BRAZING OF AL-MN-MG ALLOYS WITH CSF-ALF$_3$ NON-CORROSIVE FLUX

Tadashi TAKEMOTO*, Toshihiro SHIBUTABI and Akira MATSUNAWA***

*: Joining and Welding Research Institute, Osaka University
11-1 Mihogaoka, Ibaraki, Osaka 567-0047 Japan
**: Graduate student, Osaka University, Presently at Eng. & Machinery Center, Kobe Steel Ltd.
2-3-1, Shinhama, Arai-cho, Takasago, Hyogo 676 Japan

ABSTRACT Brazeability of Al-Mn-Mg alloys with CsF-AlF_3 non-corrosive flux has been investigated by fillet formation test on tee type specimen using a brazing sheet. The standard brazing temperature and time were 590 ℃ and 600s respectively. Fluxes used were CsF-AlF_3 system non-corrosive fluxes with different ratio of CsF/AlF_3 and $KAlF_4$-$K_2AlF_5 \cdot H_2O$ (KA) for comparison. Brazeability was remarkably depended on flux composition and magnesium content of base metal. Brazeability was lowered with increasing the magnesium content. On the whole, KA flux offered good fillet formability, however, it gave large flux penetration into base metal. In CsF-AlF_3 fluxes, the increase in CsF ratio lowered the brazeability. In CsF-AlF_3 fluxes, the penetration depth was smaller than in KA flux, especially CA flux with CsF/AlF_3 ratio of 1.2 gave similar brazeability to KA flux for magnesium containing base metals, therefore, CA flux is recommended for brazing of magnesium containing base metal such as 3004 alloy.

Keywords: *aluminum brazing, non-corrosive flux, flux penetration, Al-Mn-Mg alloys,*

1. INTRODUCTION

Aluminum brazing is an important technology in assembling of various heat exchangers. Non-corrosive flux brazing process[1,2] is a unique process because the process is not required to remove flux residue due to the stability of residue. The process has become popular in production of heat exchangers for automobile use[3,4]. The non-corrosivity of flux is derived from the insolubility of flux into water. The process offers excellent brazeability in low oxygen and low dew point atmosphere[5], however, similar to the other brazing processes, the process gave poor brazeability for magnesium containing base metals[6-8]. The poor brazeability in non-corrosive flux is based on the chemical reaction between flux constituents and magnesium in base metal. The reaction, magnesium poisoning[9,10], consumes the supplied flux available for removing oxides and forms the compounds with relatively high melting temperature, suggesting that the compounds act as obstacles against wetting.

The brazing of high strength alloys containing magnesium is important for the reduction of weight and high efficiency in heat exchangers. Recently, several CsF-AlF_3 system brazing flux has been developed, however, there is no precise investigation on the flux about the applicability for magnesium containing base metals. Accordingly, the present work aimed to investigate the applicability of CsF-AlF_3 flux for brazing of Al-Mn-Mg alloys with higher strength than Al-Mn such as 3004.

2. EXPERIMENTAL

2.1 Materials

Three commercial Al-1Mn-(Mg) alloys of 2mm thickness were used as base metals for brazing test, **Table 1**. The maximum magnesium content is 1% in 3004 alloy. The brazing sheet with single side cladding was used for brazing. The brazing sheet is composed of BA4045(Al-10Si) cladding and 3003 core material, the thickness is 1 mm. The clad ratio is 10% for single side, the thickness of cladding is then 0.1mm.

Table 1 Chemical composition of base metals, mass%

Base metals	Mg	Si	Fe	Cu	Mn	A
A3003	0.001	0.23	0.52	0.15	1.16	Ba
A3005	0.41	0.23	0.50	0.15	1.15	Ba
A3004	0.99	0.24	0.50	0.15	1.15	Ba

Table 2 Comparison of chemical compositions and characteris values of fluxes used.

Flux	Composition	g/mol	F mol/mol	F
KA	KAl_4-30mass%$K_2AlF_5 \cdot H_2O$	146.4	4.23	0.02
CA	CsF/AlF_3=1.2 *	121.0	1.91	0.01
CB2	CsF/AlF_3=2.0 *	129.3	1.67	0.01
CC2	CsF/AlF_3=2.3 *	131.3	1.61	0.01

*: mole fraction of CsF against AlF_3

The fluxes used are $KAlF_4$-$K_2AlF_5 \cdot H_2O$ (KA) and three CsF-AlF_3 fluxes with diffe CsF/AlF_3 mol fraction. The chemical compositions are indicated in **Table 2** together with the m number, fluorine mol per unit mol and fluorine mol per unit mass. The fluorine per unit mass or m decreases with the following order; KA, CA, CB2 and CC2.

2.2 Brazing and evaluation method

Brazeability of base metals were evaluated by the fillet formation test on tee-type joint. Sha and size of braze specimen is indicated in **Fig. 1**. The vertical part is a brazing sheet and t horizontal part is a base metal with different magnesium content. Prior to the test, specimens we cleaned in an acid solution to remove surface oxide. The predetermined amount of flux was pla only at the clad side of a vertical part. After brazing the total length of formed fillet was measure flux placed side (Side A) and opposite back side (Side B) respectively. Fillet formability defined b the following equation was used for evaluating brazeability.

Fillet formability(%)

$$= 100\,F_L^A/50 \quad \text{(for side A)}$$

$$= 100\,F_L^B/50 \quad \text{(for side B)}$$

, where F_L^A and F_L^B are formed fillet length at side A and side B respectively.

The non-corrosive flux penetrated into base metal containing magnesium during braze heat cycle. The penetration depth was measured at the central cross section of the braze specimen. The penetration depth was also measured by the spreading test using 3004 base metal. After giving

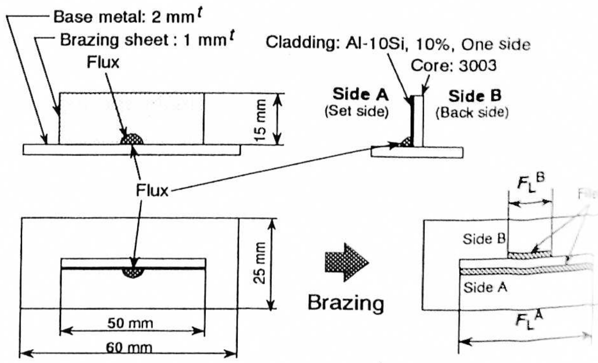

Fig. 1 Shape and size of brazing specimen and evaluation met of brazeability by formed fillet length

braze heat cycle, the flux penetration depth was measured at the central cross section.

Brazing tests were performed in high purity argon gas atmosphere, the standard brazing condition was 863K, 300s; about 900s was required to reach the brazing temperature. The X-ray diffraction analysis was conducted to reveal the reaction products, CuKα, 40kV, 20mA.

3. EXPERIMENTAL RESULTS AND DISCUSSION

Brazeability of non-corrosive flux depends on the amount of supplied flux, flux loading, therefore, the effect of the amount of flux loading on brazeability was investigated on 3003 base metal using KA and CA fluxes. **Figure 2** shows that the increase in flux loading enhanced the fillet formability in both fluxes. The flux placed side A shows better results than the opposite back side B. The KA flux has superior brazeability to CA flux, the difference in brazeability is not clear under flux loading of 10mg, where complete fillet formability was achieved at both sides A and B for both fluxes. It is recommended to use appropriate flux loading for evaluation of the difference in brazeability of fluxes. The brazeability of magnesium containing base metal is inferior to 3003 [4,6], therefore, the amount of 1mg and 10mg was adopted in the following test.

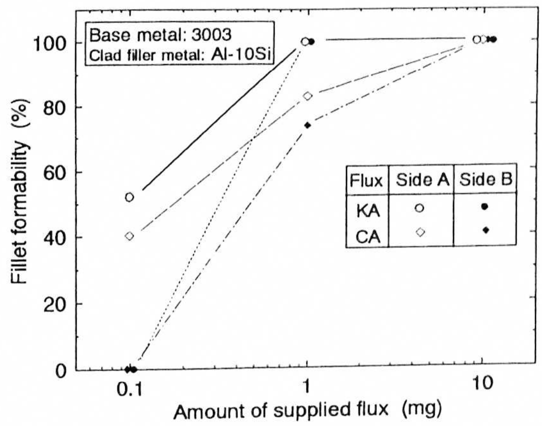

Fig. 2 Effect of amount of supplied flux on the fillet formability of 3003 base metals after brazing at 863K for 300s.

Figure 3 shows the fillet formability of non-corrosive fluxes for base metals with different magnesium content. Under the flux loading of 1mg, only KA flux with 3003 base metal showed the complete fillet formation. The other combinations of base metal and flux could not achieve the 100% fillet formation. The side A usually offered longer fillet than side B in all cases. In all fluxes the increase in magnesium content deteriorated the brazeability. Figure 3 clearly shows that the brazeability depends on the flux composition. The fillet formability became worse in the following order of fluxes.

(Good) KA > CA > CB2 > CC2 (Poor)

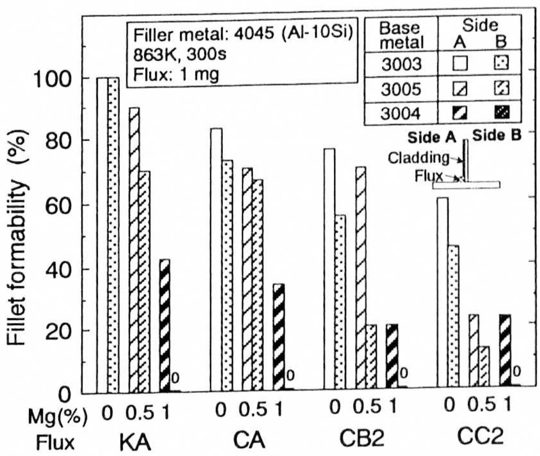

Fig. 3 Effect of magnesium content in base metal on fillet formability brazed with different fluxes at 963K for 300s.

The order coincides well with the amount of fluorine per unit mass shown in

Table 2. The higher fluorine content gave better brazeability.

The CA flux shows the best brazeability among the CsF-AlF_3 fluxes, however, the complete fillet formation could not be achieved under flux loading of 1mg. **Figure 4(a)** shows the fillet formability of 3004 base metal under flux loading of 10mg. Both KA and CA fluxes shows almost complete fillet formation, however, CB2 and CC2 fluxes show poor brazeability, especially CC2 flux showed no fillet at side B.

Our previous work on KA flux[6,10] revealed that the flux penetrated into base metal resulting in the formation of compounds with magnesium. **Figure 4(b)** indicates the penetration depth of flux into 3004 base metal after brazing. The deepest penetration was observed in KA flux, and in CC2 flux the penetration depth was extremely small. The depth decreases in the following order.

(Large) KA > CA > CB2 > CC2 (Small)

The order corresponds well with the brazeability shown in Fig. 3. The penetration depth is closely related to the brazeability, it becomes small according to the decrease in fillet formability. The CA flux showed similar brazeability to KA flux for 3004 base metal under flux loading of 10mg, and it offers smaller penetration depth than KA flux. Accordingly, the use of CA flux is recommended for brazing magnesium containing base metals.

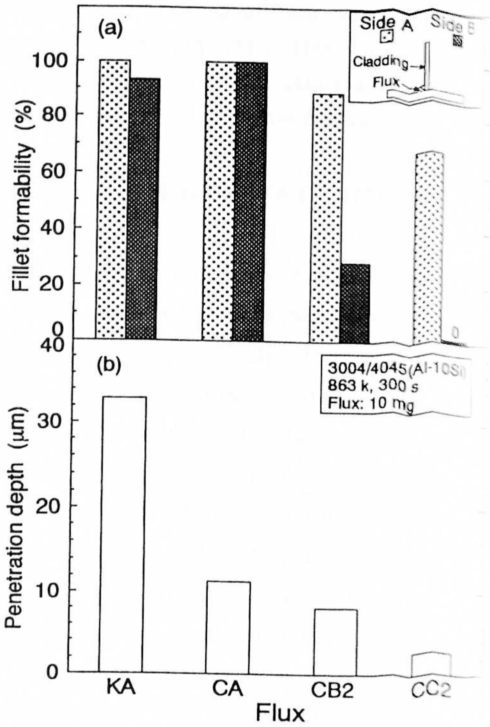

Fig. 4 Fillet formability of 3004 base metal (a) and penetration depth of flux into base metal for several fluxes (b) after brazing at 863K for 300s.

Figure 5 shows the cross section of 3004 base metal after brazing with CA flux. It is clear that penetrated CA flux formed compounds with magnesium. The elements in flux, Cs and F combined with Mg in base metal. Our previous work indicated that the KA flux formed compounds with magnesium such as $KMgF_3$ and MgF_2[6]. The X-ray diffraction analysis on CA flux revealed that CA flux is mainly composed of $CsAlF_4$ which would be the reaction products between CsF and AlF_3, of course the lines of CsF and AlF_3 are also detected. After brazing, CA flux reacted with magnesium as shown in Fig. 5, the reaction product was identified as $CsMgAlF_6$. The estimated reaction is as follows.

$$CsF + 2AlF_3 + Mg = CsMgAlF_6 + AlF \uparrow$$

The penetration depth of KA flux depends on the magnesium content of base metal, flux composition, amount of supplied flux, brazing temperature and time[6,10]. The effect of holding temperature on the penetration depth of CA flux was investigated on 3004 base metal. The CA flux of 1mg was placed at the center of 3004 base metal and then heated at several temperatures and held

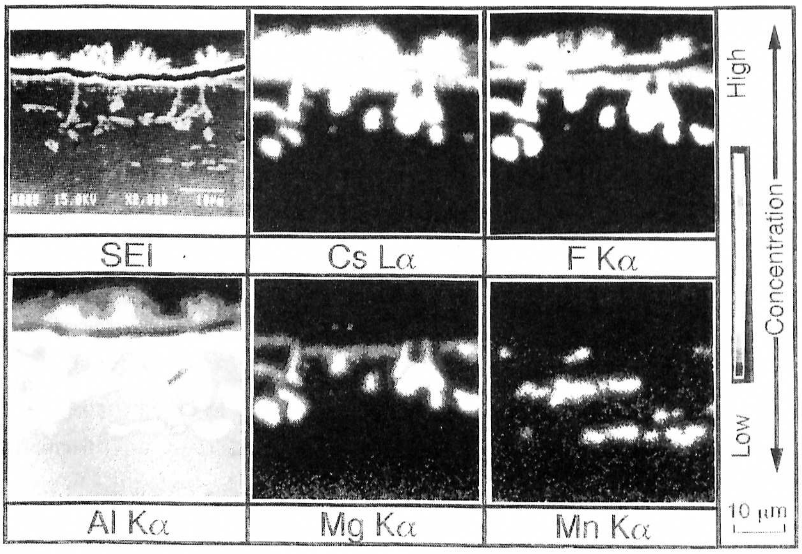

Fig. 5 Cross section of brazed 3004 base metal showing penetration of CA flux.

for 300s at each temperature. The spread area of flux is also measured because the penetration depth is a function of the amount of flux supplied per unit surface area[10]. **Figure 6** shows the plots between the penetration depth and the holding temperature. The penetration depth gradually increased with the rise in holding temperature, however, the spread area seems to be almost constant within the temperature range between 723-873K. Figure 6 indicates that the brazing at lower temperature is effective to suppress the flux penetration, therefore, the selection of appropriate filler metal with low melting temperature will be the key to improve the brazeability of magnesium containing base metals.

This work showed that the brazeability and penetration of flux is closely related, active flux offering good brazeability shows deep penetration depth, however, CA flux seems to be appropriate for brazing 3004 base metal, because the CA flux has relatively good brazeability and low penetration depth for magnesium containing base metal.

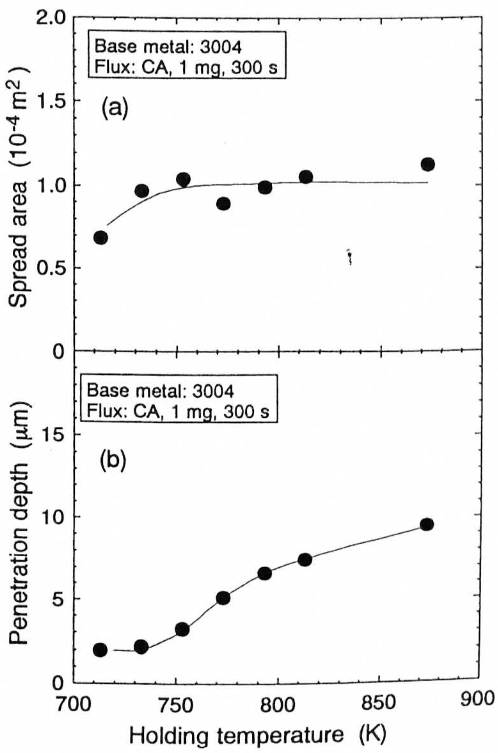

Fig. 6 Effect of holding temperature on the spread area (a) and the penetration depth (b) of 3004 base meta, used flux was CA.

4. CONCLUSION

The brazing test on magnesium containing base metal with CsF-AlF_3 non-corrosive flux been investigated in relation to the magnesium content of base metal and flux composit Brazeability was evaluated by the fillet formation test on tee type joint. The penetration dept flux into base metal was also investigated. The obtained results are summarized as follows.

(1) The $KAlF_4$-K_2AlF_5 system KA flux gave the best brazeability for 3003 base metal with magnesium, however, CA flux with CsF/AlF_3 ratio of 1.2 gave similar brazeability to KA flux 3004 base metal with 1%Mg. The CA flux gave lower penetration depth into base metal t KA flux, therefore, the use of CA flux is recommended for brazing of magnesium containing b metals.

(2) In all fluxes the increase in magnesium content of base metal lowered the brazeability, howe the increase in flux loading improved brazeability, that offered larger fillet formability.

(3) In CsF-AlF_3 system fluxes the increase in CsF/AlF_3 ratio was decreased the brazeability, howe the penetration depth of flux was also lowered with the increase in CsF/AlF_3 ratio. The incre in CsF/AlF_3 ratio corresponds to the decrease in F mol per unit mass. The F mol is a go measure for estimating the brazeability and the penetration depth of flux into magnes containing base metal.

(4) Brazing at lower temperature is recommended to suppress the flux penetration into base meta

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