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HIGH STRENGTH ALUMINUM BRAZING SHEETS FOR CONDENSER FINS OF AUTOMOTIVE HEAT EXCHANGERS

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Abstract

Aluminum brazing sheets for automotive heat exchangers are extensively used and their mechanical properties are mainly related to the microstructure of core alloys. In this study, strip-cast 3000-series aluminum alloys having high strengths are used as core alloys for aluminum clad sheets. The high strength 4343/3003M/4343 clad sheets are fabricated by the roll bonding process and further cold-rolled down to the thickness of 0.08 mm. Intermediate annealing (IA) is conducted during cold rolling at 270~350°C with 20~40% of final reduction in thickness. Tensile test is performed with the clad sheets before and after brazing heat treatment and sag resistance is evaluated measuring the deflection of sheet under the brazing condition. Ultimate tensile strength (UTS) of the as-rolled clad sheets increases in proportion to the final reduction in thickness up to 228MPa (IA 270°C, 40% reduction) and decreases with increasing intermediate annealing temperature. Post brazing UTS remains in the range from 167 to 185MPa although decreases by brazing heat treatment.

Introduction

Aluminum alloys have been widely used in an automotive heat exchanger due to their lightweight and high thermal conductivity. A parallel-flow-type of condenser is commonly used for automotive applications, where three-layer brazing fins (Al-Mn core alloy clad with Al-Si fillers) are brazed onto extruded Al tubes [1-3]. High strength of the aluminum clad sheet is required to achieve light-weighting of the components, and the mechanical properties of the clad sheet are closely related to those of the core alloy [4,5]. Brazing is performed at a high temperature of about 600°C in order to melt the brazing filler metal. Accordingly, an aluminum-alloy brazing sheet having excellent brazing properties and also having high strength and erosion resistance after brazing is needed.

Generally, a direct-chill-cast (DC-cast) A3003 aluminum alloy is adapted as a core alloy for a brazing sheet. DC-cast core alloys require numerous hot and cold rolling processes to get a thin sheet and high strength alloys are restricted to this repetitive rolling process. On the contrary, strip-cast sheets can be directly roll-bonded without plentiful rolling process prior to cladding. In addition, fast cooling rate of strip casting causes homogeneous distribution of very fine compounds through the matrix, which can contribute to strengthening of the alloy.

In the present study, twin-roll-cast aluminum alloys having high strengths are used as core alloys for aluminum clad sheets. The clad sheets with high strength core alloys are fabricated by the roll bonding process and further cold-rolled down to the final thickness. An intermediate annealing is conducted at the different temperature varying final reduction in thickness. The effect of intermediate annealing temperature and final reduction in thickness on the mechanical and brazing properties of aluminum clad sheets is elucidated by means of microstructural analysis.

Experimental

The Al-Mn core alloy (modified AA3003, 3003M) and the Al-Si filler alloy (AA4343) were fabricated by the twin-roll casting method with a thickness of 8 mm. The chemical compositions of strip-cast alloys are listed on the Table I. 3003M alloy is an Al-Mn alloy containing 1wt.% of Zn with higher amount of Cu than AA3003 alloy. AA4343 alloy is a well-known filler metal for brazing in a controlled atmosphere. The strip-cast core and filler alloys were homogenized at 480°C for 14 hrs. Prior to cladding, all the specimens were wire-brushed on the interface surfaces. Three-layered aluminum clad (4343/3003M/4343, 1:8:1 in thickness ratio) was produced by roll bonding with 60% reduction in thickness at room temperature. After roll bonding, the clad sheets were cold-rolled down to the final thickness of 0.08 mm. Cold rolling was interrupted by an intermediate annealing at the different temperature (270, 290, 310, 350°C) for 14 hours, where the final reductions were varied from 20 to 40%.

Tensile tests were performed on flat tensile specimens with a gage length of 25 mm, at a nominal strain rate of $4x10^{-4}$/sec on a universal testing machine (model: Instron4206, Instron, USA) according to ASTM E8M. Sag tests were conducted to measure the deflection of clad sheets (50 mm in length and 20 mm in width) under the brazing condition (heating up to 610°C at a speed of 50°C /min, holding for 10 minutes, and cooling down to room temperature) as illustrated in Fig. 1.

Table I. Chemical composition of core and filler alloys

Alloy	Composition (wt.%)				
	Si	Fe	Cu	Mn	Zn
3003M (core)	0.55	0.37	0.25	1.41	0.96
AA4343 (filler)	7.58	0.34	-	-	-

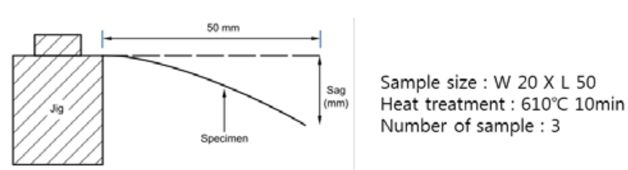

Figure 1. Schematics of sag test [6]

Results and Discussions

Figure 2(a) shows Vickers hardness change in the 3003M core alloy of the 4343/3003M/4343 clad sheet after annealing at the different temperature. The clad sheet is cold-rolled down to the thickness of 0.22mm and followed by annealing at the varying temperature from 270 to 350°C. The initial hardness of the as-rolled 3003M alloy is 93Hv. The hardness decreases with the increase of annealing temperature and is saturated to 42 to 45Hv at temperatures above 290°C. Figure 2(b) is optical micrographs of clad sheets (TD plane) after annealing. Annealed at 270 °C, the 3003M core shows the elongated grains with cold-rolled structure and grain growth is also found along the rolling direction. Cold-rolled structure completely disappears and coarse grains elongated along the rolling direction emerge by annealing at 290°C. Annealed at 350°C, relatively equiaxed grains by recrystallization are formed. Meanwhile, mixtures of grain growth and recrystallization are found in the specimen annealed at 310°C.

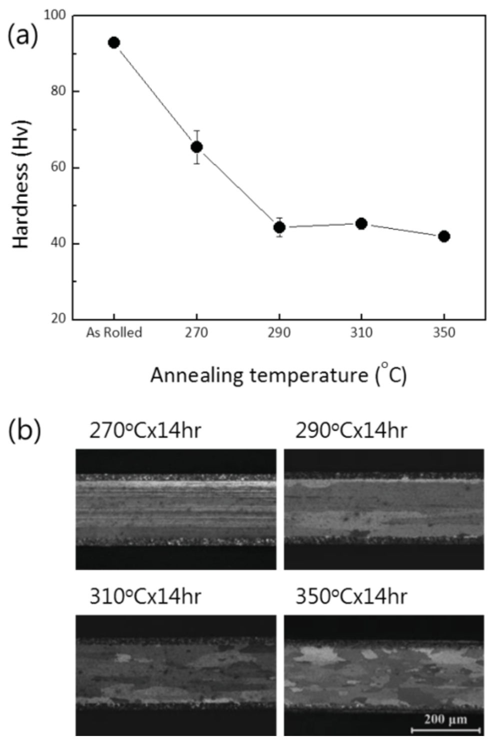

Figure 2. (a) Vickers hardness and (b) optical micrographs with respect to the annealing temperature.

Figures 3(a) through (d) are optical micrographs (TD planes) of as-rolled clad sheet at the thickness of 0.08mm with a 20% reduction in thickness. The elongated grains with cold-rolled structure are predominant in the clad sheet which is intermediately annealed at 270°C. However, coarse grains are found in the clad sheets whose IA temperatures are above 290°C. Several grain boundaries are found in the thickness direction of IA290, IA310 and IA350 specimens. Microstructures at the final thickness (0.08mm) with different IA temperature are similar to Fig. 2(b) which is just annealed microstructure at the thickness of 0.02mm. By strain hardening of 20% reduction in thickness, apparent grain structure seems to be almost the same as intermediate annealed microstructure. Brazing heat treatment (BZHT) causes grain growth in the core alloys and only 1 or 2 grains exist in the thickness direction, regardless of the IA temperatures (Figs. 4(a) through (d)). Filler metals seldom melt during BZHT because heat treatment is conducted in air, that is, an oxidizing atmosphere.

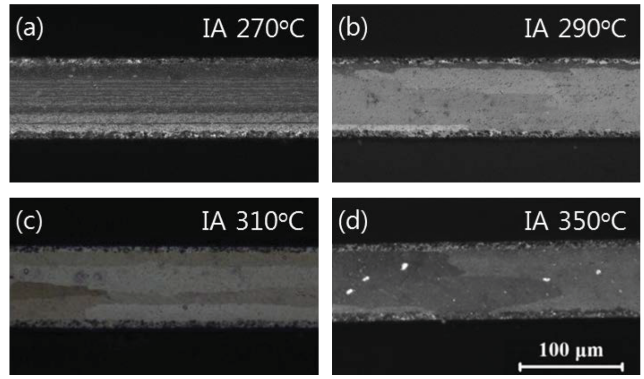

Figure 3. Optical micrographs of as-rolled clad sheets (thickness: 0.08mm, final reduction in thickness: 20%)

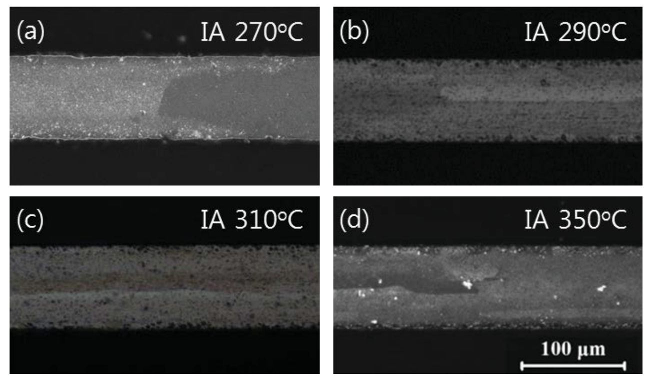

Figure 4. Optical micrographs of brazing-heat-treated clad sheets (thickness: 0.08mm, final reduction in thickness: 20%)

Figure 5(a) and (b) are ultimate tensile strengths of the clad sheets before and after BZHT according to the intermediate annealing temperature and final reduction in thickness. Before BZHT, tensile strength of clad sheets increases proportionally to the final reduction in thickness and decreases with increasing IA temperature. The IA270 clad sheet with 40% of thickness reduction has the highest strength of 228MPa. All the IA270 specimens have band-like cold-rolled microstructure as shown in Fig. 3(a). The accumulated strain in the specimen still remains by IA at 270°C and strain hardening by the following cold rolling to the final thickness. This strain hardening causes relatively high strength of IA270 specimen if compared with other specimens of higher IA temperature. Strength increment by thickness reduction is the highest in the IA310 specimens where UTS of 167, 190, 203MPa for 20, 30, 40% thickness reduction, respectively.

By brazing heat treatment, UTS decreases down to 168~185MPa except for the specimens of 20% thickness reduction (IA310, IA350). Considerable decease in tensile strength is found in the specimens with 40% reduction in thickness, which have higher before-BZHT strength than the specimens with less reduction in thickness. Tensile strength after BZHT is in the range of 167~185MPa and the highest post-BZHT strength (185MPa) is measured with IA350 specimen with 20% thickness reduction. The largest decrease in UTS is found in the IA270 specimen with 40% thickness reduction, where the strain hardening is the largest before BZHT. In the IA270 specimens, cold-rolled structure is changed to very huge grains by BZHT (Fig. 3(a) and Fig. 4(a)), which causes considerable drop in strength.

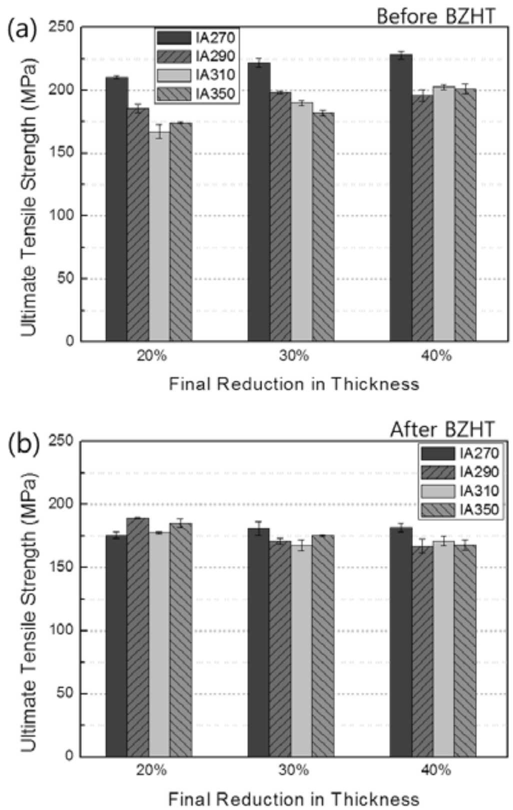

Figure 5. Ultimate tensile strength of clad sheets (a) before and (b) after brazing heat treatment (BZHT).

Figure 6 shows sag distance of the clad sheets by BZHT according to the intermediate annealing temperature and final reduction in thickness. Except for IA270 specimens, sag distance decreases with respect to the final reduction in thickness. IA270 specimens have sag distance of 29, 30, 28mm for 20, 30, 40% thickness reduction, respectively. On the other hand, sag distance of IA290, IA310, and IA350 specimens with 20 and 30% reduction in thickness is above 28mm, which is quite a large value for an application. IA290, IA310, and IA350 specimens with 40% reduction in thickness have comparable sag distance between 17 and 21mm. Sag resistance is inversely proportional to sag distance, and thus IA350 specimen with 40% thickness reduction (sag distance: 17mm) has the best sag resistance. Grain size of the core alloy of clad sheets significantly influences on the sag characteristics and cold-rolled microstructure (IA270 specimens) seems to be harmful for sag resistance. In real brazing process, however, the erosion phenomenon could happen and affect sag characteristics. Therefore, an erosion behavior in the controlled atmospheric brazing should be considered with a further investigation.

Al-Mn alloys (the 3003M core alloy in this study) are known to have high temperature precipitates such as Al_6Mn and AlMnFeSi phases. Figure 7 is phase fraction of 3003M alloy in equilibrium at the temperature range from 250 to 620^oC calculated by Factsage^{TM} software with FTlite database. In the temperature range of intermediate annealing, mass fraction of Al_6(Mn,Fe) compound slightly increases with increasing temperature and alpha-AlMnFeSi phase fraction inversely increases with temperature. At the brazing temperature, some amount of alpha phase dissolves into aluminum matrix and Al_6Mn compound becomes more stable. The mechanical properties of clad sheets can be influenced by fraction, size, and distribution of precipitates as well as grain structure of the core alloy. Therefore, further investigation on the precipitates by TEM analysis is strongly required.

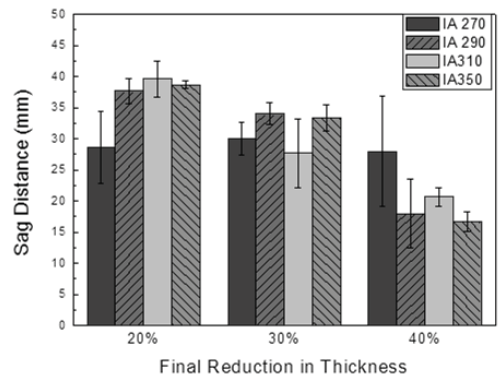

Figure 6. Sag distance of clad sheets by brazing heat treatment.

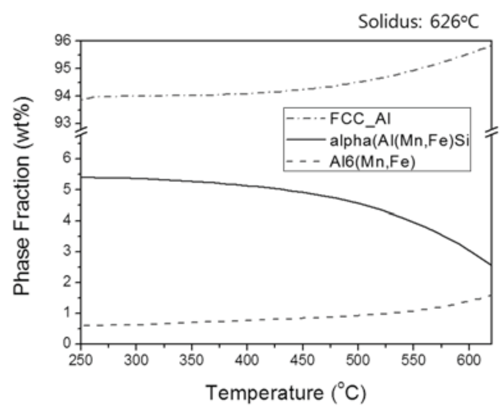

Figure 7. Calculated phase fraction of 3003M core alloy in equilibrium at the temperature range from 250 to 620^oC.

Conclusions

In this study, high strength aluminum clad sheet (4343/3003M/4343) were fabricated by roll bonding process with strip-cast core and filler alloys. Intermediate annealing temperature and final reduction in thickness significantly influenced on tensile strength and sag resistance of clad sheets. Ultimate tensile strength of the as-rolled clad sheets increased in proportion to the final reduction in thickness up to 228MPa (IA 270^oC, 40% reduction) and decreases with increasing intermediate annealing temperature. After brazing, maximum UTS was 185MPa (IA 350^oC, 20% reduction). The better sag resistance was achieved in the specimens with 40% reduction (IA: 290, 310, 350^oC) in the range of 17 to 21mm.

Acknowledgement

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