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Microstructure and Property Variation of Roll-bonded 4xxx/3003/4xxx Aluminum Clad Sheets with Thermomechanical Process

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4xxx/3xxx/4xxx aluminum clad sheets are widely used for brazing materials in the automotive heat exchangers. In this study, aluminum clad sheets were fabricated by roll bonding process and further cold-rolled with an intermediate heat treatment. The effects of thermomechanical process on the microstructure and properties of the aluminum clad sheets were investigated. After roll bonding, the clad sheets were cold-rolled and intermediately heat-treated at the different amount of reductions in order to obtain the thin aluminum clad sheets with different final reductions (17, 29, 35%). Mechanical properties of the thin clad sheets were evaluated by tensile test and brazeability was estimated by sagging test. Tensile strength of the thin clad sheets proportionally increased with the final reduction ratio. Tensile strength of the clad sheet with final reduction of 35% was slightly lower than that of the H14-treated bare sheet (the core alloy). The elongated grains with average grain thickness of 27μm were found in the core of the thin clad sheets. However, new polygonal grains were developed along the boundary of core and filler after brazing heat treatment. Sag resistance of the thin clad sheets was almost the same with the core alloy and there was not much difference in the sag resistance with the thermomechanical treatment.

Keywords: *Roll Bonding, Aluminum Clad, Thermomechanical Treatment, Tensile Property, Sag Resistance*

1. Introduction

Aluminum alloys have been widely used as a material for automotive heat exchangers due to their high thermal conductivity and specific strength. A parallel flow type condenser is commonly used for automobile applications, where a three-layer brazing sheet (Al-Mn core alloy clad with Al-Si fillers) is brazed onto an extruded Al tube. High brazeability of the clad sheet is required to avoid a collapse of the assembly during brazing cycles. Brazeability can be represented by sagging resistance which is a resistance against deformation during the brazing [1]. Sagging resistance is reportedly related to the microstructure of the core alloy [2]. Brazing clad sheet is generally fabricated by a sheet rolling process. In the present study, aluminum clad sheets are fabricated by roll bonding process. The clad sheets are further cold-rolled and intermediately heat-treated at the different amount of reductions in order to obtain the thin aluminum clad sheets with different final reductions. The effects of thermomechanical process on the microstructure and properties of the aluminum clad sheets are investigated.

2. Experimental

The core alloy was prepared with a commercial 3003 alloy with a thickness of 3mm (H14 heat-treated). The filler alloys (AA4045 and AA4343) were cast and homogenized, followed by warm rolling with a 80% reduction in thickness, followed by cold rolling with a further 75% reduction in thickness (final thickness: 0.5mm). Table 1 shows chemical compositions of the core alloy and filler alloys with comparable compositions to the standard values.

The core and the filler alloys were annealed at 450°C for 2 hours, and then stacked with a filler/core/filler sequence after chemical cleaning and surface brushing with a stainless steel brusher. The stacked alloys were roll-bonded with a 50% reduction in thickness at room temperature. After roll bonding, the clad sheets were cold-rolled and intermediately heat-treated at the different amount of reductions in order to obtain thin aluminum clad sheets with different final reductions (17, 29, 35%). Intermediate annealing (T1) was conducted at 450°C for 2 hours and annealed clad sheets were cold rolled further to the final thickness of 0.5mm. Figure 1 shows the flowchart of thermomechanical process.

Table 1.Chemical composition of the core and filler alloys (wt.%)

		Si	Fe	Cu	Mn	Zn	Al
Core alloy, 3003	Spec.	<0.6	<0.7	0.05-0.20	1.0-1.5	<0.10	Bal.
	ICP	0.20	0.53	0.13	0.93	0.001	Bal.
Filler alloy, 4045	Spec.	9.0-11.0	<0.8	<0.25	<0.10	<0.20	Bal.
	ICP	9.69	0.06	0.002	0.006	-	Bal.
Filler alloy, 4343	Spec.	6.8-8.2	<0.8	<0.25	<0.10	<0.20	Bal.
	ICP	7.40	0.03	-	0.01	-	Bal.

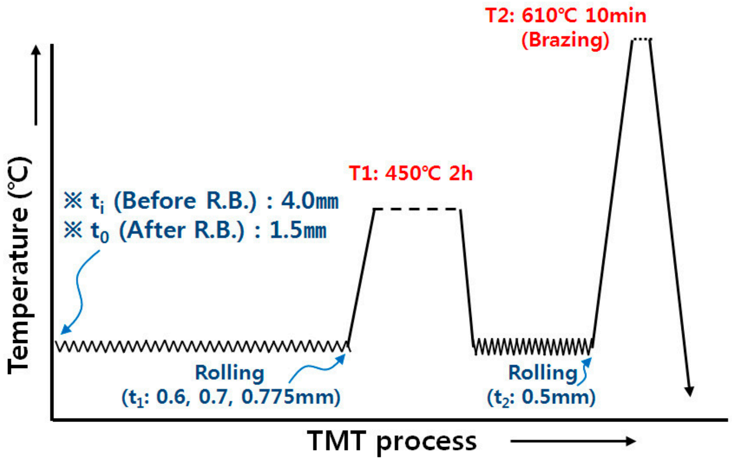

Fig. 1. Flowchart of thermomechanical process

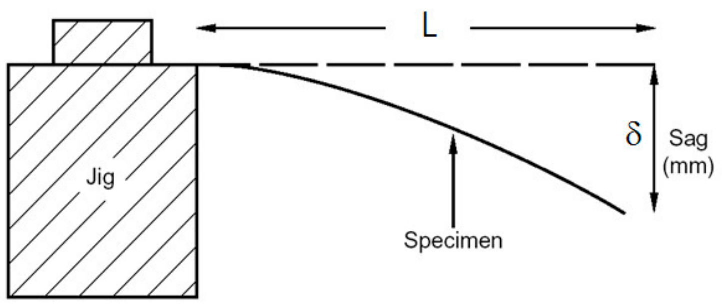

Fig. 2. Schematics of sagging resistance measuring apparatus

Microstructure was characterized using an optical microscope and a scanning electron microscope (SEM) with electron backscatter diffraction (EBSD). Tensile test was conducted on a standard universal testing machine (Instron4206) with sub-size of ASTM E8M tensile specimens (6 mm in gage width and 25 mm in gage length). Sagging test was performed to measure the deflection of sheet under the brazing condition as shown in Fig. 2, whereby a cantilever specimen with an arm length 35 mm and a width 23 mm was heated up to 610°C at a speed of 50°C /min, kept for 10 minutes, and cooled down to room temperature (T2) to make measurement [3].

3. Results and Discussions

3.1 Tensile Properties and Sagging Resistance

Figure 3 shows the effect of cold rolling and intermediate annealing on the tensile properties of 4045/3003/4045 clad sheet. Both yield strength (YS) and ultimate tensile strength (UTS) decrease after a T1 treatment, and increase again with further cold rolling. Strain hardening increase also after T1 treatment as circled in the Fig. 3. Ultimate tensile strength of T1-treated specimen is 150MPa, which is 40MPa higher than an O-treated core alloy (AA3003 bare). After final cold rolling, UTS increases up to 180MPa, which is almost the same as a H14-treated core alloy. Elongation has inverse tendency to the strength variation with thermomechanical treatment.

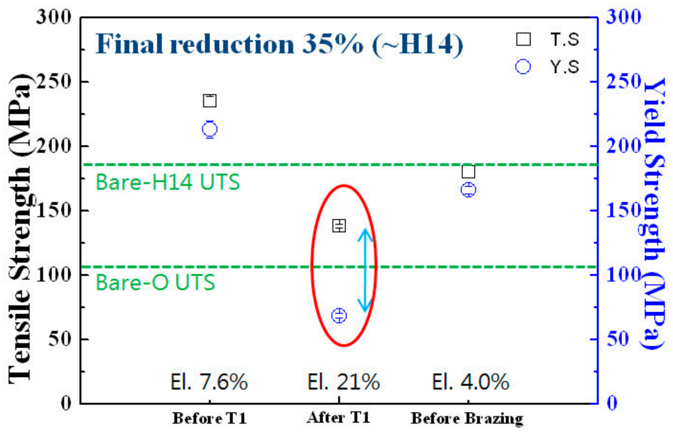

Fig. 3. Tensile properties of 4045/3003/4045 clad sheet showing the effect of cold rolling and intermediate annealing (final reduction in thickness: 35%).

Figure 4 shows variation of tensile properties with respect to the final reduction ratio. Both YS and UTS increase proportionally to the final reduction ratio. Ultimate tensile strengths of the clad sheet with the final reduction of 35% are slightly lower than that of a H14-treated core alloy. Strength of the clad sheet with AA 4045 filler alloy is negligibly lower than that of the clad sheet with AA4343 filler alloy.

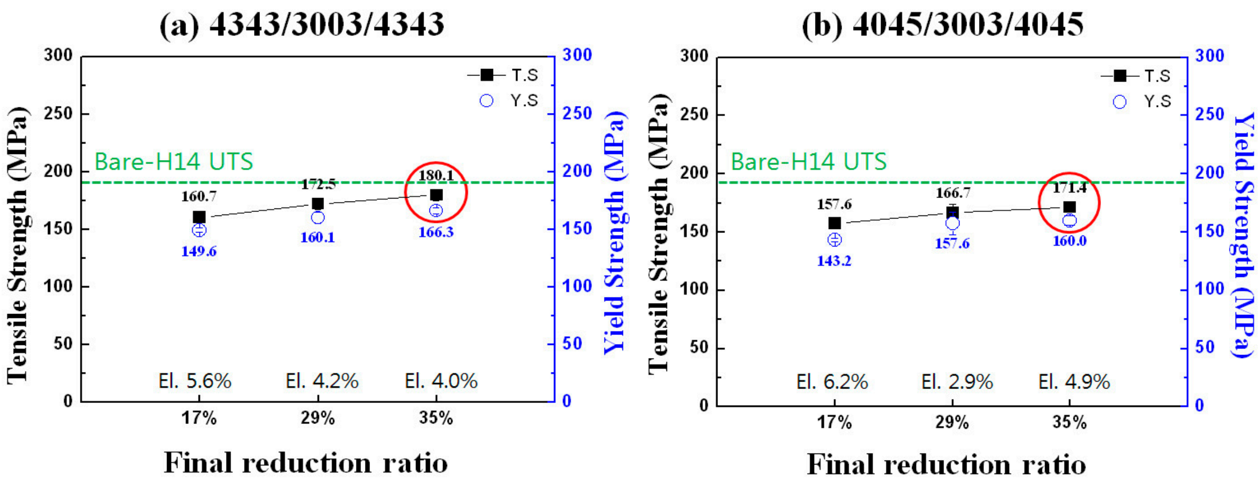

Fig. 4. Variation of tensile properties with respect to the final reduction ratio: (a) 4343/3003/4343 and (b) 4045/3003/4045 clad sheets.

Figure 5 shows variation of sag resistance with respect to the final reduction ratio. Sagging resistance of a clad sheet can be evaluated by measuring the deflection of sheet under the simulated brazing treatment at 610°C for 10 minutes. For standardization, sagging distance is normalized by the arm length, that is, sagging ratio (δ/L). Compared with a conventional high-strength Al fin material [3], favorable sagging resistance can be obtained in all the clad sheets. Sagging ratio of the clad sheet with AA 4045 filler alloy is slightly higher than that of the clad sheet with AA4343 filler alloy, while no considerable difference is detected. Sag resistance of the thin clad sheets is almost the same with the core alloy (sagging ratio: 2.6%).

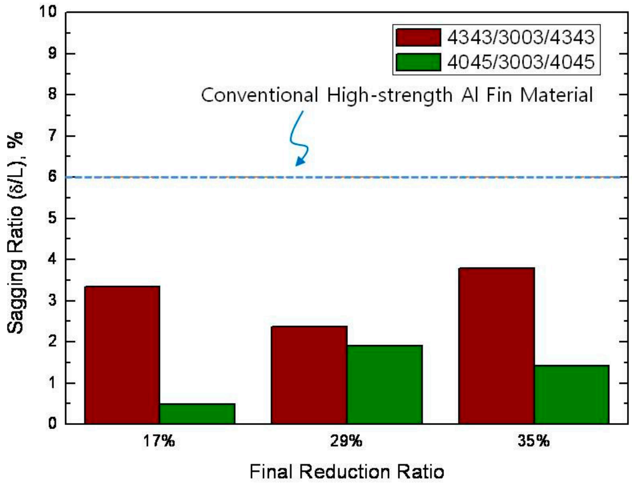

Fig. 5. Variation of sag resistance with respect to the final reduction ratio where sagging ratio (δ/L) represents sag resistance. Sag resistance of conventional Al fin material from the reference [3].

3.2 Microstructure

The core/filler boundary region of the roll-bonded clad sheet has finer and much more elongated grain structures with high angle (>15°) grain boundaries due to a severe shear deformation during roll bonding (Fig. 6, left). However, near-center region of the roll-bonded clad sheet has coarse and elongated grains due to less deformation (Fig. 6, right). No specific feature of grain structures is found in the different filler alloys.

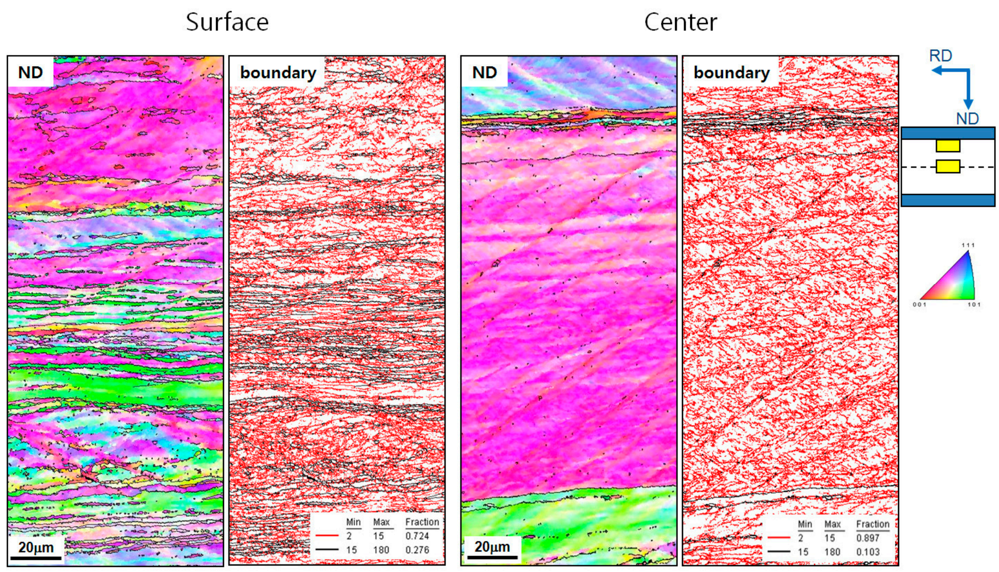

Fig. 6. EBSD results showing microstructures of the as-roll-bonded 4045/3003/4045 clad sheet.

Figure 7 shows microstructures of the core and filler alloys after the T1 heat treatment. The core alloy of the T1-treated clad sheet has much more elongated grains in the rolling direction with an average thickness of 27µm. The filler region has equiaxed grain structure with recrystallization, whose grain size is much smaller than the core alloy. Grain growth seems to be delayed by Si particles distributed throughout the filler alloy.

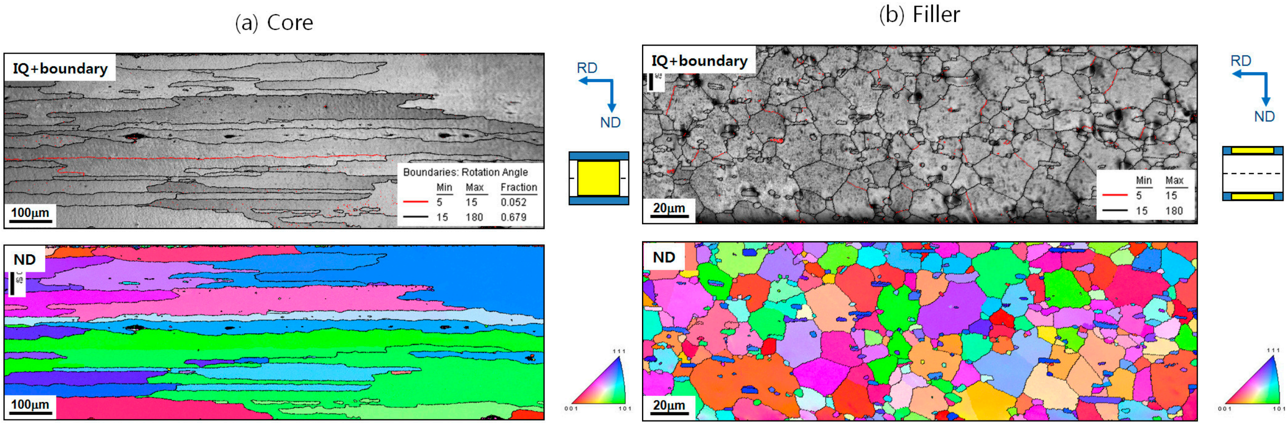

Fig. 7. EBSD results showing microstructures of the (a) core and (b) filler of 4343/3003/4343 clad sheet (t: 0.6mm) after the intermediate annealing (T1).

4. Conclusions

Aluminum clad sheets (4343/3003/4343 and 4045/3003/4045) were fabricated by roll bonding process. Tensile strength of the thin clad sheets proportionally increased with the final reduction ratio. Tensile strength of the 4343/3003/4343 clad sheet with a final 35% reduction in thickness was 180MPa, which was slightly lower than that of the H14-treated A3003 sheet. The elongated grains with average grain thickness of 27µm were found in the core of the thin clad sheets, while equiaxed and smaller grains were found in the filler region. Sag resistance of the thin clad sheets was almost the same with the core alloy and there was not much difference in the sag resistance with the thermomechanical treatment.

Acknowledgement

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