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Mechanical Properties of Al/Al-Mg/Al Clad Sheets Fabricated by Roll Bonding Process

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Al/Al-Mg/Al alloy sheets were fabricated by roll bonding at ambient temperature and the mechanical properties of the annealed sheets were investigated. The bond strength of the sheets increased with increasing thickness reduction rate of roll bonding. No defects like crack or void are observed at the bonded interface after roll bonding at thickness reduction rate above 50%. After annealing at 400^{o}C for 1hour, the sheets have a well bonded interface and the microstructure of the sheets consisted of fully recrystallized grains. Tensile strengths of the sheets were similar with the values calculated by area fraction and strength of each Al sheets. Stress-strain curves show same strain hardening characteristics with core Al-Mg sheets. Meanwhile the elongation of the Al/Al-5.5wt%Mg-0.3Cu/Al sheets was higher than that of Al-5.5wt%Mg-0.3Cu sheets. Especially, the local elongation of the sheets increased about 2~3%. The increase of the plastic strain ratio effected the tensile deformation behavior of Al clad sheets, so that the tensile elongation improved in Al/Al-5.5wt%Mg-0.3Cu/Al clad sheet.

Keywords: *Al-Mg, Clad, Roll bonding, Tensile properties, Microstructure*

1. Introduction

Aluminum clad materials have been used for several applications like aluminum automotive braze sheet and high corrosion resistant airplane part [1-3], which have been manufactured by roll bonding process. Nowadays, the process have been studied to make multi layered metallic composite. The materials allow selection of the appropriate combinations of clad and core alloys to produced desired mechanical properties. As modern industries develop further, there is a continuous increase in the demand and production of those multi layer metallic composite. Multi layered composite sheets are generally produced by roll-bonding. The clad layer is bonded to the core by rolling under significant loads at ambient temperature or elevated temperature. Among metal cladding technology, cold roll bonding has widely used in recent years for making aluminum clad materials due to its simple process and applicability.[4-6] Al-Mg alloy have a favorable combination of strength and formability, its properties can be improved by increasing Mg content to get enough solid solution hardening, however, the high content of Mg in Al-Mg alloys results in loss of corrosion resistance. Al cladding is one of promising way to get a high strength and good corrosion resistance Al-Mg alloys because of pure Al clad and high strength core Al-Mg alloy. In this paper, Al/Al-Mg/Al clad sheets were fabricated by roll bonding process at ambient temperature, also the effects of process parameters on bonding properties of Al/Al-Mg/Al clad sheets and the mechanical properties of the sheets were investigated.

2. Experimental procedure

Al/Al-Mg/Al clad sheets were fabricated by roll bonding process at ambient temperature. The schematic of the process is shown in Figure 1. The clad Al is AA1050 aluminum sheets(99.5% Al), and the core sheets is AA5182(Al-4.5wt%Mg-0.5wt%Mn) and Al-5.5wt%Mg-0.3wt%Cu. The thickness of initial materials were 2.0mm for the core Al-Mg sheets and 0.5mm clad 1050 Al. Before roll bonding, the surface to be bonded was properly cleaned and prepared to remove any surface layer by wire brushing in order to get good bonding. After the surface treatment, two sheets were stacked to make the brushed surface in contact and fixed to each other tightly by stainless steel wires. A two-high rolling mill was used for roll bonding with reduction up to 50% in one pass without lubrication. The roll diameter was 300 mm and the roll peripheral speed was about 5m/min. The average Vickers hardness (*Hv*) of the roll bonded sheets was measured at randomly selected points using a load of 200g for 10s. The tensile specimens were machined from the rolled sheets according to the ASTM E8M standard. The gauge length of the tensile specimen was 25 mm and the gage width was 6mm. Before tensile test, the specimens were annealed at 400°C for 1hour to increase bond strength and sheets formability. Tensile tests at ambient temperature were conducted on a standard universal testing machine at an initial strain rate of $8.3\times10^{-4}s^{-1}$. The optical microstructure of the samples was observed using polarized light. Electro-chemical etching was carried out in Baker's solution of 5 ml HBF_4 and 200 ml distilled water by the use of a stainless steel cathode. All the optical and SEM microstructures were observed on the longitudinal sections of the rolled samples.

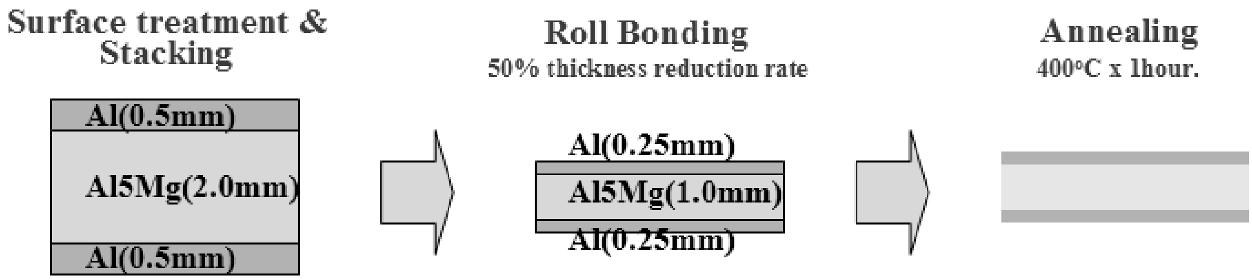

Fig.1 Schematic of roll bonding process for Al/Al-Mg/Al sheets

3. Result and Discussion

3.1 Roll bonding of Al/Al-Mg/Al

Al/Al-4.5wt%Mg-0.5Mn/Al and Al/Al-5.5wt%Mg-0.3Cu/Al clad sheets were fabricated by roll bonding at ambient temperature. Figure 1 shows the bonded interface of Al/Al-5.5wt%Mg-0.3Cu/Al sheets fabricated by roll bonding at different rolling reduction rate. Minimum rolling reduction rate is 33% to get well bonded interface as shown in Figure 1 (a). The bonded layer was preserved at the high rolling reduction, no defects like crack or void were observed at the bonded interface after roll bonding at thickness reduction rate above 33%. The bond strength of Al/Al-Mg/Al sheets was measured by 180° peel test under basis of the ASTM D 903-98. As increasing rolling reduction rate, the peel strength of Al/Al-Mg/Al increased from 0.3N/mm to 13N/mm. The bond strength of the Al/Al-5.5wt%Mg-0.3Cu/Al sheet is higher than that of Al/Al-4.5wt%Mg-0.5Mn/Al at same rolling reduction rate. For example, the 180° peel strength of Al/Al-5.5wt%Mg-0.3Cu/Al at rolling reduction rate of 50% is 12N/mm, while that of Al/Al-4.5wt%Mg-0.5Mn/Al is 3.8N/mm. The difference of bond strength seems to be originated from the difference of yield strength of initial materials. [4] The hardness of Al/Al-Mg/Al sheets roll bonded by 50% rolling reduction rate were measured along thickness direction and shown in figure 3. After roll bonding the hardness increased in core Al-Mg sheets due to large strain hardening of Al-Mg system, but clad pure Al have same value after roll bonding.

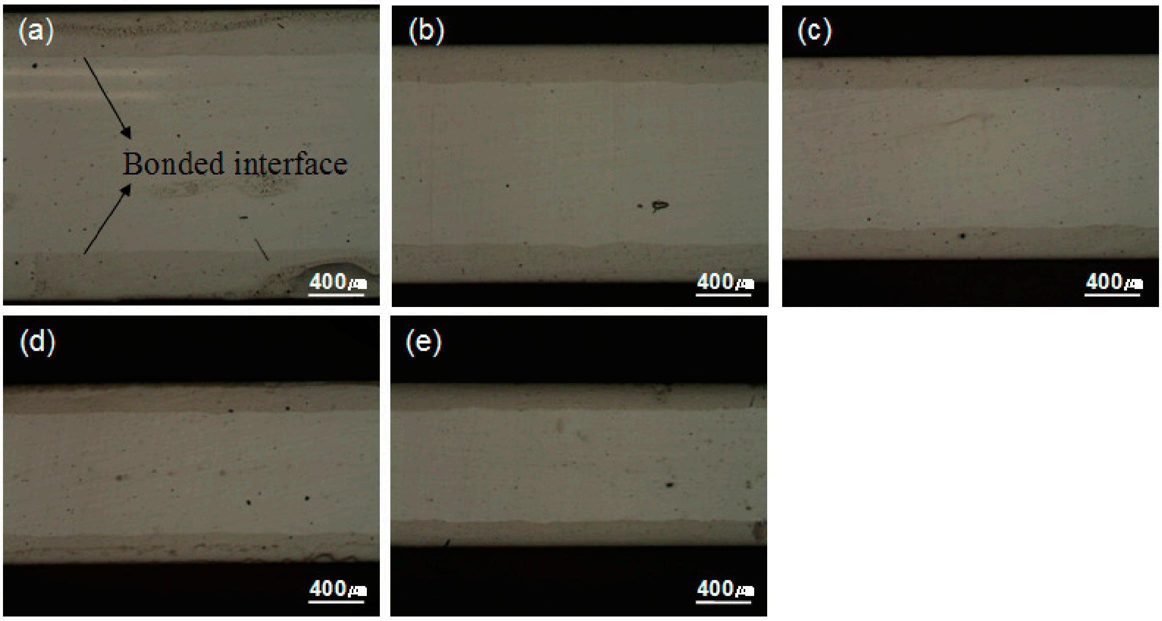

Fig.2 Bonded interface of Al/Al-Mg/Al sheets fabricated by roll bonding under the different rolling reduction; (a) 33%, (b) 43%, (c) 51%, (d) 58 and (e) 63%

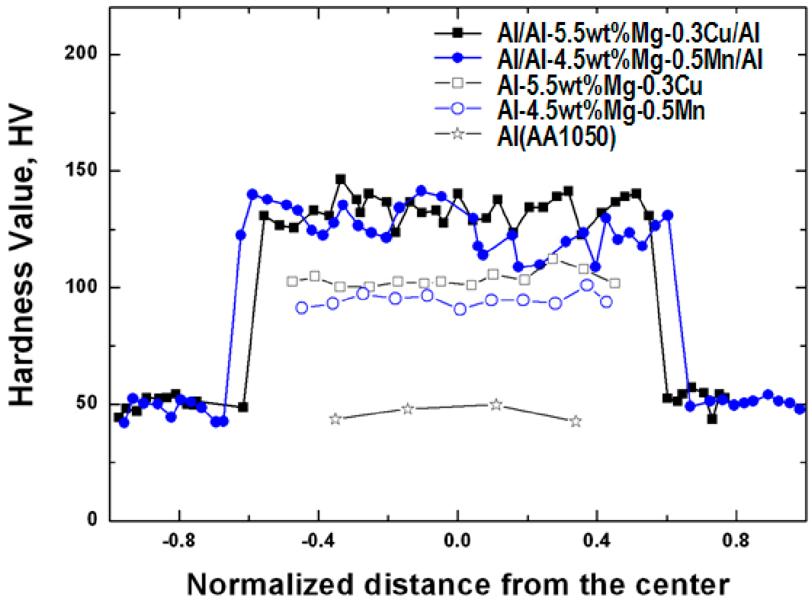

Fig.3 Micro vicker hardness (Hv) of Roll bonded Al/Al-5wt%Mg/Al sheet.

3.2 Microstructure of Al/Al-Mg/Al sheets

In order to increase bond strength and formability, roll bonded sheets were annealed at 400^{o}C for 1hour. The microstructure of annealed Al/Al-Mg/Al sheets was investigated by Orientation Image Map (OIM) and shown in Figure 4 and the microstructure was observed on the longitudinal sections of the annealed sample. In case of the annealed Al/Al-4.5wt%Mg-0.5Mn/Al, bonded line keep straight and clear. The clad pure Al have fully recrystallized large grain, the grain size near surface and interface is larger than other area because of high shear strain by rolling at surface and by wire brushing at bonded interface. Meanwhile the grain size of the core Al-4.5wt%Mg-0.5Mn is very fine and homogenous through the whole thickness. The core sheets have fully recrystallized equiaxed grains and quite random orientation. That is, the annealed Al/Al-4.5wt%Mg-0.5Mn/Al sheets have a great different microstructure between core and clad materials. In case of Al/Al-5.5wt%Mg-0.3Cu/Al sheets, bonded interface line is wavy and not clear by grain growth at bonded interface. The clad pure Al have full recrystallized large grains, also the grain size of core Al-5.5wt%Mg-0.3Cu is nearly same with clad pure Al.

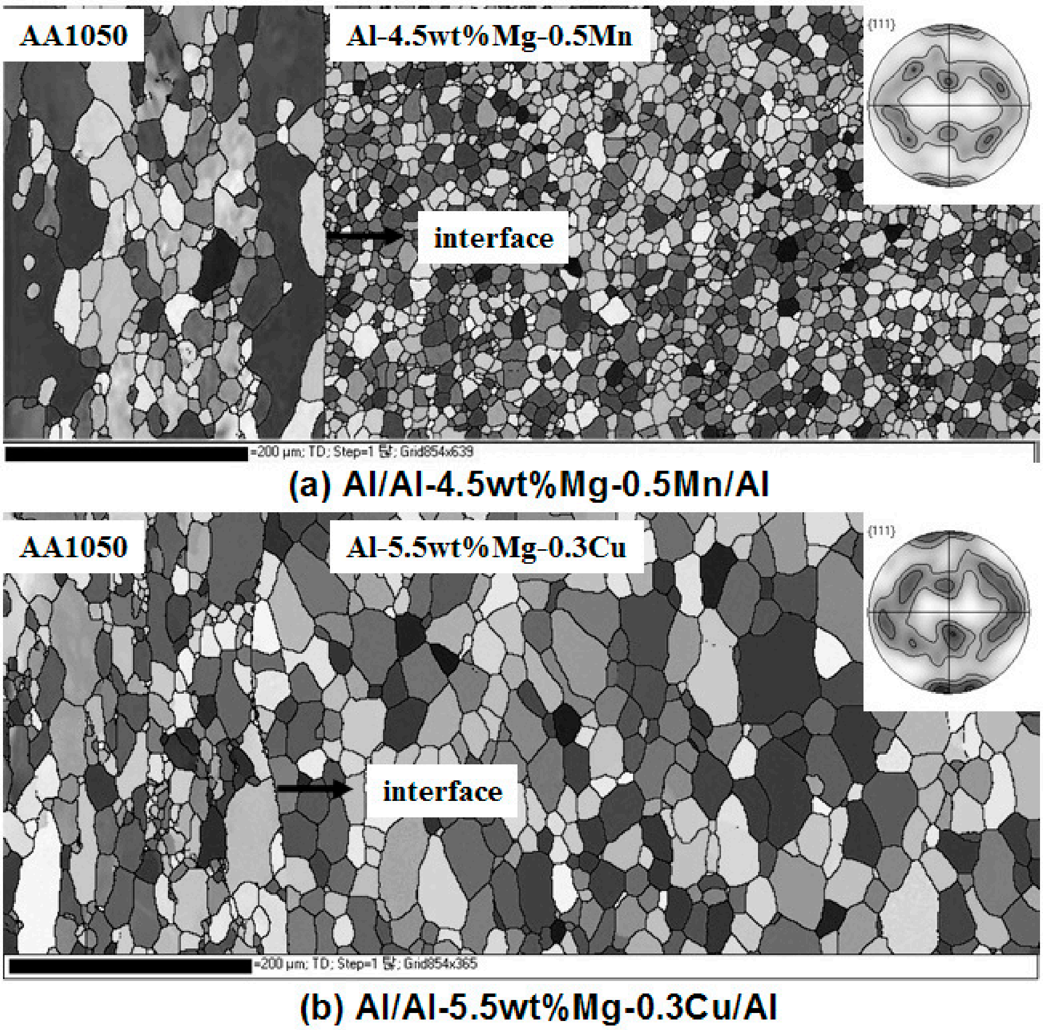

Fig.4 Microstructure of Al/Al-5wt%Mg/Al sheet annealed at 400^{o}C for 1hour; (a) Al/Al-4.5wt%Mg-0.5Mn/Al and (b) Al/Al-5.5wt%Mg-0.3Cu/Al

3.3 Tensile properties

In order to evaluate deformation behavior of the annealed Al/Al-Mg/Al clad sheets, the tensile properties of the samples were measured. Figure 5 shows tensile stress-strain curves of the annealed Al(AA1050), Al-Mg and Al/Al-Mg/Al sheets. The stress-strain curves of Al/Al-Mg/Al can be estimated from tensile data of the clad pure Al and core Al-Mg sheets. The estimated tensile stress-strain curves were also presented in Figure 5. Pure Al has low yield strength of 50MPa and tensile strength of 100MPa, but Al-Mg alloy sheets have high yield strength and strain hardening. The tensile strength of Al-4.5wt%Mg-0.5Mn and Al-5.5wt%Mg-0.3Cu sheets were 290MPa and 330MPa, respectively, which were 3times higher than that of AA1050 sheets. The calculated tensile stress-strain curve of Al/Al-4.5wt%Mg-0.5Mn/Al is nearly same with the measured curve, but the tensile fracture occurred at tensile elongation limit of Al-4.5wt%Mg-0.5Mn sheet. It means that the tensile behavior of Al/Al-4.5wt%Mg-0.5Mn/Al sheets followed core Al-4.5wt%Mg-0.5Mn sheets. Meanwhile, tensile deformation behavior of Al/Al-5.5wt%Mg-0.3Cu/Al sheet is different from the calculated one. The tensile curve shows lower flow stress and larger elongation than the calculated curves. That is, the tensile behavior of Al/Al-5.5wt%Mg-0.3Cu/Al does not follow the core materials, the clad Al affects significantly on the tensile behavior of the sheets. In order to clarify the effects, the tensile elongation and plastic strain ratio(R) were measured and shown in Figure 6. The plastic strain ratio of Al clad sheets is higher than single Al-5.5wt%Mg-0.3Cu sheets. The increase of the plastic strain ratio effect the tensile deformation behavior of Al clad sheets, so that the increase in tensile elongation occurred. Especially, the local elongation of Al/ Al-5.5wt%Mg-0.3Cu /Al sheets increased about 2~3% compared to Al-5.5wt%Mg-0.3Cu. The well bonded interface and similar microstructure between the core and clad materials is a possible reason for the improving the tensile elongation of the Al/ Al-5.5wt%Mg-0.3Cu /Al clad sheets.

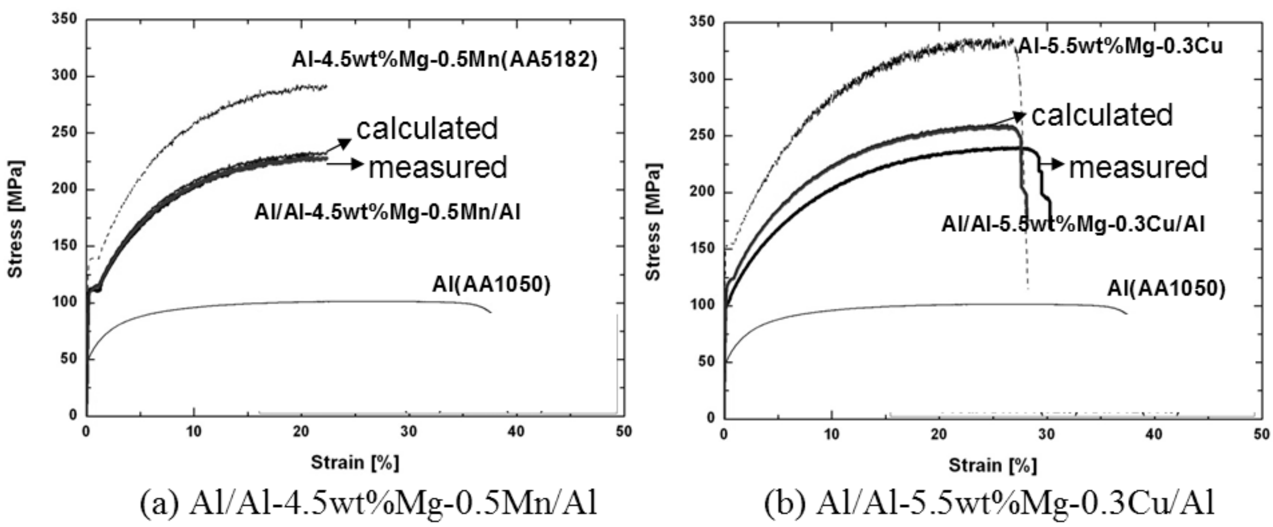

Fig.5 Tensile stress-strain curves of Al/Al-Mg/Al sheet annealed at 400°C for 1hour; (a) Al/Al-4.5wt%Mg-0.5Mn/Al and (b) Al/Al-5.5wt%Mg-0.3Cu/Al

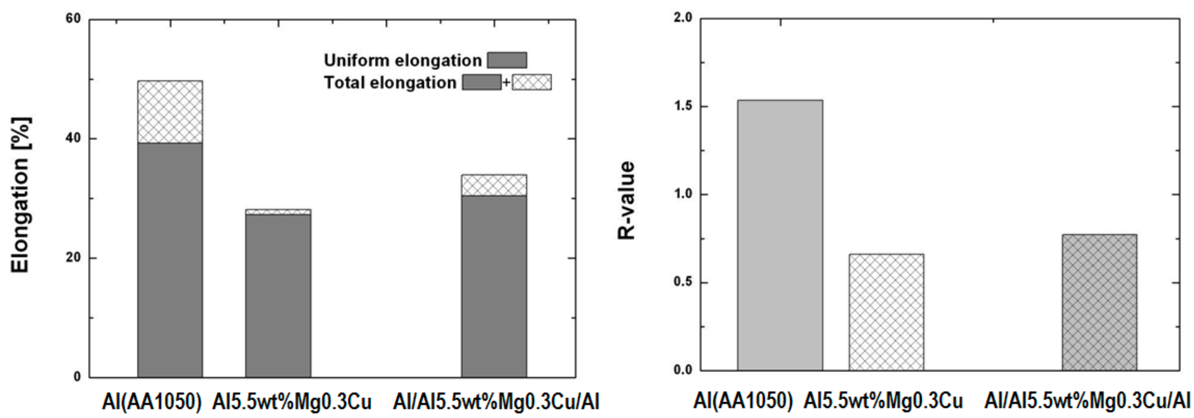

Fig.6 Tensile elongation and plastic strain ratio(R) of Al/Al-5.5wt%Mg-0.3Cu/Al sheet annealed at 400°C for 1hour.

4. Conclusion

Al/Al-4.5wt%Mg-0.5Mn/Al and Al/Al-5.5wt%Mg-0.3Cu/Al clad sheets were fabricated successfully by roll bonding at ambient temperature. The bond strength of the sheets increased with increasing thickness reduction rate of roll bonding. No defects like crack or void are observed at the bonded interface after roll bonding at thickness reduction rate above 50%. After annealing at 400^{o}C for 1hour, the sheets have a well bonded interface without void and 2nd phase and the microstructure of the sheets consisted of fully recrystallized grains. Tensile strengths of the Al/Al-4.5wt%Mg-0.5Mn/Al sheets were same as the values calculated by area fraction and strength of each Al sheets. Stress-strain curves show same strain hardening characteristics and elonagtion with core Al-4.5wt%Mg-0.5Mn sheets. Meanwhile the elongation of the Al/Al-5.5wt%Mg-0.3Cu/Al sheets was higher than that of core Al-5.5wt%Mg-0.3Cu sheets. The plastic strain ratio of Al clad sheets is higher than single Al-5.5wt%Mg-0.3Cu sheets. The increase of the plastic strain ratio effect the tensile deformation behavior of Al clad sheets, so that the increase in tensile elongation occurred. The well bonded interface and similar microstructure between the core and clad materials is a possible reason for the improving the tensile elongation of the sheets.

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