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MICROSTRUCTURE AND MECHANICAL PROPERTIES OF AA1050/ AA6061/AA1050 MULTI-LAYER SHEET FABRICATED BY COLD ROLL BONDING PROCESS

A cold roll-bonding process was applied to fabricate an AA1050/AA6061/AA1050 multi-layer sheet. Three Al sheets in which an AA6061 sheet is inserted inside two AA1050 sheets of 2 mm thickness, 40 mm width and 300 mm length were stacked up after surface treatment, and the material was then reduced to a thickness of 1.0 mm by multi-pass cold rolling. The AA1050/AA6061/AA1050 laminate complex sheet fabricated by roll bonding was then hardened by a natural aging (T4) and an artificial aging (T6) treatments. The microstructures of the as-roll bonded and the age-hardened Al complex sheets were revealed by optical microscope and electron back scatter diffraction analysis, and the mechanical properties were investigated by tensile and hardness testing. The strength of the as-roll bonded complex sheet was found to increase by 2.6 times, compared to that value of the starting material. Both AA1050 and AA6061 showed a typical recrystallization structure in which the grains were equiaxed after heat treatment. However, the grain size was smaller in AA6061 than in AA1050.

Keywords: cold roll bonding process, AA1050/AA6061/AA1050 complex sheet, mechanical properties, electron back scatter diffraction, microstructure

1. Introduction

In recent, a lot of studies for lightweight of automobile have been done because of importance of the energy saving and green environment [1-12]. Especially, the 6xxx aluminum alloys for automotive body panel have been studied extensively because of their benefits such as medium strength, formability and weldability [13]. However, the corrosion resistance and ductility of 6xxx aluminum alloy are lower than those of the other aluminum alloys. Such low corrosion resistance and ductility would be improved when 1xxx aluminum alloys which have both high corrosion resistance and ductility are stacked on 6xxx aluminum alloy by roll bonding process. It is also expected that the substitution of such aluminum alloys for steels will result in great improvements in energy economy, recyclability and life-cycle cost. Hence, it is necessary to enhance strength and ductility for further applications of aluminum alloys to the automobile industries. The control of microstructure and/or texture is essential for improvement of their properties. This study aims to produce a complex aluminum alloy to exhibit more excellent mechanical properties through cold roll bonding process and aging treatment.

2. Experimental

The materials used in the present study are commercial AA1050 and AA6061 (Al-Mg-Si alloy) sheets with chemical compositions as Table 1. As-received AA1050 and AA6061 sheets were annealed at 480 and 500°C for 1 hour in order to remove completely the residual stress, respectively. Three Al sheets in which an AA6061 sheet is inserted inside two AA1050 sheets of 2 mm thickness, 40 mm width and 300 mm length were stacked up after such surface treatment as degreasing and wire brushing, and the material was then reduced to a thickness of 3.8 mm by one-pass cold rolling. The laminate sheet bonded by the rolling was further reduced to 1.0 mm in thickness by the conventional rolling of four passes. The rolling was performed at ambient temperature without lubricant using a 2-high mill with a roll diameter of 400 mm. The AA1050/AA6061/AA1050 laminate complex sheet was then hardened by a natural aging(T4) and an artificial aging (T6) treatments. The microstructure of longitudinal cross sections normal to the transverse direction were observed by an optical microscope (OM). Micro-texture measurements by electro-backscattering-diffraction (EBSD) analysis were performed on JSM-700F field emission scanning electron microscope (FE-SEM) equipped with a TSL-OIM EBSD analysis system. The EBSD measurements were conducted on the planes perpendicular to the transverse direction (TD) of the sheets.

The mechanical properties of the samples were investigated by tensile and hardness test. The tensile test was performed by initial strain rate of $10^{-3}s^{-1}$ at ambient temperature with an Instron-type tensile testing machine. The test pieces were machined so that the tensile direction was parallel to the rolling direction.

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TABLE 1
Chemical compositions of AA1050 and AA6061used (wt%)

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
AA1050	0.03	0.29	0.02	0.01	0.01	—	0.01	0.009	RE
AA6061	0.6	0.7	0.3	0.15	1.0	0.155	0.25	0.15	RE

The gauge length and width were 32 mm and 6 mm, respectively. The variation of Vickers hardness through the thickness of the samples was also measured with the load of 0.98N.

3. Results and discussion

3.1. Microstructure

Optical micrographs on the TD plane of the samples after roll-bonding and subsequent aging treatments are shown in Fig. 1. The roll-bonded sample shows a sandwich structure in which an AA6061 is inserted between two AA1050 sheets, as shown in Fig. 1a. Both AA1050 and AA6061 shows a deformation structure in which the grains are elongated to the rolling direction. In addition, the bonding interfaces between AA1050 and AA6061 are clearly identified. On the other hand, the age-treated samples show a recrystallization structure in both AA1050 and AA6062, regardless of heat treatment conditions. It is also found that the grain size is larger in AA1050 than in AA6061 in the age-treated every materials.

Fig. 2 shows the grain boundary (GB) map, the normal direction (ND) map and the rolling direction (RD) map obtained by EBSD measurement of the samples after rolling and heat treatment. The color of each point indicates the crystallographic direction parallel to ND and RD of the sample, corresponding to the colored stereographic triangle, respectively. After rolling, the grains are elongated to the rolling direction at all regions through the thickness in both AA1050 (Fig. 2a) and AA6061 (Fig. 2b). AA1050 has a recrystallization structure consisting of clean coarse grains with the average grain size of 35 mm after T6 treatment. It is also found through GB map that the fraction of high angle grain boundaries is higher than that of low angle grain boundaries in every T6 treated materials. As shown in Fig. 2b, AA6061 has also a recrystallization structure with the average grain size of 15mm after T6 treatment. This means that the grains in AA6061 are finer than those of AA1050. It is well known that the alloys with low purity have finer microstructure because the solutes decrease the grain boundary mobility and hence restrains grain growth [14]. The fraction of high angle grain boundary in AA6061 is above 0.9, larger than that of AA1050. It is also notable that these solutes effect on increases of the fraction of high angle grain boundaries.

3.2. Mechanical Properties

Fig. 3a shows the hardness distribution in thickness direction of the materials before and after rolling. It is found that the hardness of both materials increases due to work hardening by rolling, but increasing rate is larger than in AA1050. This is because work hardening rate is higher in AA6061 than in AA1050. As shown in Fig. 3b, the hardness decreases after T4 treatment in both AA1050 and AA6061, however the decreasing rate is larger in AA1050 than in AA6061. And it is found that the variation of hardness with aging time is larger in AA6061 than in AA1050, even though the variation is tiny in both materials. Fig. 3c is the variation of hardness distribution in thickness direction of the sample with aging time of T6 treatment. The hardness in AA1050 region decreases largely due to softening by annealing, however it in AA6061 region rather increases due to aging hardening, resulting in great difference in hardness between both regions.

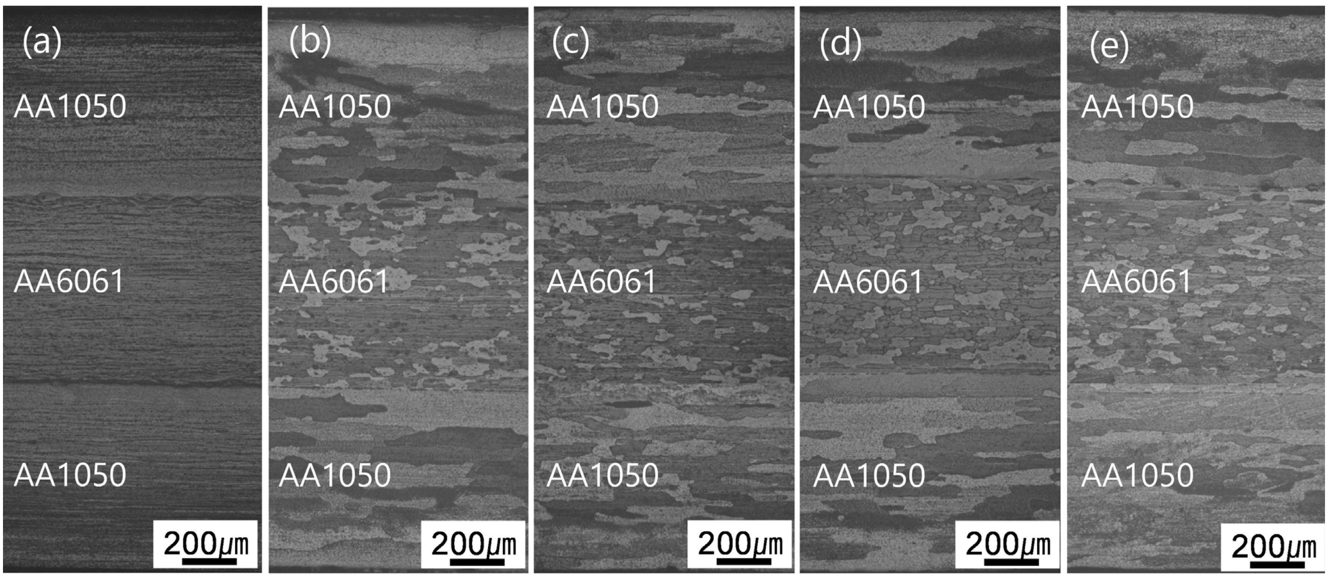

Fig. 1. Optical microstructures of AA1050/AA6061/AA1050 alloys fabricated by cold roll-bonding process and aging treatment. (a) as-rolled material, (b) T4-96h, (c) T6-1h, (d) T6-3h, (e) T6-5h

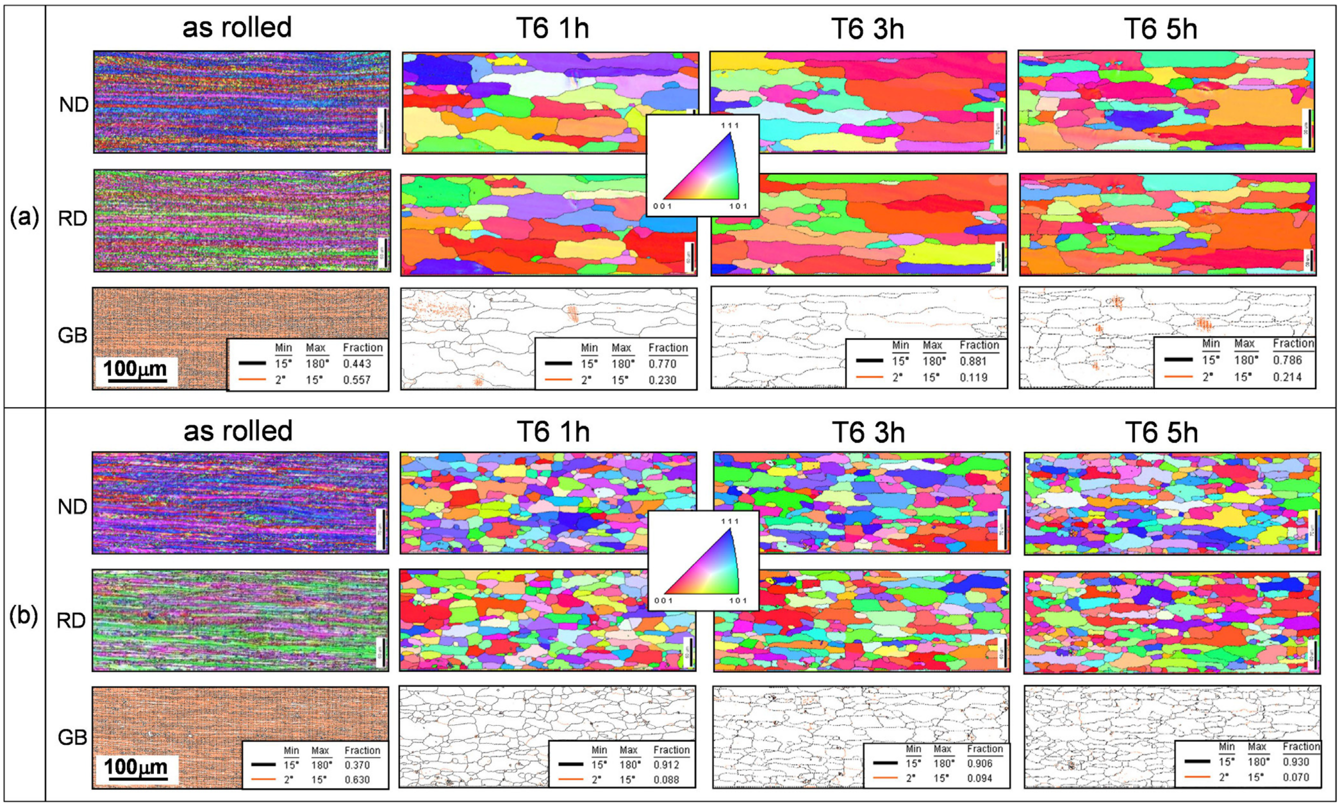

Fig. 2. The grain boundary (GB) map, the normal direction (ND) map and the rolling direction (RD) map obtained by EBSD measurement of the samples after rolling and aging treatment. (a) AA1050, (b) AA6061

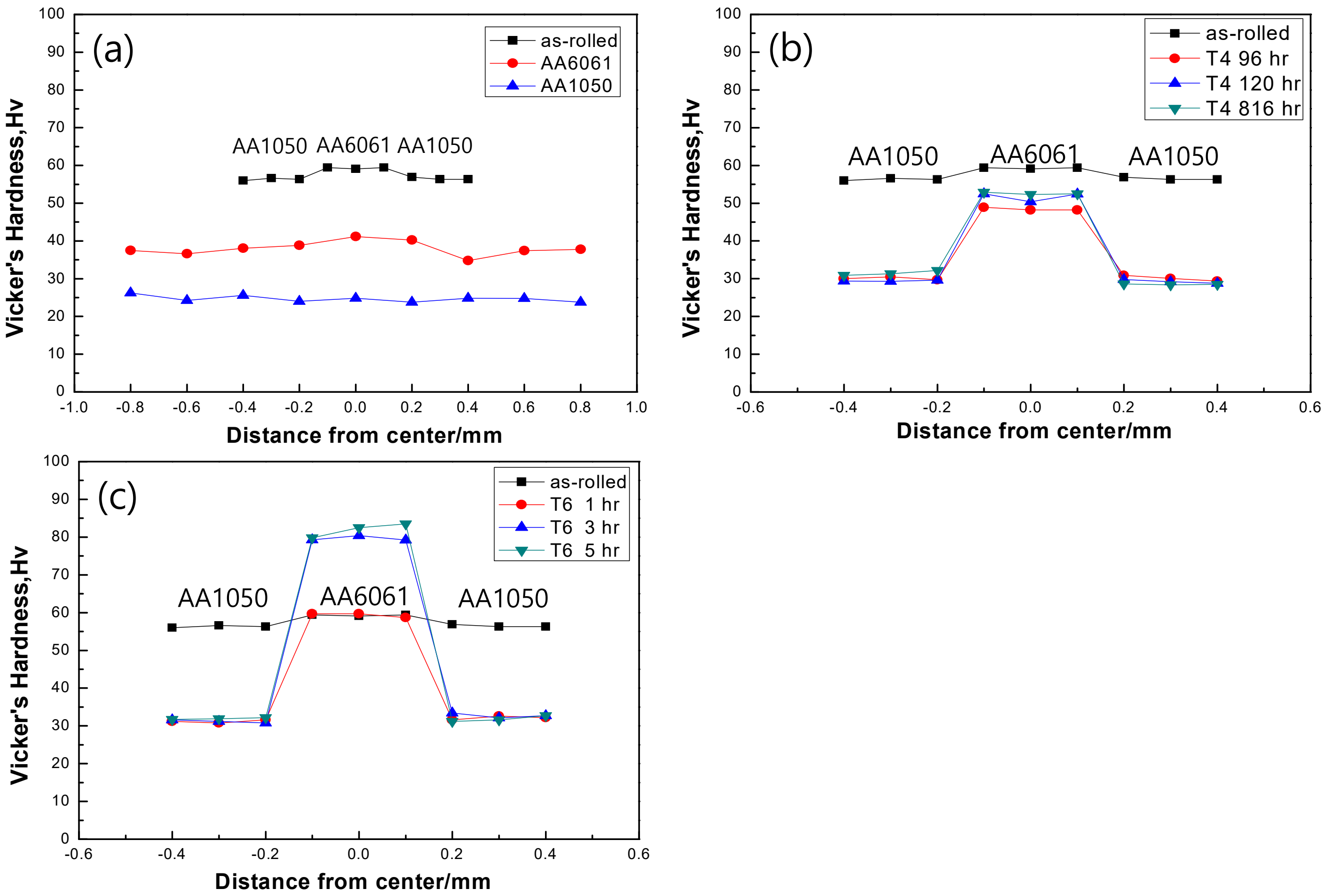

Fig. 3. The variation of hardness distribution in thickness direction with rolling and aging treatment. (a) before and after rolling, (b) T4 treatment, (c) T6 treatment

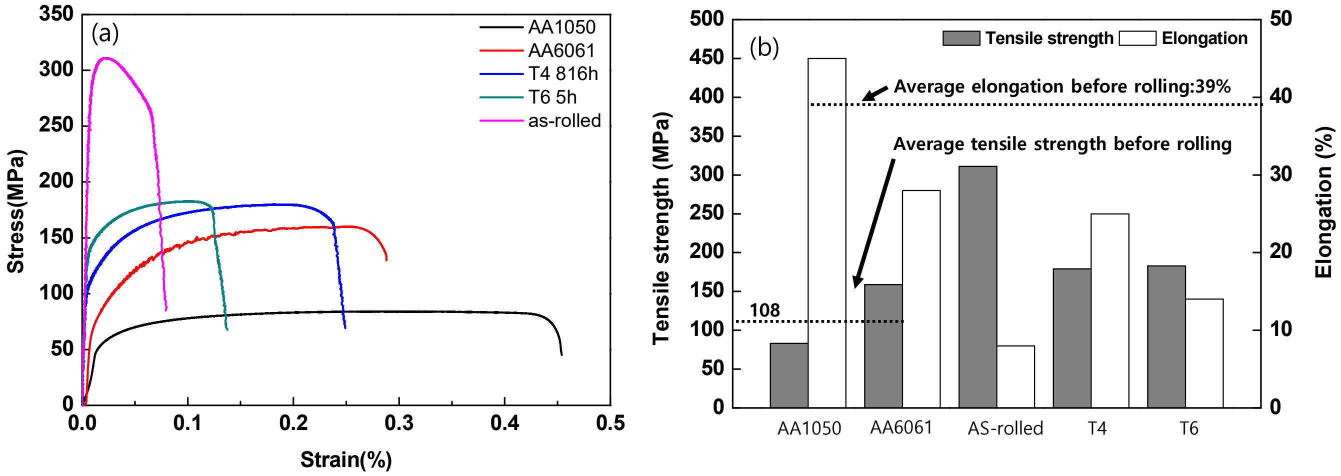

Fig. 4. Nominal stress-strain curves(a) and the mechanical properties(b) of AA1050/AA6061/AA1050 alloys after the as-rolled and aging treatment

The variation of tensile properties of the materials with aging treatment is shown in Fig. 4. The as-received materials of AA1050 and AA6061 show low strength and large elongation because they are the as-annealed states, as shown in Fig. 4a. The as-rolled material exhibits lower ductility and higher strength due to the work hardening by the cold rolling of 75% total reduction. The tensile strength of the material decreases and the elongation increases largely after T4 and T6 aging treatment. The variation of mechanical properties of the material with aging treatment is summarized in Fig. 4b. The as-rolled material shows a maximum tensile strength of about 310 MPa, which is about 2.6 times higher than that of the as-received materials. And it is found that the T4 treated material has more excellent mechanical properties than those of T6 treated material.

4. Conclusions

In this study, an AA1050/AA6061/AA1050 multi-layer sheet was successfully fabricated by a cold roll-bonding process and subsequently aging treating. The microstructures of the as-roll bonded and the age hardened Al complex sheets were revealed by OM and EBSD analysis and the mechanical properties were investigated by tensile testing and hardness testing. The strength of the as-roll bonded complex sheet was found to increase by 2.6 times, compared to that value of the starting material. Both AA1050 and AA6061 showed a typical recrystallization structure in which the grains were equiaxed after aging treatment. However, the grain size was smaller in AA6061 than in AA1050.

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