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THE INFLUENCE OF THE BRAZING PROCESS ON THE MECHANICAL STRENGTH OF BRAZING SHEET MATERIAL

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Abstract

Aluminum brazing sheet material is widely used in the automobile industry for heat exchanger applications. The applications require that certain mechanical property behavior be obtained. The material used in this investigation is composed of three different alloys (AA 3003, core; AA 4343, cladding; AA 1145, cladding). As-rolled sheets with a high reduction of 88 % were subjected to simulated vacuum brazing at 580°C, 593°C, 607°C and 648°C , respectively. For comparison , different thermomechanical processing procedures prior to brazing were employed and an additional salt bath dip brazing process was used. The difference of preheat and intermediate anneal treatments used in this study was found to have no significant contribution to variation of mechanical strength of the post brazed sheet . The post brazed strength mainly depends on the brazing temperature and decreases with increasing brazing temperature . By synthetic evaluation it is concluded that 593°C is a better brazing temperature when compared with the other three temperatures used in this study. Metallographic examination reveals that after brazing the core AA 3003 alloy and the cladding AA 1145 alloy are completely recrystallized. The cladding AA 4343 alloy melted and formed a molten layer which spread on to the surface of the sample and resolidified. Microhardness (HV, 25 gf) measurements indicate that in the as-rolled condition AA 4343 alloy has a higher microhardness level than the core alloy (AA 3003) or the other cladding alloy (AA 1145). After brazing, the microhardness values decreased in all three alloy layers, but in the molten and resolidified layer of AA 4343 alloy there was a significant variation of microhardness level.

Introduction

Aluminum brazing sheet material is widely used in the automobile industry for heat exchanger application. In service, the heat exchanger is subjected to conditions that include mechanical loading, vibration, and corrosion environments. For this critical component a certain strength level is required besides the requirements of heat-transfer and corrosion resistance. Vacuum brazing has become a well established technique for the production of automobile aluminum heat exchangers. The vacuum brazeability and post braze corrosion resistance of the brazing sheet material have already been investigated extensively [1] [2]. However, in order to save weight and material cost and to improve resistance to fatigue, a higher post brazed strength of the brazing sheet material is required. To further improve the synthetic quality of a heat exchanger

produced from brazing sheet material by vacuum brazing the mechanical behavior of aluminum alloy brazing sheet material must be studied systematically.

Generally, the brazing sheet material undergoes certain thermomechanical processes prior to brazing. If in some cases a difference in thermomechanical treatment has no significant influence on post brazed strength, then a simplification of the process prior to brazing could be considered. This simplification would be of benefit to both the manufacturer and the user of brazing sheet material. The initial purpose of this study is to evaluate the influence of differences of treatment prior to brazing on the post brazed strength.

On the other hand , as previous work has shown [3] , brazing (at $1x10^{-5}$ Torr) at a temperature below 582°C or above 599°C results in unacceptable fillets. Another objective of this study is to investigate the influence of brazing temperature on the post brazed strength of the brazing sheets. Because it is difficult to directly take tensile samples from a brazed heat exchanger, a simulated brazing method was used. From the as-rolled final gage sheet, 140 mm x 30 mm x 0.33 mm simulated brazing samples were taken and followed by heating , soaking and cooling in a laboratory vacuum furnace . The samples were then cut to standard tensile samples.

Experimental Detail

The brazing sheet material used in this study was received as a 2.79 mm thick hot band. The hot band with a clad ratio of 10 % (on each side) is composed of three different alloys: AA 4343 (cladding); AA 3003 (core); AA 1145 (cladding). The chemical composition of this material is given in Table I.

The hot band (preheated at 412°C-437°C for 2 or 16 hr) was annealed in a laboratory air furnace at 360°C or 390°C for 2 hr, respectively. It was then cold rolled to a final gage of 0.33 mm. The samples for the simulated brazing were of a size of 140 mm x 30 mm x 0.33 mm.

Table I. Chemical Composition of Brazing Sheet

Alloy ID	Chemical Composition (wt.%)					
	Si	Fe	Cr	Mn	Mg	Ti
AA 3003	.15	.25	.30	1.15	.003	.015
AA 4343	7.75	.20	.05	.02	.01	-
AA 1145	.05	.38	.02	.02	.002	.003

The samples for simulated brazing were divided into two groups. One group was heat-treated in a laboratory vacuum furnace and another group was heat-treated in a laboratory salt bath for comparison.

The brazing temperatures used were 580°C, 593°C, 607°C, 648°C in both vacuum and salt bath conditions.

A flat sheet sample of brazing sheet was mounted in a quartz chamber of a vacuum furnace in a horizontal position with the brazed cladding side (AA 4343 alloy) upwards. The furnace temperature was controlled from the sample. The surface of the sample was touched by the hot end of the thermocouple. The vacuum pumping system evacuated the quartz chamber to a high vacuum (about $2x10^{-5}$ Torr). The heating time up to the brazing temperature was 20 min.. At peak temperature the sample was held 5 min , then cooled down in a vacuum condition.

For salt bath brazing the flat sheet samples were dipped into the bath. The heating time up to the brazing temperature was about 2 min.. At the peak temperature the samples were held 2 min.. After brazing the samples were rapidly removed from the salt bath and quenched in water .

Tensile samples were prepared from the simulated brazed samples. Tensile tests were performed at room temperature at a constant cross-head speed of 0.508 mm $min.^{-1}$. The microstructure of the brazed samples was examined by optical microscopy on sheet cold mounted and then polished and etched using standard techniques for aluminum alloys. In order to determine the microhardness level of the core and cladding alloy layers, a Buehler Micromet II digital microhardness tester was employed.

The processing practice for the brazing sheets is shown in Table II.

Table II. Processing Practice of Brazing Sheet

Sample ID	Preheat Time (at 412°C-437°C)	Intermediate Anneal	Brazing Manner	Cooling Manner
1-S-V	2h	360 °C x 2h	vacuum	vacuum
1-S-D	2h	360 °C x 2h	bath	water
1-L-V	16h	360 °C x 2h	vacuum	vacuum
2-S-D	2h	390 °C x 2h	bath	vacuum
2-L-D	16h	390 °C x 2h	bath	water

Results and Discussions

For the material that was preheated at 412°C-437°C for 2 hr and intermediately annealed at 360°C for 2 hr the mechanical strength and microhardness in the as-rolled condition is shown in Table

III. After brazing the UTS and the TYS of this material is shown in Fig. 1 and Fig. 3. It is seen that after vacuum brazing in the range of temperature of 580°C-648°C both UTS and TYS decreased. The drop of UTS is 127.46 MPa at 580°C and 147.52 MPa at 648°C while the drop of TYS is 175.15 MPa and 191.13 MPa, respectively. Both the UTS and TYS decreased with increasing temperature. For comparison the salt bath brazing treatment at the same temperature yielded similar results.

It is to be noticed that the UTS is 138.14 MPa at 593°C while it is 118.58 MPa at 607°C and 118.43 MPa at 648°C. From the standpoint of ultimate strength a 593°C is a better vacuum brazing temperature than 607°C or 648°C. For yield strength a similar temperature dependence is presented. The TYS is 59.53 MPa at 593°C while it is 55.33 MPa at 607°C and 47.40 MPa at 648°C. The vacuum heat treatment resulted in higher ultimate strengths and lower yield strengths when compared with the salt bath heat treatment.

Table III Mechanical Strength and Microhardness of As-rolled Sheet

UTS (MPa)	TYS (MPa)	Alloy	Microhardness (HV) Average Value	Maximum Value
		AA 4343	112.05	236.5
265.95	238.53	AA 3003	81.07	87.3
		AA 1145	58.12	61.3

For different preheat and intermediate anneal processings (preheat 2 hr or 16 hr, anneal at 360°C or 390°C) and different brazing conditions (vacuum vs. bath) the comparison of UTS or TYS is shown in Fig.2 and Fig.4. The results show that the difference of preheat and intermediate anneal conditions of the hot bands has no significant contribution to the variation of strength of the brazing sheets. The brazing manner (vacuum vs. salt bath) has some influence on the yield strength but little influence on ultimate tensile strength. The post braze ultimate strength and yield strength mainly depend on the brazing temperature. Five studied cases revealed such a common trend that when the temperature reached 607°C , a dramatic drop of ultimate strength occurred.

Microhardness tests were performed at a load of 25 gf for 20 sec.. The HV value indicates that in the as-rolled condition the cladding alloy AA 4343 has a higher average hardness value (HV 112.05) than the core alloy AA 3003 (HV 81.07) or the other cladding alloy AA 1145 (HV 58.12). In the AA 4343 alloy layer there is a larger variation of the HV value. The difference between the maximum value and average value was HV 124.45, while in the AA 3003 alloy the difference was HV 6.23 and in the AA 1145 alloy it was HV 3.18.

After brazing the average microhardness values in the three alloy layers decreased compared with the as-rolled condition. The drop of microhardness at 580°C was from HV 112.05 to HV

62.69 in AA 4343 alloy , from HV 81.07 to HV 41.53 in AA 3003 alloy and from HV 58.12 to HV 34.12 in AA 1145 alloy.

For the AA 4343 alloy layer the change of microhardness level with brazing temperature was found to be larger compared with the AA 3003 alloy layer or the AA 1145 alloy layer. For the AA 3003 alloy layer the microhardness levels varied with brazing temperature more smoothly, as shown in Fig. 5.

For each alloy layer a comparison between average value and maximum value of microhardness was presented to evaluate the variation of microhardness level within a layer. In the AA 4343 alloy layer a larger variation of microhardness level was observed, as shown in Fig.6. In the AA 3003 alloy layer the variation of microhardness level was rather small, except after brazing at 580°C. In this case the variation was large, as shown in Fig.7. From Fig.8 it is seen that after brazing at 580°C, 593°C, 607°C for the AA 1145 alloy layer the variation of microhardness level is small, but after a 648°C brazing a great variation appeared. This was due to the spreading of molten AA 4343 alloy on the surface of AA 1145 alloy at the higher brazing temperature of 648°C.

The deformation structure of brazing sheet is shown in Fig.9. There are three distinct deformed layers of AA 4343 alloy, AA 3003 alloy and AA 1145 alloy. In the AA 4343 alloy layer the white α-Al and black silicon particles are clearly observed . Fig.10 shows a recrystallized grain structure of AA 3003 alloy and of AA 1145 alloy obtained after brazing at 580°C. The resolidified cladding of AA 4343 alloy and the silicon particles in it are still distinct and well defined. When the brazing temperature reached 593°C, in the core AA 3003 alloy layer and in the cladding AA 1145 alloy layer a completely recrystallized grain structure is distinguished while in the cladding AA 4343 alloy a more fully molten and resolidified structure is seen than that obtained after brazing at 580°C, as shown in Fig.11 . After brazing at 607°C and 648°C the grain structures are shown in Fig.12 and Fig.13, respectively. Owing to the wide spreading of the cladding alloy AA 4343 at higher temperatures this layer is narrow and extended in a zigzag manner along the surface of the sample. At 648°C the cladding alloy AA 4343 is severely melted and flowed along the surface of the sample. In this case on certain parts of the sample a lack of filler metal is observed. A resolidified structure of the cladding AA 4343 alloy after wide spreading on the surface was shown in Fig.14. For the core AA 3003 alloy and the cladding AA 1145 alloy a well defined recrystallized structure is seen.

In order to further evaluate the effect of brazing temperature an additional test was designed and performed as follows. Samples of a brazing sheet and a AA 3003 alloy sheet (both 80 mm x 15 mm x 0.33 mm, in as-rolled condition) were overlapped 8.38 mm and were subjected to the same vacuum brazing cycle as described above. After brazing , standard tensile samples were cut. The overlapped brazed area was 6.09 mm x 8.38 mm. The samples were strained to failure in tension at a constant cross-head speed of 0.508 mm min^{-1}. The tensile results show that for the four different brazing temperatures used only the 580° C sample was torn off at the overlapped area. The other samples were fractured at other positions rather than at the overlapped area . This result implies that the brazing strength of the 580° C sample is lower than that of the other samples . This is due to the fact that at a brazing temperature of 580°C insufficient melting caused poor filleting . When a comparison and evaluation synthetically of the brazing strength and of the post brazed strength of the brazing sheet is made, it is evident that 593°C was a better

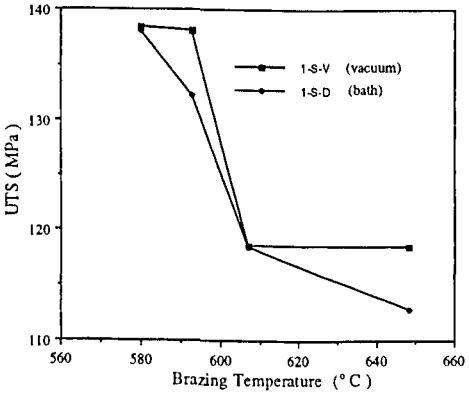

Fig.1 UTS of Brazing Sheet

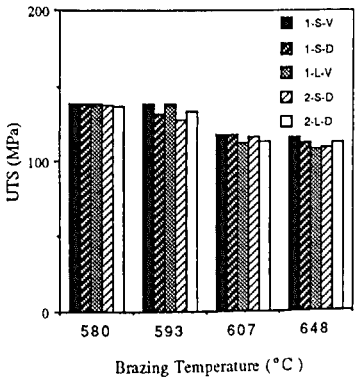

Fig. 2 Comparison of UTS

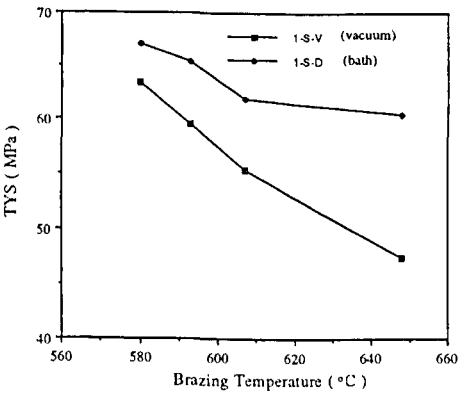

Fig. 3 TYS of Brazing Sheet

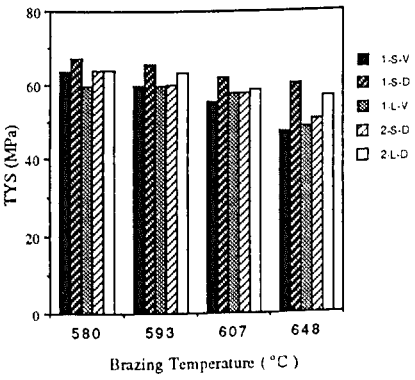

Fig. 4 Comparison of TYS

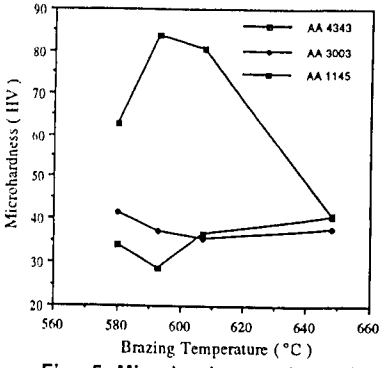

Fig. 5 Microhardness of Brazing Sheet

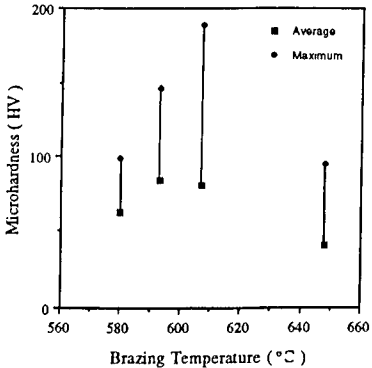

Fig. 6 Variation of microhardness Level in AA 4343 Alloy

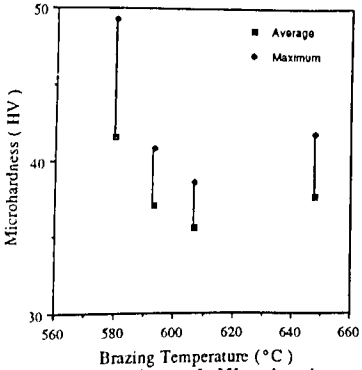

Fig. 7 Variation of Microhardness Level in AA 3003 Alloy

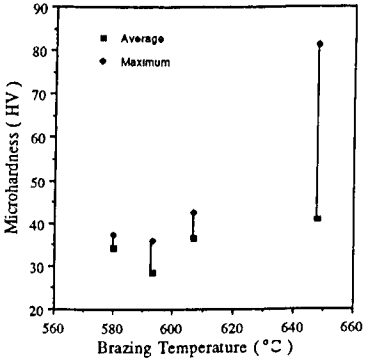

Fig. 8 Variation of Microhardness Level in AA 1145 Alloy

brazing temperature than other three temperature used in this study.

Conclusions

1. The difference of prior brazing treatment used in this study has no significant contribution to variation of ultimate tensile strength of post brazed sheets.

2. In this study , the post brazed strength mainly depends on the brazing temperature. It decreases with increasing brazing temperature. When the brazing temperature reaches 607°C, a sharp drop in ultimate tensile strength occurs.

3. From a mechanical strength standpoint a 593°C is a better brazing temperature than the other brazing temperatures (580°C, 607°C, 648°C) used in this study.

References

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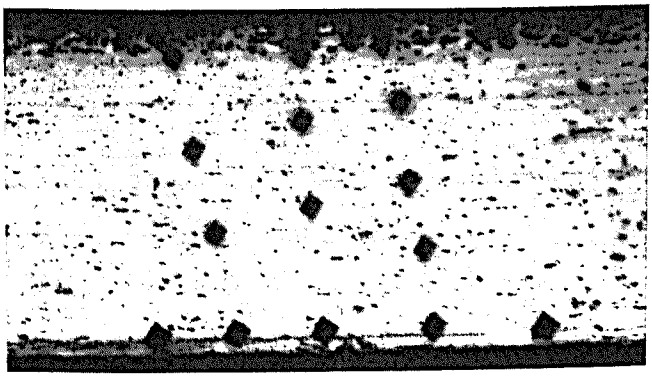

Figure 9. Deformation structure of brazing sheet, in the as-rolled condition with a reduction of 88 % 200X

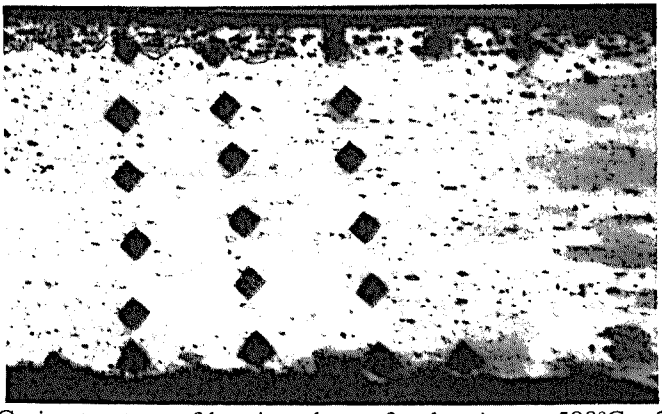

Figure 10. Grain structure of brazing sheet after brazing at 580°C 200X

Figure 11. Grain structure of brazing sheet after brazing at 593°C 200X

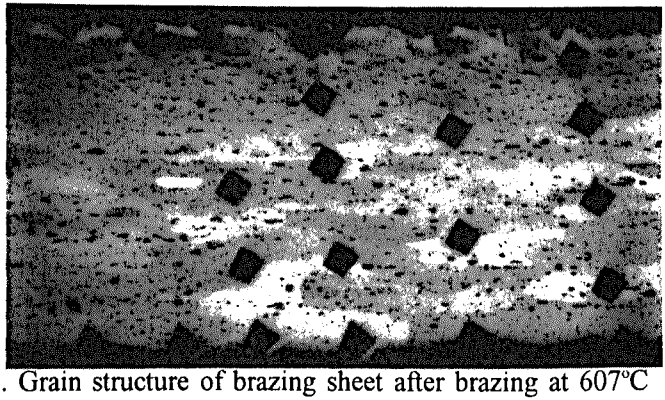

Figure 12. Grain structure of brazing sheet after brazing at 607°C 200X

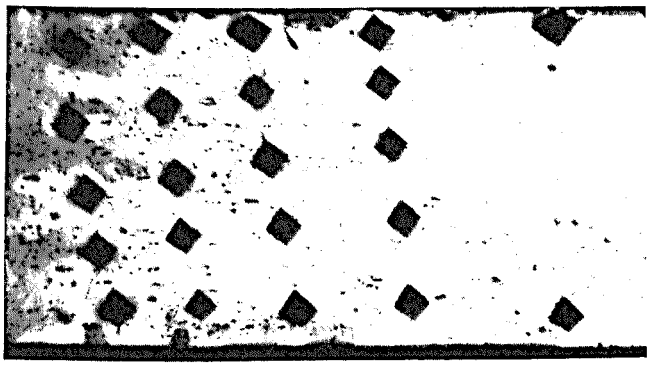

Figure 13. Grain structure of brazing sheet after brazing at 648°C 200X

Figure 14. Grain structure of brazing sheet after brazing at 648°C 200X