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Effect of Mn Content on Microstructure of Twin Roll Cast Al-Mg-Mn Alloys

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Al-5wt%Mg-Mn alloy sheets with different Mn contents (0.7~1.5wt %) were fabricated by twin roll casting and hot rolling process and the microstructure of the sheets was investigated. The twin roll cast Al-Mg-Mn alloy sheets had a fine dendrite size and very small inclusions due to high cooling rate of twin roll casting. All cast sheets showed a good workability during hot rolling process. However, the hot rolled sheets had a different microstructure according to Mn content. After annealing at 450°C for 1hour, Al-5wt%Mg-0.7wt%Mn sheets showed fully-recrystallized eqiaxed grain. Meanwhile, microstructures of the annealed Al-5wt%Mg-Mn sheets with higher content of Mn consisted of large elongated grains and a number of fine Al_6Mn precipitates in grain. The density of the precipitate increased with increasing Mn content. Large number of fine Al_6Mn precipitates inhibits static recrystallization of Al-5wt%Mg-Mn sheets during annealing process. In addition, high density of Al_6Mn precipitates in the annealed Al-5wt%Mg-1.5wt%Mg sheets increase the tensile strength and the yield strength up to 420MPa and 230MPa, respectively.

Keywords: *Al-Mg-Mn, Twin roll casting, Microstructure, Grain size, Strength.*

1. Introduction

Twin roll strip casting has been well known as a cost effective process to make an aluminum thin strip directly from the melt [1-4]. In addition, a high cooling rate of twin roll strip casing could improve mechanical properties by refining cast structure in several aluminum alloys. However, a conventional twin roll strip casting process has disadvantages like a limitation of alloy composition and low mechanical properties due to inhomogeneity in microstructures and chemical compositions through the sheet thickness. Particularly, it is more difficult in high strength aluminum alloys with high contents of alloying elements [4-5]. Al-Mg alloys have a favorable combination of strength and formability as well as good corrosion resistance and weldability, and therefore of interest in light weight structural application in the transportation industry. Also, minor alloying element addition such as Mn increase strength of Al-Mg base alloys by refining grain size and precipitation of fine Al-Mn dispersoid [6]. In order to make a high strength Al-Mg-Mn alloy sheet by twin roll strip casting, newly designed Cu-Cr twin rolls were used to get sufficiently cooling rates and process parameters such as roll speed and amount of cooling water were changed. The optimum cast conditions were found to fabricate a high strength Al-Mg strip in the previous works.[5,7] Al-5wt%Mg-Mn alloy sheets with different Mn contents (0.7~1.5wt %) were successfully fabricated by twin roll casting and hot rolling process and the microstructure of the sheets was investigated in present experiment. This study mainly focused on the effects of Mn content on microstructure and tensile properties of the annealed Al-Mg-Mn alloy sheets.

2. Experimental procedure

A special strip caster with Cu-Cr twin rolls cooled by water circulation was designed to get a high cooling rate at the roll gap. The roll diameter was 300mm. Molten Al alloy was transferred to the roll gap through tundish and nozzle. The nozzle was set basically to keep the contact length between melt and rolls at 35mm. The contact length was changed to reduce a surface crack of the strip. [7] The melt was cooled by the rotating twin rolls and solidified into thin strip with the thickness of 4mm and the solidification was completed in the roll gap. The Al-Mg-Mn alloys with a different content of Mn were melted in an electric melting furnace and transferred to the rolls at 680°C. The casting speed was changed from 3m/min to 5m/min by controlling the rotating speed of the rolls. The cast strips were annealed at 450°C for 10 hour to reduce reduce segregation along grain boundaries. The cast strip was rolled to thin sheets with a thickness of 1.0mm at 300°C. The cold-rolled sheets were annealed at 400°C and 450°C for 1 hour to investigate and effect of annealing treatment on microstructure and mechanical properties. The microstructures of Al-Mg cast strip and rolled sheets were observed by an optical microscope after the mechanical polishing and electro-chemical etching. The size and chemical composition of precipitates in Al-Mg-Mn sheet were analyzed using TEM (Transmission Electron Microscope) with an EDS (Energy Dispersive Spectrometer) analyzer. The tensile specimens of the rolled sheets were prepared according to ASTM E8M; the tensile properties of the annealed sheets were evaluated by an Instron 4201 tensile testing machine at ambient temperature.

3. Result and Discussion

3.1 Microstructure of Al-Mg-Mn cast strip

Al-5wt%Mg-Mn strips with different content of Mn were fabricated successfully by twin roll strip casting on the basis of optimum process condition. [7] In order to reduce crack formation on the strip surface, the contact length between rolls and melt was changed; the contact length of upper cast roll was larger than one of lower roll, and the roll separating force was controlled The microstructure on the thickness center of cast strips was shown in Figure 1. The microstructure consist of very fine dendrites and small inclusions on the grain boundaries, which DAS (Dendrite Arm Spacing) is below 10μm and the size of inclusions is below 1μm. The DAS slightly increased with increasing Mn contents, while the grain size was nearly same regardless of Mn content. In the previous reports of the microstructure of Al-Mg cast strip [7], the DAS have a great relationship with content of Mg, but the minor addition of Mn did not effect on the microstructure of Al-Mg-Mn strip in this experiment. In order to get a homogenous microstructure, annealing treatment at 450°C for 10 hour was conducted. The microstructure of annealed strip was shown in Figure 2. In Al-5wt%Mg-0.7Mn strip, most Mg segregations between dendrite were dissolved in Al matrix, homogenous microstructure was obtained. The grain size of the annealed samples decreased with increasing Mn content. The small dark particle with the size below 1μm still existed between grains in the strips with high Mn content. The particle was identified with $Al_6(Fe,Mn)$ inclusions by EDS analysis. The grain size of annealed Al-5wt%Mg-1.5Mn strip was much finer than that of annealed Al-5wt%Mg-0.7Mn, and it was caused by large number of $Al_6(Fe,Mn)$ particle which inhibited the grain growth during annealing process.

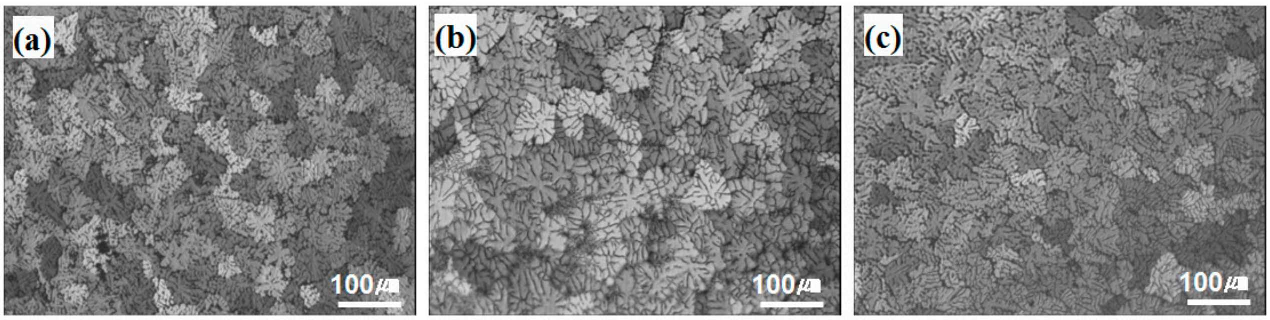

Fig.1 Microstructure of Al-Mg-Mn cast strip; (a) Al-5wt%Mg-0.7Mn, (b) Al-5wt%Mg-1Mn, (c) Al-5wt%Mg-1.5Mn

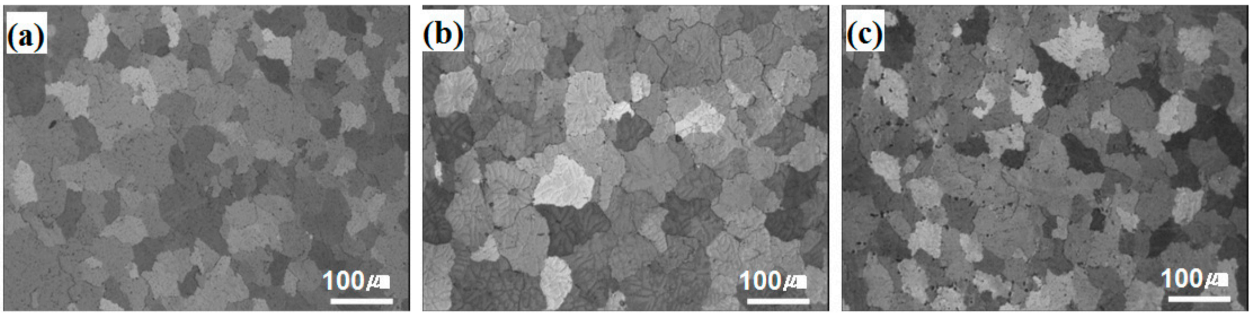

Fig.2 Microstructure of Al-Mg-Mn cast strip after annealing at 450^{o}C for 10hr.; (a) Al-5wt%Mg-0.7Mn, (b) Al-5wt%Mg-1Mn, (c) Al-5wt%Mg-1.5Mn

3.2 Microstructure of hot-rolled Al-Mg-Mn alloy sheets

The Al-5wt%Mg-Mn cast strips were hot rolled to thin sheets with a thickness of 1mm at 300^{o}C. The hot-rolled sheets were annealed at 450^{o}C for 1hr. Figure 3 shows the microstructure of the annealed sheets, the microstructure was observed on the longitudinal sections of the annealed sample. It is seen that the annealed Al-5wt%Mg-0.7 sheets have a fully recrystallized microstructure, while the Al-5wt%Mg-1.0Mn and Al-5wt%Mg-1.5Mn sheets have elongated grains along the rolling direction. The thickness of elongated grain reduced with increasing Mn content. It means that the high content of Mn results in retarding dynamic and static recrystallization during hot rolling and subsequent annealing process. It is well known that Mn element in Al-Mg-Mn alloy make a very fine Al-Mn dispersoids in Al matrix during casting and annealing process, and Al-Mn dispersoids retard recrystallization and grain growth.[6,8,9]

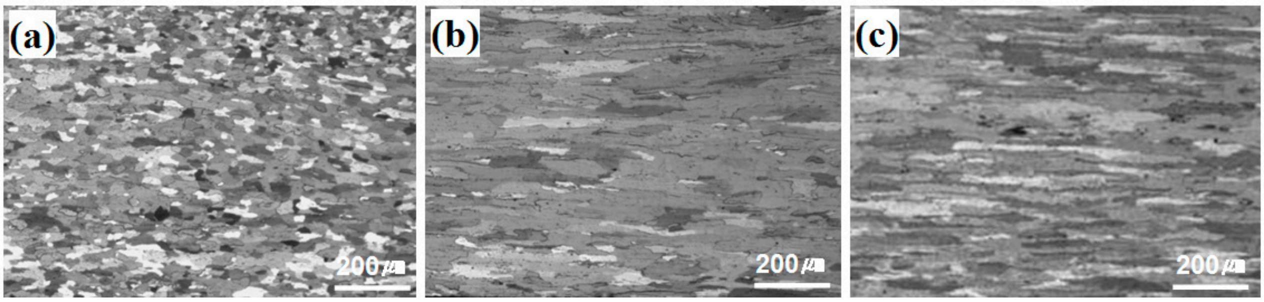

Fig.3 Microstructure of Al-Mg-Mn sheets after hot rolling and annealing at 450^{o}C for 1hr.; (a) Al-5wt%Mg-0.7Mn, (b) Al-5wt%Mg-1Mn, (c) Al-5wt%Mg-1.5Mn

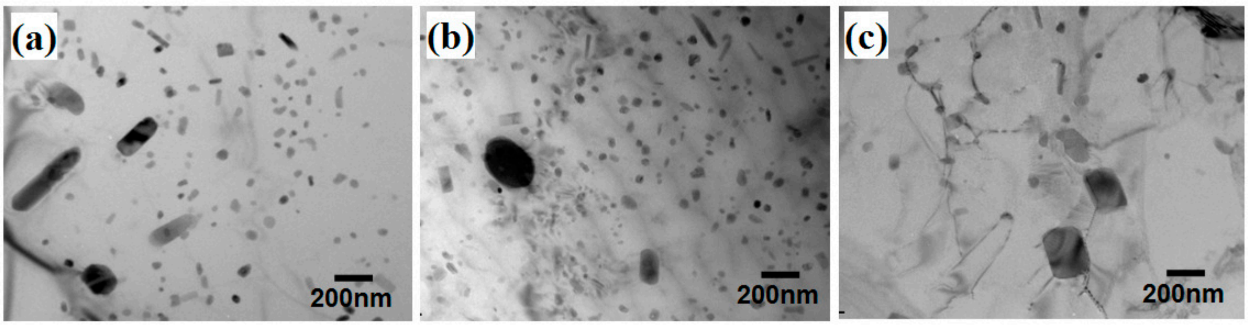

Fig.4 Precipitates in the annealed Al-Mg-Mn sheets.; (a) Al-5wt%Mg-0.7Mn, (b) Al-5wt%Mg-1Mn, (c) Al-5wt%Mg-1.5Mn

In order to investigate the effects of Mn, Microstructure was observed by TEM and was shown in Figure 4. There are two kinds of particles, one is relatively large particles with rectangular shape, and the other is very fine dispersoid with round shape. When the chemical composition of the particles was analyzed by EDS, the large particles were Al(Fe,Mn) intermetallics and the small dispersoids were Al_6Mn. The size and dispersion of the particles were different according to the Mn content. The size of Al_6Mn dispersoid increased with increasing Mn content and the distribution of the particles was more homoregenious in Al-5wt%Mn-1.5Mn. The large amount of Al_6Mn dispersoild in Al-5wt%Mg-Mn seems to give a great effect on the microstructure consisted of unrecrystallized elongated grain.

3.3 Tensile properties

In order to evaluate deformation behavior of the annealed Al-Mg-Mn sheets, the tensile properties of the samples annealed at different temperature were measured. Figure 5 shows tensile stress-strain curves of Al-5wt%Mg-Mn with different content of Mn. In the tensile stress-strain curves of Al-Mg-Mn sheets annealed at 400°C (Fig.5 (a)), tensile deformation behaviors of Al-5wt%Mg-0.7Mn and Al-5wt%Mg-1.0Mn sheets present similar characteristic, while Al-5wt%Mg-1.5wt%Mn sheets have higher tensile stress than other alloy sheets. The increase in the strength of Al-5wt%Mg-1.5Mn is caused by the high density of Al_6Mn precipitates in Al matrix, which was mention in previous sections. In the specimens annealed at 450°C for 1hour, the sheets have a higher strength and lower elongation than the specimens annealed at 400°C. Generally, a strength of annealed Al-Mg alloy sheets reduced with increasing annealing temperature due to static recovery and recrystallization. However, in present study, Al-5wt%Mg-1.5Mn sheets shows higher strength at higher annealing temperature During twin roll strip casting, Mn alloying element was supersaturated in Al matrix and fine Al_6Mn precipitates were formed during final annealing process after hot rolling. It is a reason for high strength of Al-5wt%Mg-1.5Mn annealed at 450°C. Figure 6 is tensile properties of Al-5wt%Mg-xMn sheets. In Al-5wt%Mg-Mn alloys having low content Mg(below 1.0wt%), strength and elongation is not so much effected by annealing condition. Meanwhile, Al-5wt%Mg-1.5wt% alloy sheets shows higher tensile strength at 450°C, it is correlated with high density of Al_6Mn precipitates in Al matrix. The maximum tensile strength and yield strength of the samples in this study were 428MPa and 236MPa of the Al-5wt%Mg-1.5wt% alloy sheets annealed at 450°C for 1hour, respectively. Al-Mg-Mn sheets fabricated by twin roll casting and rolling have a superior strength to conventional Al-Mg-Mn alloy sheets due to fine Al_6Mn precipitates in Al matrix.

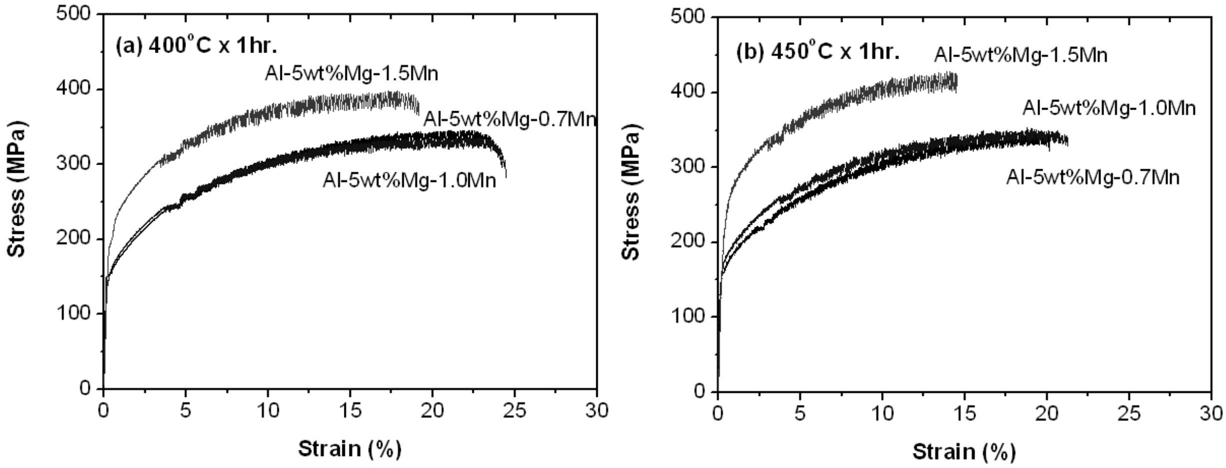

Fig.5 Tensile stress-strain curves of Al-5wt%Mg-xMn sheet annealed at (a) 400°C and (b) 450°C for 1hour.

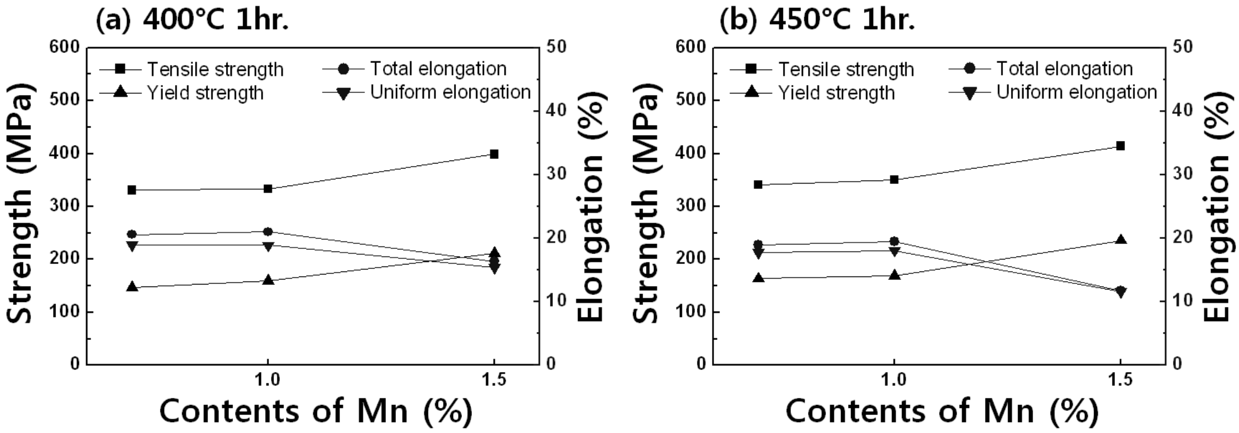

Fig.6 Tensile properties of Al-5wt%Mg-xMn sheet annealed at (a) 400°C and (b) 450°C for 1hour.

4. Conclusion

Al-5wt%Mg-Mn sheets with different content of Mn were successfully fabricated by twin roll casting and hot rolling process. Annealed Al-5wt%Mg-Mn sheets have fully recrystallized fine grain, while annealed Al-5wt%Mg-Mn with Mn content above 1.0wt% showed unrecrystallized elongated grain structure. The density of fine Al_6Mn precipitates increased with increasing Mn content so that large number of fine Al_6Mn precipitates inhibited recrystallization and grain growth in Al-5wt%Mg-Mn with high content Mn. In Al-5wt%Mg-Mn alloys having low content Mg(below 1.0wt%), strength and elongation is not so much effected by annealing condition. Meanwhile, annealed Al-5wt%Mg-1.5wt% alloy sheets shows higher tensile strength at 450°C, it is correlated with high density of Al_6Mn precipitates in Al matrix. That is, strength of Al-5wt%Mg-1.5Mn alloy sheets increased with increasing annealing temperature due to additional precipitation of fine Al_6Mn precipitates at elevated temperature. The maximum tensile strength and yield strength of the samples in this study were 428MPa and 236MPa of the Al-5wt%Mg-1.5wt% alloy sheets annealed at 450°C for 1hour, respectively. Al-Mg-Mn sheets fabricated by twin roll casting and rolling have a superior strength to conventional Al-Mg-Mn alloy sheets due to fine Al_6Mn precipitate in Al matrix.

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