Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 1591-1595

Effect of Grain Refinement on Forming and Brazing Characteristics of Al-Mn Alloy

Jesik Shin[1], Bonghwan Kim[1], Yunbae Kim[1], Jinwon Hong[1], Byungoon Moon[1], Hoon Cho[1]
[1]Korea Institute of Industrial Technology, 7-47 Songdo-Dong, Yeonsu-Gu, Incheon 406-840, South Korea

This study aimed to investigate the effect of grain refinement on forming and brazing characteristics of an Al-Mn base clad aluminum sheet. A three-layer A4343/A3003/A4343 aluminum clad sheet of 0.7 mm thickness was fabricated using hot roll bonding process. The inoculating amount of Al-10Ti alloy, one of grain refiner, was systematically changed until the Ti level of cast ingots reached 0.1%. The hardness of the 0.1%Ti containing clad sheet did not significantly changed after the roll bonding process. After brazing process, eutectic silicon was refined the bonding strength of tee shape brazed sample increased gradually with increasing Ti content. When Ti content of the core alloy was as high as 0.1%, sagging resistance was remarkably improved.

Keywords: *Wrought aluminum; refinement; cladding; forming; brazing*

1. Introduction

Al-Mn base wrought aluminum alloy, one of aluminum alloy, has been widely used for automobile heat exchanger components. The materials for automobile heat exchanger components have to meet the highest combination of formability, strength, bondability and etc., because the space under the hood for its installation should be minimized and the gauge of the used materials must be reduced even under higher operating pressures for weight reduction of vehicles.

In manufacturing heat exchanger, a three layered aluminum sheets, consist of an Al-Mn core alloy clad on both sides with an Al-Si filler alloy, are favorable than single layer sheet. The brazing process using the clad aluminum sheet is suitable for compact and geometrically complex construction, leading to weight reduction, and rapid production, and cost reduction. A number of components are press-formed at room temperature and then assembled to a net shape. The assembled heat exchangers are heated up to a temperature, at which the filler melts while the core remains solid [1-3]. Therefore formability and brazeability of the clad aluminum sheet must be improved simultaneously.

The grain size in aluminum alloys plays an important role in wrought aluminum alloys; replacing large columnar gains of as cast aluminum ingots with fine equiaxed grains affects significant effects on strength, toughness, formability, second phase distribution and etc. And also interestingly, it is recently reported that even in Al-Si casting alloy, the grain refinement using Ti addition affects microstructure and mechanical properties. During brazing process, complex phenomena such as melting and flow of clad layer, inter-diffusion of solute, and re-solidification take place, making a difference in topology and microstructure of residual clad and brazed joint [4,5].

Therefore, in this study, it was aimed to investigate the effect of grain refinement on forming and brazing characteristics of Al-Mn base clad aluminum sheet. Al-Ti master alloys were used for grain refining of Al-Mn alloy, and the consequent effect of grain refinement on strength and formability of the clad aluminum sheet was examined through hardness and tensile tension tests. The effect of grain refinement on brazing characteristics was investigated by evaluation of bonding strength and combined examination of wettability and sagging tests.

2. Experimental

An Al-Mn base core alloy (A3003) of 4.4 kg was prepared by induction melting and pouring into a metal mold. For grain refining of Al-Mn base core alloy, an Al-10Ti master alloy was added into the alloy melt and then the inoculated melt was held at 750°C for 30 min. In order to investigate quantitatively the effect of grain refinement on forming and brazing characteristics of the clad aluminum sheets, Ti content was changed up to 0.1wt.%. Grain size was measured after deeply etching with Tucker regnant using an image analysis. An Al-Si base filler alloy (A4343) was also prepared by the induction melting and the metal mold casting without inoculation process. The cast ingots were homogenized at 500°C for 1~8 hours prior to roll bonding process. The chemical composition of the core and clad alloys are summarized in Table 1.

Table 1. Chemical composition of Al-Mn alloy and Al-Si alloy used in this study (wt.%)

	Si	Mn	Cu	Fe	Ti	Al
Core alloy, 3003						
No inoculation	0.062	1.028	0.069	0.246	0.000	bal.
Inoculation(0.01Ti)	0.079	1.123	0.111	0.380	0.016	bal.
Inoculation(0.1Ti)	0.090	1.106	0.110	0.363	0.157	bal.
Filler alloy, 4343	7.973	0.004	0.002	0.061	0.004	bal.

The A4343 filler alloy was hot rolled to the thickness of 2 mm and then clad to both sides of the 10 mm thick A3003 core alloy. This 3 layer clad aluminum sheet was hot rolled to the thickness of 3.5 mm at 480°C, followed by cold rolling to the thickness of 2 mm. This roll bonded aluminum sheet was subjected to intermediate annealing at 480°C for 10 min, and then cold rolled to 0.7 mm, which caused 65% reduction in thickness. Brazing was carried out under a nitrogen atmosphere using the following cycle: room temperature → 625°C, 4 °C/min → holding for 25 min → air cooling.

The consequent effect of grain refinement on strength and formability of the clad aluminum sheet was examined through hardness and tensile tension tests. The strain rate was 10^{-3} s^{-1}. In order to investigate brazeability, bonding strength evaluation and sagging tests were carried out. For sagging test, the clad sheet of 50 mm length was held at 625°C for 25 min under an Ar atmosphere and then furnace cooled.

3. Results and Discussion

Fig. 1 shows the macrostructure variation of A3003 alloy ingots with inoculation treatment using Al-10Ti master alloy. In non-inoculated ingot, grain was very coarse and columnar structure was well developed. The average grain size reached around 4,000 μm and the area fraction of equiaxed zone was only 25%. As Ti content increased to 0.1%, grain size decreased gradually to 75 μm, and full equiaxed structure was obtained.

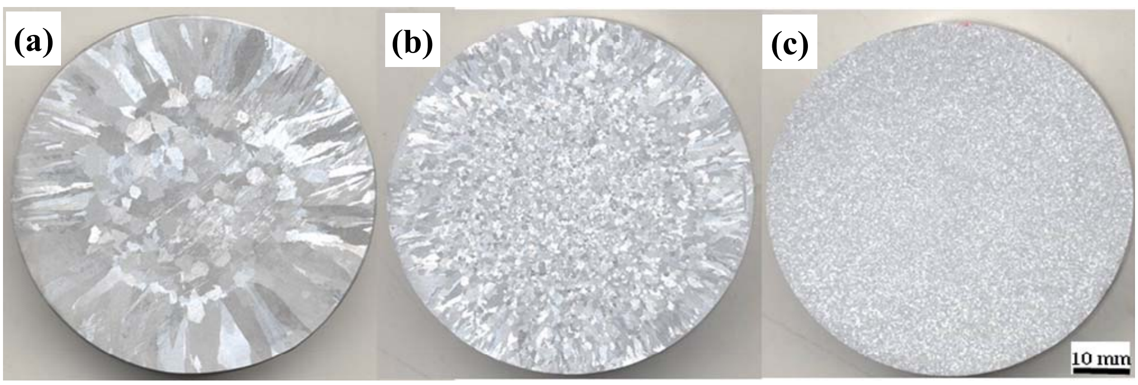

Fig. 1 The representative macrostructures of A3303 alloy as a function of Ti level; (a) 0%, (b) 0.01%, and (c) 0.1%.

Fig. 2 shows hardness variation of as-cast ingots and clad sheets with Ti content. In as-cast state, hardness increased with increasing Ti content because of Ti intermetallic compound formation and/or solid solution hardening effect. After roll bonding process, including hot and cold rolling, hardness increased by 10~20% except the clad sheet containing 0.1%Ti. In clad sheet, lower hardness is expected to be advantageous to cold pressing process for complex shape components. It is likely that high content Ti affected recrystallization nucleation behavior, resulting in hardness decrement. Advantageous Reproducibility test and mechanism ascertaining examination are needed.

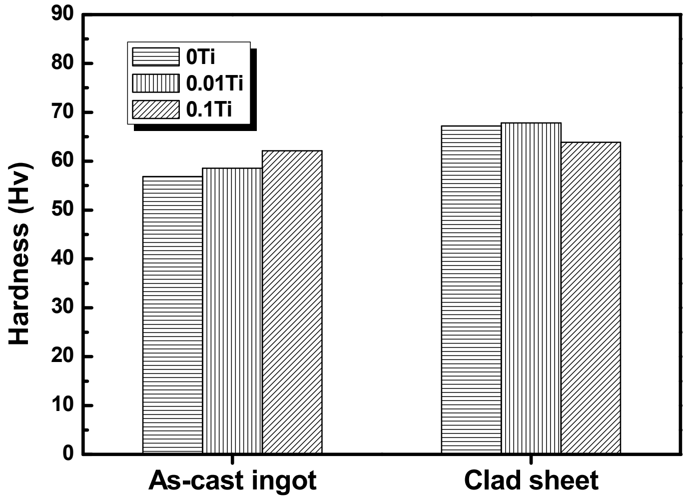

Fig. 2 Hardness variation of as-cast ingots and clad sheets with Ti content.

In order to evaluate brazeability, tensile tension test was carried out using a vertically brazed tee sample made of two clad sheets. In contradiction to hardness results of clad sheets of Fig. 2, bonding strength increased gradually with increment of Ti content, as shown in Fig. 3. Fracture occurred at the end of brazed joint for all specimens.

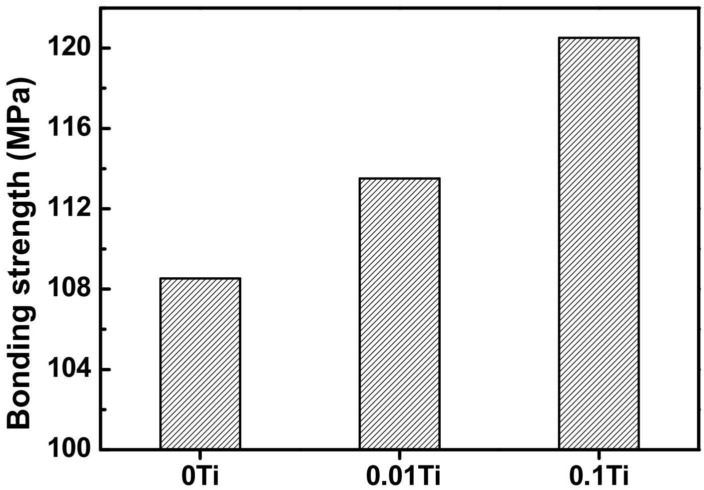

Fig. 3 Bonding strength of clad sheets after brazing as function of Ti content.

The topology and microstructure of brazed joint are important to avoid the leakage of coolant and the collapse of heat exchanger made of the clad aluminum sheets. Fig. 4 shows the microstructural change of the brazed joint with Ti content. Interestingly, eutectic silicon was observed to be finer in the sample made of 0.1%Ti containing clad sheets. This result may be responsible for solute atom migration phenomena between the core and filler layers. That is, Ti solute atoms, which immigrated from A3003 core alloy through diffusion and partial dissolution of the core during brazing process, were supposed to affect the size of primary and eutectic phases. The improvement of bonding strength in Fig. 3 may be attributed to refinement of eutectic silicon phase. The bright particles adjacent to the interface between primary and eutectic phases was proved to be Al(Mn,Fe)Si phase. The immigration of Si from the Al-Mn core layer into the Al-Si filler melt stimulated the precipitation of Al(Mn,Fe)Si phase.

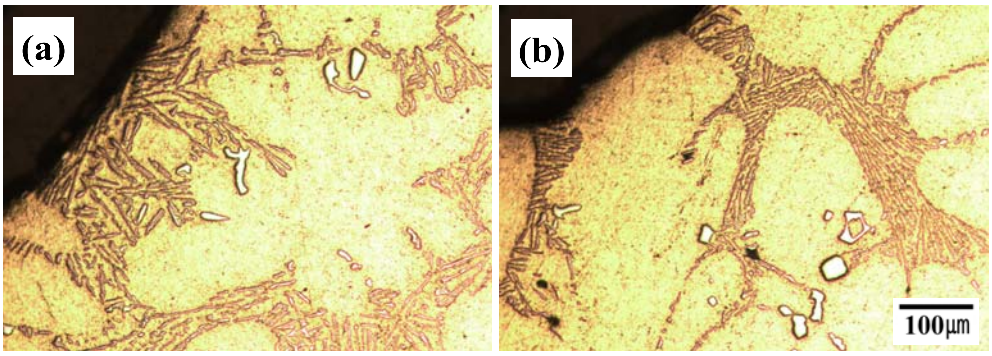

Fig. 4 Optical micrographs of the brazed joints as a function of Ti content; (a) 0% and (b) 0.1%.

Enough high sagging resistance is required in order to guarantee the dimensional precision of heat exchanger, since brazing process is carried out at high temperature using a number of thin clad sheets. The sagging distance with Ti content was measured and summarized in Fig. 5. 0.1%Ti containing clad sheet showed the lowest sagging distance, while sagging distance significantly increased as Ti content increased to 0.01%. It appears that this phenomena is related to uniformly dispersed fine Ti intermetallic compound caused by high Ti content and the severe deformation of the roll bonding process.

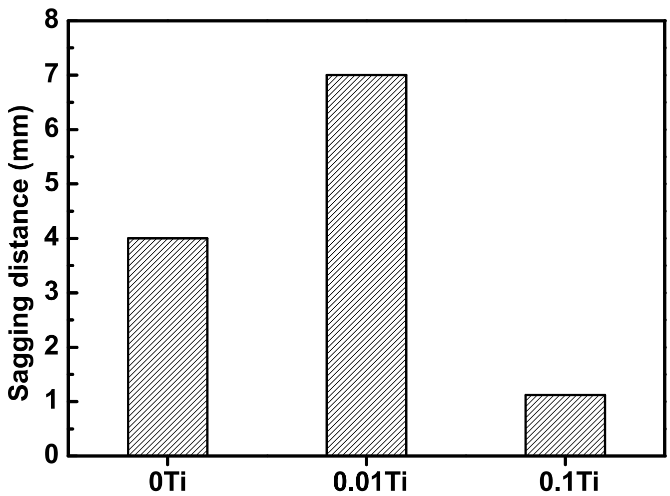

Fig. 5 Sagging distance as a function of Ti content.

4. Summary

A three-layer A4343/A3003/A4343 aluminum clad sheet of 0.7 mm thickness was fabricated using hot roll bonding process. The effect of grain refinement on forming and brazing characteristics of an Al-Mn base clad aluminum sheet was investigated using Al-10Ti alloy for refining A3003 core alloy. The Ti level of A3003 ingots was systematically changed up to 0.1wt.%. The roll bonding process did not increase the hardness of the 0.1%Ti containing sample, while those of non-inoculated and 0.01%Ti inoculated samples increased by 10~20%. After brazing, eutectic silicon was refined the bonding strength increased gradually with increasing Ti content. 0.1%Ti containing clad sheet showed the lowest sagging distance, while sagging distance significantly increased as Ti content increased to 0.01%. Throughout the experimental results, it may be concluded that Ti level of A3303 core alloy affected a significant effect on forming and brazing characteristics of the clad aluminum sheets produced by the roll bonding process.

References

[1] J. Liu, M. Li, S. Sheu, M. E. Karabin and R. W. Schultz: Mater. Sci. Eng. A479 (2008) 45-57.
[2] X. X. Yao, R. Sandström and T. stenqvist: Mater. Sci. Eng. A267 (1999) 1-6.
[3] J. S. Yoon, S. H. Lee and M. S. Kim: J. Mater. Proc. Tech. 111 (2001) 85-89.
[4] B. Suárez-Peña and J. Asensio-Lozano: Mater. Charac. 57 (2006) 218-226.
[5] F. Gao, D. P. Sekulic, Y. Qian and X. Ma: Mater. Lett. 57 (2003) 4592-4596.