this alloy system was about 610°C. To clarify the effect of the brazing temperature, brazability was compared after brazing at 603,610 and 620°C. Prior to brazing, specimens were ground with emery paper (No. 600). Unbrazed and extremely poorly brazed parts were designated as unsatisfactory brazed parts (UBP), and the ratio of the length of UBP to the total length of vertical member was designated as unsatisfactory brazed ratio (UBR). A representative UBP is shown in Photo. 1.

The relation between UBR and the brazing temperature is shown in Fig. 2. UBR is about 0.3 at 603°C and decreases with the rise of brazing temperature up to 620°C, where it decreases to 0.13. UBP is observed in all specimens tested in the temperature range, fillet is formed along all around of the vertical member, but the fillet area is greatly different from here and there.

Figure 3 shows the relation between the maximum crosssectional fillet area and leg length and the brazing temperature. Fillet area and melted area increased with increasing the brazing temperature. Horizontal fillet leg length is not so changed with the temperature but vertical one fairly decreases at 603°C. Ideal fillet satisfies the relation of $L_V=L_H$. Therefore the ratio of L_V to L_H (L_V/L_H) is useful for the comparison of brazability. Figure 4 shows L_V/L_H at each temperature. L_V/L_H becomes constant over the brazing temperature range of 610–620°C. But its maximum value is only 0.6, which means that the horizontal fillet leg length is considerably longer than that of the vertical one. The calculated ideal fillet area and fillet leg length is 2.5mm^2 and 3.4mm respectively, on the other hand, obtained ones largely deviated from these values (Fig. 3).

3.2 Influence of the emery paper roughness

Figure 4 suggests that the vacuum brazing of this system is suitable over the temperature between 610–620°C. Figure 3 (a) shows that the melted area at 620°C is great. Then in the following tests, the brazing temperature was fixed to 612°C, tests were carried out to investigate the effect of paper roughness on brazability. The

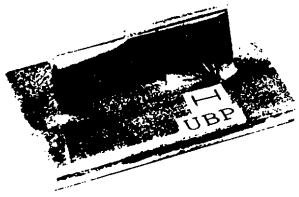

Photo 1 Example of unsatisfactory brazed part (UBP)

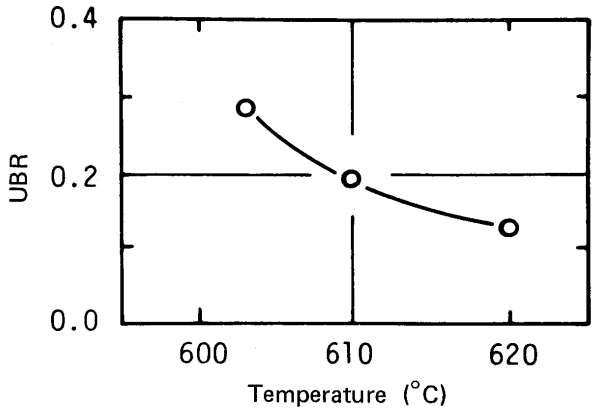

Fig. 2 Relation between UBR and brazing temperature

relation between the paper roughness and UBR is shown in Fig. 5. Sound fillets are not obtained in the specimens ground with the paper of No. 80 and 1500. But the specimens ground with the paper of No. 320–600 showed fillets containing UBR of 20–40%. Figure 5 indicates that the brazability is between when the specimens were ground with medium rough paper rather than rough or fine paper. The relations between the paper roughness and crosssectional fillet area (S_F) and leg length ratio (L_V/L_H) are shows in Fig. 6. The figure shows the scattering range of several measurements. As shown in this figure, there is a large scattering fillet area and the horizontal leg length of fillet is longer than that of the vertical one.

3.3 Pretreatment of filler alloy

Figure 5 indicates that it is impossible to decrease the UBR below 20%. To presume the cause of UBP, the melting process of filler alloy was observed through the window equipped to the furnace. The fact was found that the oxide film of filler alloy disturbed the flow of melted filler alloy. After melting of filler alloy, the oxide film still remains as a continuous thin film as if a "castoff skin", a part of this film adheres to the base metal (horizontal and/or vertical member) inhibiting the fillet formation, this led the unsatisfactory brazed parts.

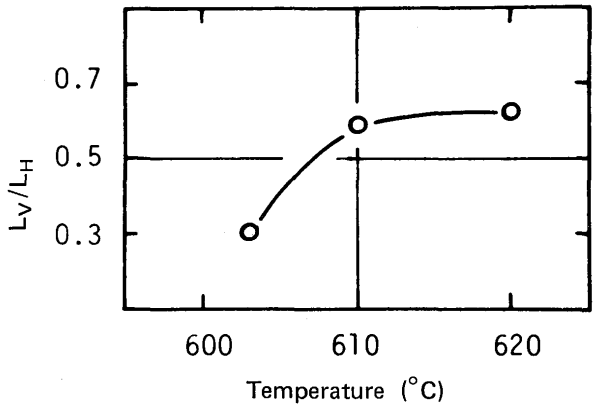

Fig. 4 Effect of temperature on L_V/L_H

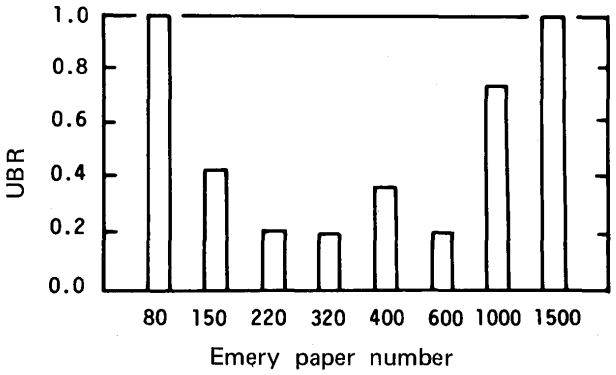

Fig. 5 Relation between UBR and emery paper number

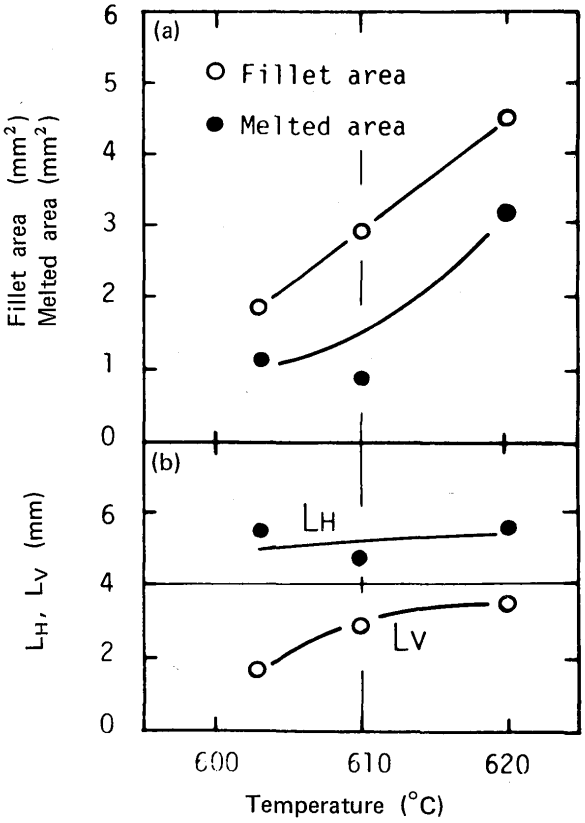

Fig. 3 Relations between brazing temperature and (a) fillet area and melted area, (b) fillet leg length

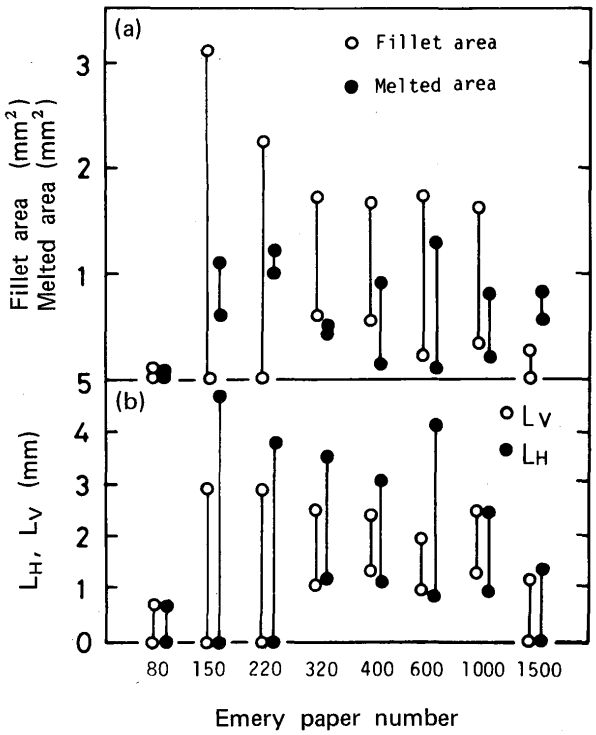

Fig. 6 Relations between emery paper number and (a) fillet area and melted area, (b) fillet leg length

Supposed that the oxide film of filler alloy became flaky and is crushed into fine fragments, finely dispersed oxide may not strongly disturb the fillet formation and it is expected that the sound fillet formation became easier. The oxide films of filler alloys which contain magnesium as an activator is believed to be destroyed when the activator volatiles at brazing temperature. The action does not only create the fresh (oxide free) surface of filler alloy but also decreases the adhesionability of oxide film. This seems to be a main role of the activator. Therefore a certain pretreatment of filler alloy is thought to be suitable for the formation of a flaky surface film at brazing temperature. The filler alloy was subjected to several chemical and thermal pretreatments including etching and vacuum annealing etc. But these pretreatments did not decreased the UBR to extremely low value. It is suggested that the destruction of surface film of filler alloy is difficult only by chemical pretreatment. Then the following experiment was carried out to destroy the surface film mechanically.

3.4 Inserted type brazing method

To destroy the oxide film of filler alloy, filler alloy sheet (25^{l}x3^{w}x1.35^{t} mm) was pre-inserted between the vertical and the horizontal members. And a little pressure was applied by heat resistant spring. The vertical member goes down toward the horizontal member when the filler alloy melts. This movement is expected to destroy the surface oxide film and to produce fresh surface which enables sound fillet formation. In fact, excellent fillet was obtained by this method. Appearance of the brazed joint is shown in Photo. 2 in relation to the paper roughness. Excellent uniform fillets are obtained using the paper of No. 80–1000. UBP is not observed in these specimens.

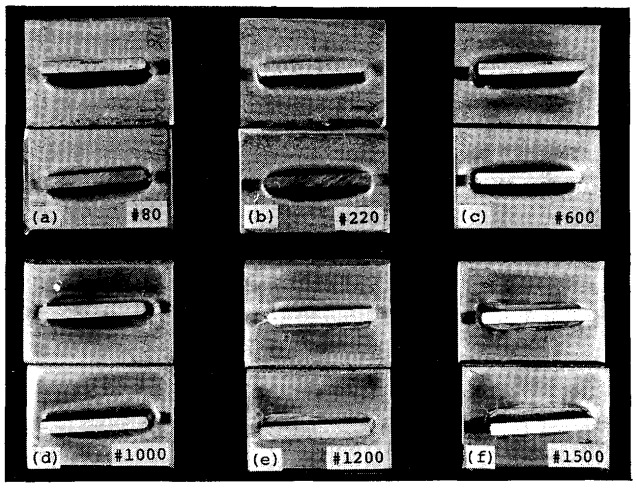

Photo 2 Appearance of vacuum brazed specimens (Numbers in Photo coincide with the emery paper number).

But satisfactory fillet was not formed with the paper of No. 1200 and 1500. Crosssectional fillet area was large enough and the value of L_V/L_H was over 0.8 in the specimens with the paper of No.220–1000, but was small in No. 1200 and 1500.

The obtained results indicate that the grinding with medium rough paper is suitable for the pretreatment of aluminum vacuum brazing. Detailed results and discussions will be published in the following paper.

4. Summary

Aluminum vacuum brazing using Al–Si filler alloy is difficult to obtain excellent fillet in case the filler alloy rod set closely to the vertical member. Surface oxide film of filler alloy is believed to be responsible for the scattering of fillet area. Inserted type brazing methods made it possible to obtain uniform sound fillet formation. Medium rough paper is adequate for the pretreatment of this method.

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