Vacuum Brazing of Aluminum (Report-II)†

—Effect of Emery Paper Grinding—

Ikuo OKAMOTO* and Tadashi TAKEMOTO**

Abstract

Vacuum brazing of aluminum with BA 4047 (Al-12%Si filler alloy) can be performed by an inserted type brazing method, in which the filler alloy is preset between the vertical and horizontal members of tee type joint. Grinding by emery papers of 80–600 grade is recommended for the surface pretreatment. On the other hand, grinding by fine emery papers (1500 grade) causes the contamination of surface layer by inclusion of emery paper component SiC and showed poor fillet forming. The decrease in brazability by inclusion appears to be the scarce reaction between the filler alloy and SiC. For the estimation of brazability in preplaced filler alloy method, some parameters are discussed. The ratio of vertical leg length (L_V) to horizontal leg length (L_H) is adopted as a convenient and clear parameter. A spreading test is useless for estimating the ability of fillet formation.

1. Introduction

Flow factor[1)2)] is one of a convenient parameter to estimate a brazed fillet performed by a brazing sheet (**Fig. 1(a)** and **(b)**). But it is not always useful when the fillet form is not uniform or fillet form is different in each side (**Fig. 1(c)** and **(d)**). Therefore, new methods to be substituted for the flow factor had been proposed[3)4)]. These methods are based on the ability of filling a clearance by molten claddings.

However, when a preplaced brazing method is applied, a convenient method for estimating brazability is not yet established. This appears to be attributable to the difficulties of preplaced brazing of aluminum in vacuum. The authors adopted an insert type brazing method, in which the filler alloy sheet was preinserted between the vertical and horizontal members of tee type joint specimen. This made vacuum brazing possible without the use of a magnesium getter metal or addition to the filler alloy[5)]. As first stage in the present work, the estimation method for the insert type brazing will be discussed. Then, the effect of emery paper grinding on the brazability was investigated using several grades of emery papers. A spreading test was also carried out for the explanation of fillet forming mechanism.

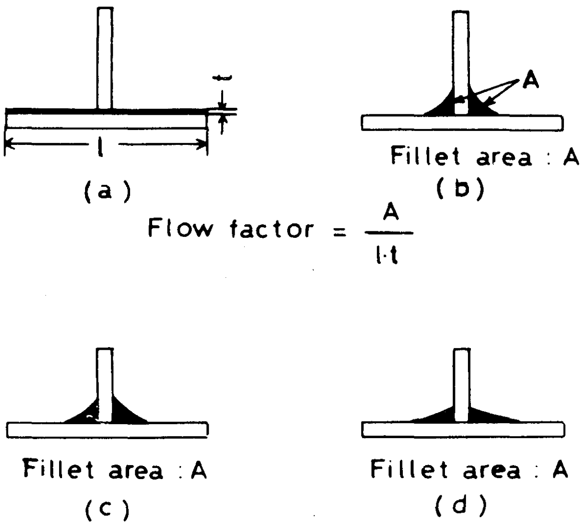

Fig. 1 Designation of flow factor.

2. Experimental Procedures

2.1 Fillet forming test

The used base plate is commercially pure aluminum (1100) and filler alloy is Al-12.1%Si alloy (BA 4047). The chemical compositions were listed in the previous paper[5)]. The setting way of tee type joint specimen is shown in **Fig. 2.** A sheet filler alloy ($1.35^t \times 3^w \times 25^l$) is preinserted between the vertical and horizontal members of tee type joint and a pressure of 20 g/mm^2 is applied to the filler alloy through a heat resistant spring. Prior to setting, both base plates were ground with emery papers of 80–1500 grades and rinsed in acetone by an ultrasonic cleaner. The vacuun braz-

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* Professor
** Reserch Instructor

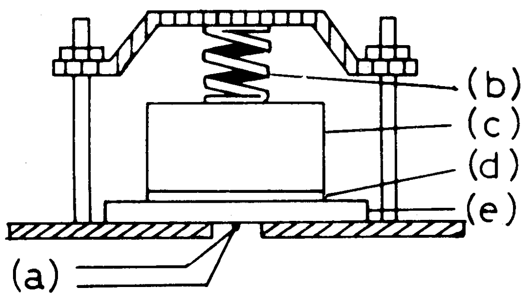

Fig. 2 Schematic view of tee joint specimen. (a) thermocouple, (b) heat resistant spring, (c) vertical member, (d) filler alloy, (e) horizontal member

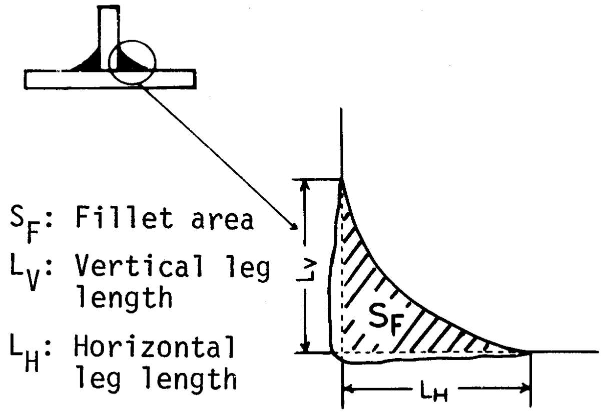

Fig. 3 Designation of fillet size.

ing furnace was evacuated to 2×10^{-5} torr. Precise experimental procedures were shown in the previous paper[5].

2.2 Spreading test

A spreading test in vacuum was carried out to investigate the relation between the fillet forming ability and the spreadability and to make clear the effect of applied pressure. The filler alloy $(2\times2\times0.5^t)$ was set on the center of the horizontal base plate $(25^l\times15^w\times3^t)$ and pressed to 20 g/mm² through the spring. The vacuum level and heat cycles are same as the fillet forming test.

3. Results and discussions

3.1 Estimating method for fillet forming test

The estimating mathods for the brazability when a brazing sheet is used are as follows; (1) flow factor, the ratio of the amount of the formed fillet to that of the cladding, (2) the ability of clearance filling[3)4)]. In this work, the cross sectional fillet area (S_F) was measured correspondingly the flow factor and the leg length ratio, L_V/L_H(L_V: vertical leg length, L_H: horizontal leg length), was measured as a parameter for the ability of fillet forming. **Fig. 3** shows the designation of a fillet. Other factors such as uniformity of fillet size and surface condition of fillet (void or roughness) were also classified by the visual inspection.

To investigate the effect of surface pretreatment of base plate on the above mentioned factors, the specimens ground by various grades of emery papers (80–1500 grade) were brazed at about 600°C. The results are shown in **Table 1.** The sound uniform brazed fillet with smooth surface (mark; ○) was obtained by grinding with 80–1000 grade, however, the satisfactory fillet was not formed by 1500 grade (●). S_F, L_V and L_H were measured from the cross-section at the center of the longitudinal direction, and they are the mean value of both sides. The calculated value of S_F and $L_V(=L_H)$ for ideal fillet size are 3.2 mm² and 2.75 mm respectively. The value of S_F is beyond the ideal one, because the fillet size at the center of the specimen is larger than that of the edge. As the residual amount of filler alloy between the vertical and horizontal member cannot contribute to the formation of fillet, this residues should be rejected from the caluculation of S_F and L_V. The residual amount depends on the brazing temperature, filler alloy composition (mainly silicon content) and applied stress.

Table 1 Comparison of various parameters such as S_F, L_V and L_V/L_H.

Emery paper (grade)	Brazing temperature (°C)	Appearance of fillet*	S_F (mm²)	L_V (mm)	L_V/L_H
80	598	○	3.7	2.5	0.90
600	603	○	4.0	2.6	0.90
1000	602	○	4.9	2.9	0.86
1500	606	●	2.5	1.2	0.20

* ○: Good, ●: Scarcely brazed

Therefore, the standard value of S_F and L_V are the function of brazing conditions. On the other hand, L_V/L_H is convenient and clear because the brazability get better when it approaches 1. L_V/L_H is 0.9–0.86 when ground by 80–1000 grade emery papers, but it is extremely small by 1500 grade. The change in L_V/L_H with emery paper grade is similar to the change in visual appearance of fillet. The scattering range of L_V/L_H is smaller than the other indexes. In this work, L_V/L_H was adoppted as the estimating parameter, and in addition to this, visual appearance and S_F were also taken into account.

3.2 Effect of surface pretreatment on fillet forming ability

This experiment was carried out to clarify the effect of emery paper grinding on fillet forming ability precisely. **Fig. 4** shows the effect of emery paper grade on the appearance of fillet formed at various temperatures. The uniform fillet was formed at 585–595°C by 80 and 600 grade (marks; ○ - ⊕), however, the fillet surface was more smooth in 600 grade. The results of 1000 grade at 585–600°C are inferior to those of 80 and 600 grade, but showed stable fillet formation at more than 600°C. The large fillet was not obtained by 1500 grade up to 630°C, at this temperature surface roughness became remarkable (⊕) and the flow of filler alloy is not uniform. Therefore, the sound fillet could not be formed by 1500 grade. In the designation of Fig. 4, the open circle means satisfactory good smooth fillet and the solid circle means extremely small fillet or non uniform filler alloy flow (poor brazing). Other classifications are noted in the figure captions.

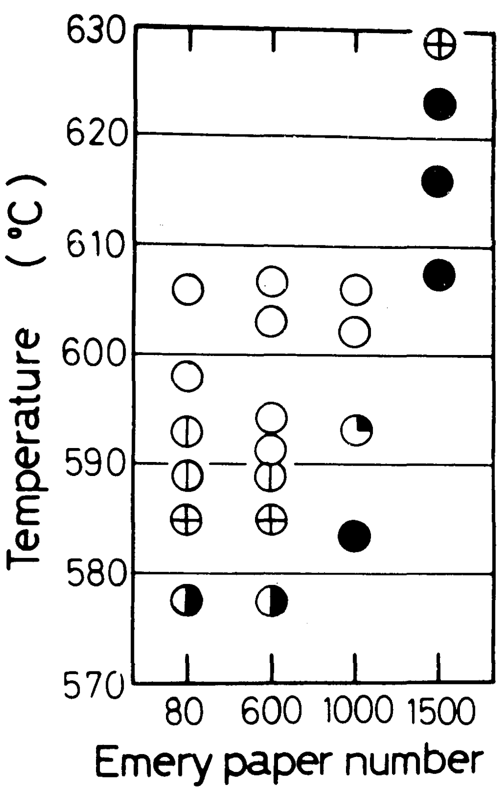

Fig. 4 Results of visual inspection of fillet formed on specimen ground by emery papers at various temperatures. Appearance of fillet is classified as follows: ○; good, ⦶; slightly rough surface, ⊕; rough surface →●; poor fillet formation.

Figure 5 shows the relation between L_V/L_H and the brazing temperature. L_V/L_H exceeds 0.8 in 80 and 600 grade even at 585°C, and it shows the constant value of 0.8–0.9 up to 610°C. In 1000 grade, L_V/L_H is about 0.6 at 590°C and increases with the rise in temperature, and it exceeds 0.8 at more than 600°C. From Figs. 4 and 5, it is obvious that 80 and 600 grade is superior to 1000 grade for the surface treatment of aluminum vacuum brazing. On the other hand, L_V/L_H is only 0.65 even at 630°C in 1500 grade, by which aluminum cannot be satisfactory brazed. Fig. 5 also shows that L_V/L_H reaches the constant value at a certain temperature except 1500 grade. S_F was large enough when L_V/L_H exceeds 0.8. Accordingly, the certain temperature promises that L_V/L_H is over 0.8 and the fillet is uniform and large enough with smooth surface. And the temperature for the base plate ground with 80, 600 and 1000 grade emery papers is 595, 590 and 605°C respectively. The temperature will be designated as the lowest temperature to obtain a sound brazed joint.

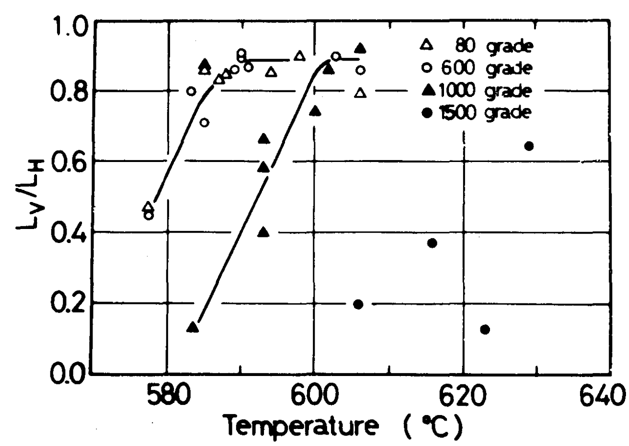

Fig. 5 Effect of emery paper number on the relation between L_V/L_H and brazing temperature.

3.3 Spreading test

A spreading test is widely adopted to estimate the flowability of solder and filler alloys, however, recent work pointed out that the filler alloys with good spreadability is not always superiour to the ability for fillet forming and clearance filling. In this work, spreading tests were carried out in vacuum to investiage the effect of surface pretreatment of base plate and the applied stress on spreadability. The results are shown in **Photo. 1.** The difference in spreading

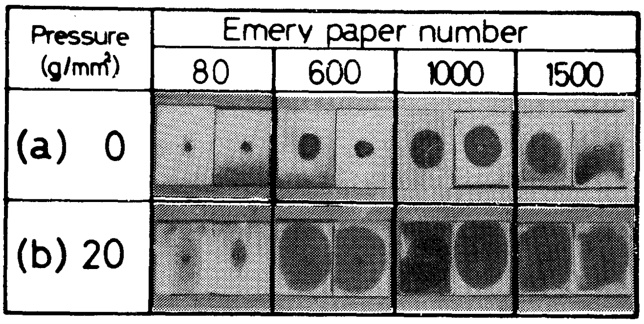

Photo. 1 Effect of pressure applied on the filler alloy and emery paper number on spreadability.

characteristics may become dominant at lower temperature. Therefore, the spreading test was done at 590°C, at which the good braze joint as mentioned above section is possible in 600 grade. As shown in Photo. 1, the spread area is larger in the pressed specimens, and under applied pressure it is larger in 600–1500 grade than in 80 grade, and is almost equal among the former ones. Under no pressure, the spread area is extremely small in 80 grade. The results in 1500 grade is quite different from each specimen. From Photo. 1, one of the effect of the pressure on filler alloy flow is the mechanical destruction of the surface oxide film on the filler alloy by the movement of vertical member. Then the clean surface molten alloy is pushed out to both fillet sides and rapidly reacts with the base plates. On the contrary, a sound braze joint cannot be performed under no pressure or when the filler alloy is preplaced on both fillet sides, because the surface oxide film of filler alloy cannot be destroyed completely and consequently the flow and wetting are disturbed by the film.

The spreading behavior is similar in 600 grade and 1500 grade, but the fillet forming ability is quite different from each other, the former is excellent and the latter is poor. In addition to this phenomenon, 80 grade is inferior in spread area than that of 1000 grade, however, the result of the fillet forming test is superior to 1000 grade, because the braze joint can be performed at lower temperature. As mentioned above, there is no correspondence between the result of spreading test and fillet forming test. This indicates that the spreading test is not available for the estimation of fillet forming.

3.4 Effect of emery paper grinding

The depth ground by emery paper is more than 10μ, accordingly the surface oxide layer of as received condition is completely removed. The thickness of surface oxide film grown by reoxidation in air at room temperature is reported to be about 45Å[6,7]. Under the hypothesis that the reoxidated film thickness is independent on the emery paper grade, the difference of fillet forming ability must be dependent on the other properties of ground surface. The surface roughness profile perpendicular to the grinding direction is shown in **Fig. 6.** The surface by 80 grade is extremely rough but the others are similar fine profile. Even though similar surface profile in 600, 1000 and 1500 grade, satisfactory fillet was not obtained only by 1500 grade grinding, but 80, 600 and 1000 grade made good fillet. As the result, there is no correspondence between the surface roughness and the ability of fillet forming.

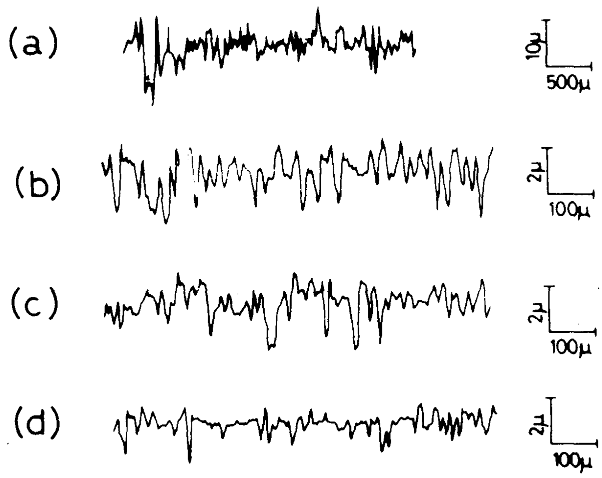

Fig. 6 Surface roughness profile of base matals ground by various grades of emery papers. Measured direction is perpendicular to the grinding direction.

Photograph 2 is a scanning electron micrograph of inclusion in emery paper ground surface. These particles are retained even after ultrasonic rinse in acetone for several minutes. The amount of inclusion is abundant in fine paper grinding (1500 grade). **Fig. 7** is the energy dispersive X-ray analysis of in-

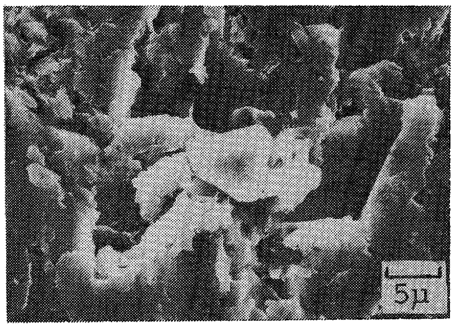

Photo. 2 Scanning electron micrograph of included particle in emery paper (1000 grade).

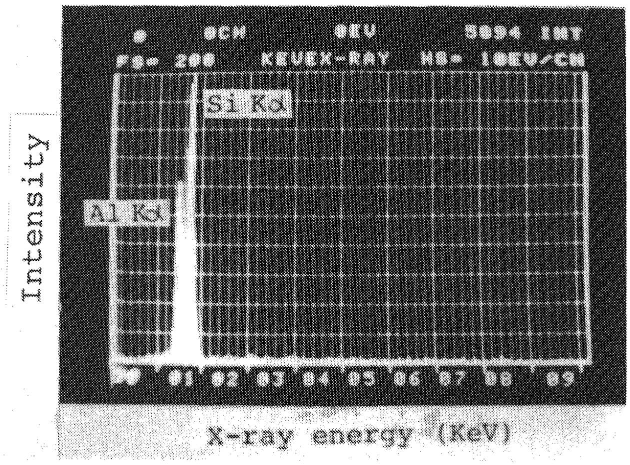

Fig. 7 Energy dispersive X-ray analysis of included particle in surface. The particle is believed to be SiC.

clusion. The silicon appears to be SiC because the result of X-ray analysis by a diffractometer (**Table 2**) indicated that the components of emery paper were α-SiC(II) and (III) and the scattering lines of β-SiC were also included in the former ones. Silicon carbide is stable even at a high temperature and have scarce reactivity with other materials. The inclusion of SiC in the surface area will effect on the wetting between the base metal and the molten Al-Si filler alloy. To investigate this point, the filler alloy was heated on a sintered α-SiC plate at 615°C. But the filler alloy could not react with SiC through the heating cycle and no wetting was occurred. Therefore, the alloy could easily be peeled off from the SiC base palte after cooling. From this fact, large numbers of included SiC particle on aluminum surface may prevent rapid flow of filler alloy. The analytical results of the surface are shown in **Table 3.** The silicon content in the surface ground by 80 and 600 grade is similar to that of the base plate, but the silicon content increases by 1000 grade and 1500 grade grinding, which is due to the inclusion of SiC. The SiC particle size decreased with the increase in grade number, then the total surface area of SiC particles increased with the

Table 3 Silicon content in surface ground with various emery papers.

Emery paper number	80	600	1000	1500	base plate
Si content (wt%)	0.10	0.20	0.81	1.59	0.08

Table 2 X-ray analysis of emery paper (1500 grade).

Obsevations		α-SiC (I)		α-SiC (II)		β-SiC	
d (Å)	I	d (Å)	I/I_o	d (Å)	I/I_o	d (Å)	I/I_o
2.667	w			2.67	0.4		
2.622	M	2.61	0.6				
2.578	M			2.59	0.5		
2.515	S	2.51	0.7	2.52	0.4	2.51	1.0
2.356	M	2.36	0.5	2.36	0.5		
2.181	w	2.19	0.4			2.18	0.1
2.084	vw			2.08	0.3		
1.998	vw	2.00	0.3				
1.828	vw	1.67	0.3	1.83	0.2		
1.608				1.61	0.4		
1.540	M	1.54	0.8	1.54	0.6	1.54	0.6
1.423	w	1.419	0.5	1.419	0.5		
		1.329	0.3				
1.315	M	1.309	0.8	1.311	0.7	1.310	0.6
1.290	w	1.285	0.3	1.287	0.4		
1.258	vw	1.253	0.3	1.254	0.3	1.256	0.1

Intensity: vw<w<M<S

increase in grade number, as compared with same content. Therefore the fine SiC inclusions with large surface area prevent the rapid reaction between the base plate and molten filler alloy, which is the main reason of the decrease in brazability.

The direct observation of the filler alloy flow revealed that a good braze joint could be performed under the condition that rapid wetting between the vertical member and the molten alloy occurred. On the other hand, when the reaction is delayed by the inclusion or undesirable surface treatment, scarce climb of filler against the vertical member occurred and the molten filler alloy spread plainly on the horizontal member leading poor fillet. **Fig. 8** shows this schematically. When the pretreatment of base metal is pertinent and the wetting ocurred quickly, the molten alloy reacts with the vertical member and forms a fillet (Fig. 8(a)). But when the wetting is delayed by undesirable surface treatment, molten alloy is flattened on the horizontal member with the rise in temperature and wetting occurs after a little temperature rise. However, the formed fillet is far from the ideal one (Fig. 8(b)). Thus, the fillet forming proceeds under this non-ideal state with the rise in temperature, namely, with the increase in heating time. As can be seen in Fig. 5, in case that the pretreatment of base metal is not proper, the formed fillet has low value of L_V/L_H. In fact, when both the vertical and horizontal members were pretreated by chemicals, L_V/L_H and fillet area decreased. But when the vertical member is ground with emery paper, L_V/L_H increases, even together with chemical treated horizontal member. **Fig. 9** shows the effect of the pretreatment of horizontal member on L_V/L_H at various temperatures. The precise description of the pretreatment is shown in the previous paper[5]. L_V/L_H of chemically treated specimens are lower than that of emery ground ones, and the higher temperature (more than 600°C) is required for the satisfactory fillet forming. L_V/L_H of as-received surface (only degreased with acetone) is low and the higher temperature is required for fillet forming. The poor brazability dependent on the above mentioned pretreatments may be attributed to the delayed wetting due to the thickness or the characteristics of surface film or adsorped moisture on the surface layer. Accordingly, it will be concluded that the rapid reaction between the molten filler alloy and the vertical member is essential for the ideal fillet forming.

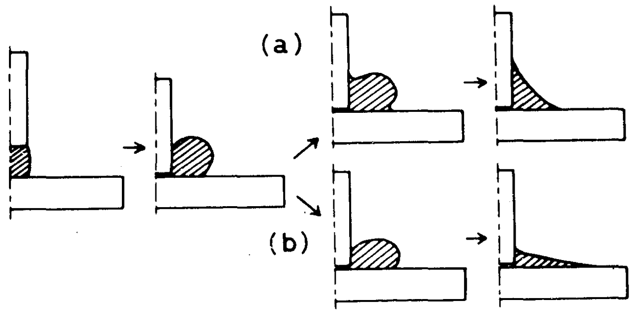

Fig. 8 Schematic diagrams of fillet forming process. Sound fillet can be formed by pertinent pretreatment of base plates (a), but filler alloy flows plainly on horizontal members by inadequate pretreatment (b).

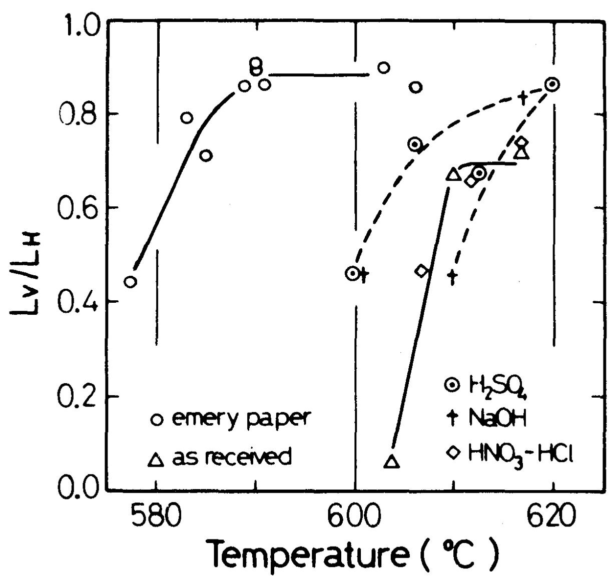

Fig. 9 Effect of surface treatment of horizontal member on L_V/L_H. Vertical members were ground with 600 grade emery paper.

4. Summary

An inserted type brazing method, in which the filler alloy is preset between the vertical and horizontal members of tee type joint, is recommended for the vacuum brazing of aluminum with Al-Si filler alloy. Grinding by emery papers of 80–600 grade is suitable for the surface treatment of aluminum vacuum brazing. The obtained results are summarized as follows.

(1) The ratio of vertical leg length (L_V) to horizontal leg length (L_H) in brazed fillet is a convenient and clear parameter for estimating the fillet forming ability. In satisfactory brazed joints with uniform fillet form and smooth surface, L_V/L_H exceeded 0.8.

(2) Grinding by fine emery papers led contamination of ground surface by including the emery paper com-

ponent SiC. The sound fillet was not formed by grinding with 1500 grade emery paper which retained much inclusions on treated surface. The scarce reactivity of SiC with molten Al-Si filler alloy is responsible to the poor fillet forming in 1500 grade.

(3) The sound fillet was obtained by grinding with 80–600 grades emery papers in which a little inclusion was observed.

(4) The pertinent surface pretreatment of base metal is essential for the sound fillet forming, especially the vertical member should be pretreated so that reacts rapidly with molten filler alloy.

(5) Clear correspondence was not found between the spreadability and the fillet forming ability.

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