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Microstructures and Properties of Al-Mn Aluminum Alloys Fabricated by a Twin Belt Caster

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Process routes for Al-Mn aluminum alloy sheets produced via an advanced twin belt caster (FLEXCASTER^{TM}) have been successfully tried. Compared with a conventional DC processed Al-Mn aluminum alloy sheets, the FLEXCAST^{TM} Al-Mn aluminum alloy sheets have higher tensile strength at elevated temperatures from 474 to 673K due to high solute solution of Mn as a consequence of the rapid cooling rate during solidification and elimination of a homogenization step from the process. It is found that there is a good correlation between the strength at 473K and the solute solution amount of Mn, and fine precipitate is a very important factor for higher strength at 673K.

Keywords: *Twin belt caster, Al-Mn aluminum alloy, solid solution amount of Mn, tensile strength, evaluated temperature.*

1. Introduction

The demand for the aluminum alloy sheets with excellent heat resistibility is becoming to increase to contribute higher energy savings. The Al-Mn series alloy, such as the AA3003 is one candidate material for satisfying this needs because solutionized Mn in matrix retracts recrystallization following two reasons [1, 2], one is that solutionized Mn has low diffusion coefficient than other element and pinning the dislocation and sub-grain boundary, resulting to raise the recrystallized temperature. Another reason is that precipitated Mn bearing particles during heating delay the subsequent recrystallization significantly. It is possible to get a good heat resistance Al-Mn alloy by supersaturation of Mn in matrix via rapid cooling solidification process, e.g. twin roll continuous casting. Nagahama reported that Al-1.6~2.5wt%Mn binary alloys fabricated via a twin roll continuous caster had higher tensile strength at 473-573K than a conventional DC processed material [3]. However, there is little research on commercial Al-Mn alloys, such as the AA3003 alloy.

Recently, an advanced twin belt continuous caster (FLEXCASTER^{TM}) has been developed, and successfully produces Al-Mg series aluminum alloy sheets for automotive parts [4]. The FLEXCASTER^{TM} casts at a high cooling rate during solidification, and the following process does not include homogenization and hot rolling steps, so the high solid solution of Mn is available from the process.

The objective of this study is to develop a FLEXCAST3003 series aluminum alloy sheet and evaluate its microstructures and tensile properties at elevated temperatures. For comparison, an conventional DC processed AA3003 alloy sheet is used in this study.

2. Experimental Procedure

2.1 Preparation of materials

The chemical compositions of alloys used in this study are listed in Table 1. The FLEXCAST3003 aluminum alloy A and B with different level of Fe and Si contents were cast with high cooling rate in the range of 10^1-10^2K /s. The slab was then cold rolled to final gauge sheet of 1mm without heat treatment to obtain H18 temper. The 1mm thick DC3003-H18 aluminum alloy sheet fabricated via a conventional DC process is used for comparison. Some samples were heated at 473K up to 1000 h to simulate the long period application in an elevated temperature condition.

Table 1 Chemical compositions of alloys used in the study(mass%)

Alloy	Mn	Si	Fe	Cu	Zn	Ti
FLEXCAST3003-A	1.03	0.39	0.62	0.08	0.02	0.02
FLEXCAST3003-B	1.03	0.55	0.34	0.07	0.03	0.01
DC3003	1.04	0.37	0.54	0.11	0.03	0.03
JIS3003	1.00〜1.50	≦0.6	≦0.7	0.05〜0.20	≦0.10	-

2.2 Evaluation of tensile properties at elevated temperatures

Samples were prepared along rolling direction in accordance with S type (parallel area with length of 20mm and width of 6 mm, shoulder radius of 3mm) in the JIS H 7501 specification. They were heated to 473-673K and kept for 15minutes following by tensile testing at strain rate of $10^{-3}s^{-1}$. Stress-strain curves, 0.2% yield strength (YS) and ultimate tensile strength (UTS) were measured by tensile testing specified by JIS Z 2241.

2.3 Evaluation of Microstructures

Grain structures of longitudinal sections were observed by polarizing microscope after buff grinding and anodizing. Precipitates were examined by TEM equipped with EDX after sample was thinned by means of electrolytic polishing in nitric acid-methanol solution. Solid solution amount of Mn was measured by heat phenol resolution method [5].

3. Results and Discussion

3.1 Tensile strength at temperature 473-673K

Fig. 1 shows the stress-strain curves of the FLEXCAST3003-A and the DC3003 aluminum alloy sheets with H18 temper which tensile tested at 473, 573 and 673K. Compared with the DC3003, the FLEXCAST3003 sheet has higher tensile strength and lower elongation.

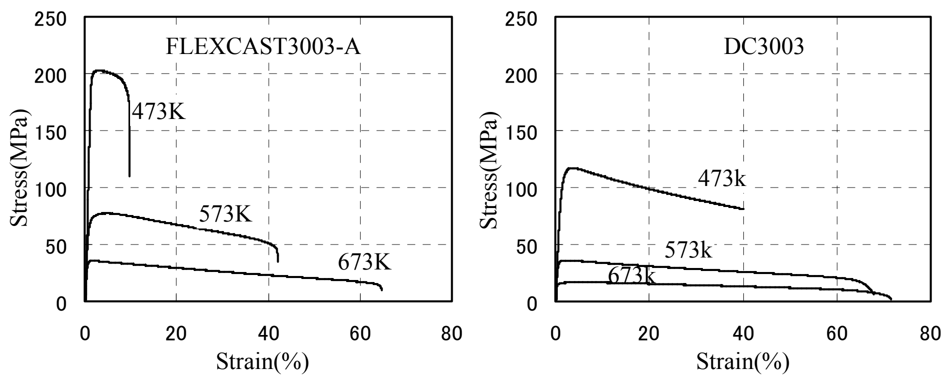

Fig. 1 Stress-strain curves of the FLEXCAST3003 and the DC3003 tensile tested at elevated temperatures.

The correlation between YS or UTS and tensile temperatures is plotted in Fig. 2. YS and UTS of the FLEXCAST3003-A aluminum alloy sheets are almost twice as high as the DC3003 aluminum alloy sheet. Table 2 summaries the solid solution amount of Mn for both materials before and after tensile testing.

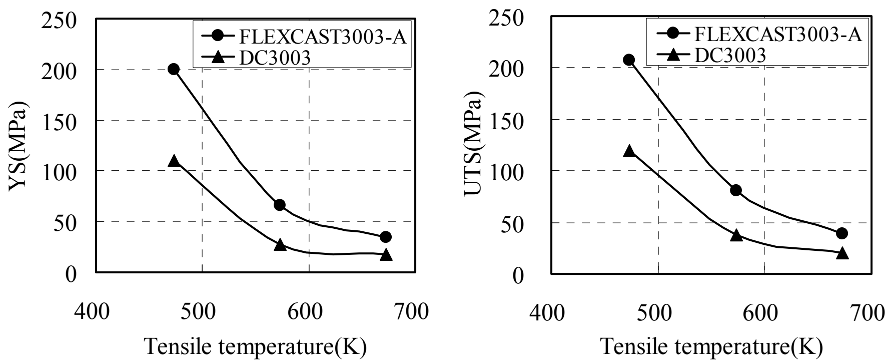

Fig. 2 A correlation between YS or UTS and tensile temperatures.

Table 2 Solid solution amount of Mn in the FLEXCAST3003-A and the DC3003(mass%)

Alloy	As H18 temper	After tensile test at 473K	After tensile test at 673K
FLEXCAST3003-A	0.87	0.75	0.13
DC3003	0.09	0.12	0.11

The solid solution amount of Mn in the FLEXCAST3003 is about ten times as high as the DC3003 before tensile test, and it decreased as tensile temperature increased. The solid solution amount of Mn in the FLEXCAST3003 is still about six times as high as the DC3003 even after the tensile test at 473k. This corresponds to the higher tensile strength in the FLEXCAST3003 because dislocation becomes difficult to move by solutionized Mn [6]. However, as tensile temperature raise to 673k, the solid solution amount of Mn in the FLEXCAST3003 is almost the same as that in the DC3003, so the difference of tensile strength between the FLEXCAST3003 and the DC3003 at 673K should comes from the other factors rather than the solid solution of Mn. Fig. 3 shows grain structures after tensile tested at 473, 573 and 673K. The DC3003 has recrystallized structures after tensile tested at 573K and 673K while the FLEXCAST3003 has unrecrystallized structures even after the test up to 673K, which is corresponding to the lower elongation of the FLEXCAST3003 as shown in Fig. 1.

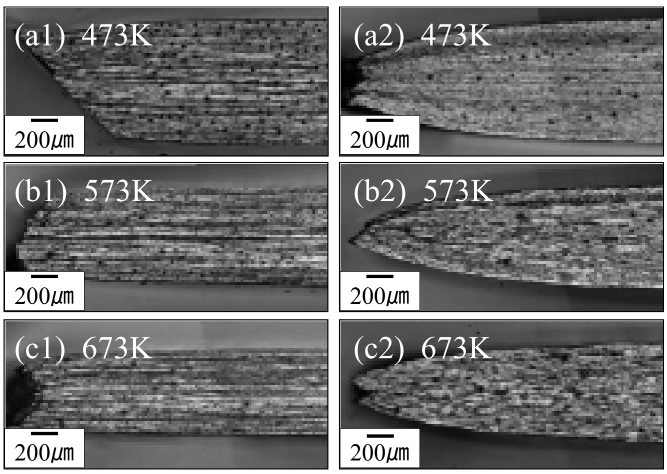

Fig. 3 Grain structures after tensile test at different temperatures in the FLEXCAST3003 (a1,b1,c1) and the DC3003 (a2,b2,c2).

Fig. 4 shows microstructures examined with a transmission electron microscopy. At 473K, the FLEXCAST3003 has high density of dislocations, and the DC3003 shows the sub-grain structures with few dislocations. As the tensile temperature raise to 673K, sub-grain structures are clearly observed in the FLEXCAST3003, but the DC3003 material shows a completely recrystallized grain structures. In addition, high density of fine precipitates, which are analyzed as AlMnSi phases by EDX, are observed in the FLEXCAST3003.

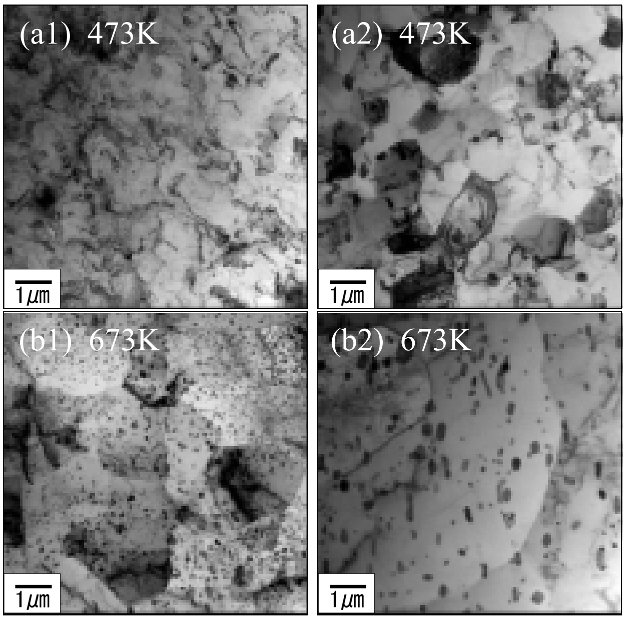

Fig. 4 TEM photos of the FLEXCAST3003 (a1,b1) and the DC3003 (a2,b2) after tensile tested at 473K and 673K.

Fig. 5 is STEM-DFI of the FLEXCAST3003, given tensile test at 673K, which shows that dislocations are pinned by fine precipitates. So, it is thought that the high density of fine precipitates formed during tensile testing contribute to the higher tensile strength of FLEXCAST 3003 at 673k.

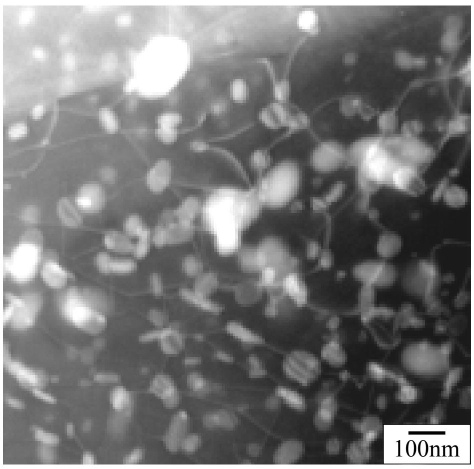

Fig. 5 STEM-DFI photo of the FLEXCAST 3003 after tensile tested at 673K.

3.2 Tensile strength at 473K after keeping for long periods

Considering the actual application conditions for high temperatures, it is important to evaluate the tensile strength at using temperatures after kept for long periods. Here, the tensile strength of the FLEXCAST3003-B and the DC3003 aluminum alloy sheets at 473K after heated up to 1000 h were measured. Fig. 6 shows the change of YS or UTS at 473K with keeping times. The YS or UTS of the FLEXCAST3003-B is about 1.4 times as high as the DC3003 even they are kept at 473K until 1000 h.

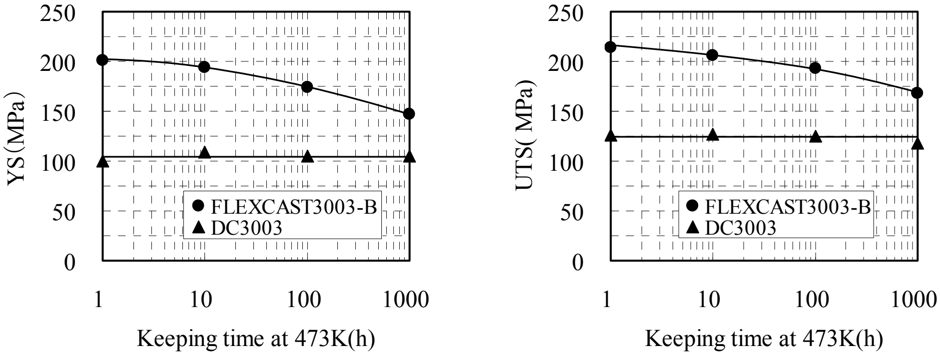

Fig. 6 A correlation between YS or UTS and keeping time

Fig. 7 shows grain structures after kept at 473K for 1000 h, both alloys show unrecrystallized grain structures. Fig. 8 shows low density of precipitates in both alloys.

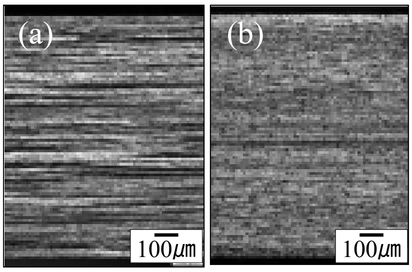

Fig. 7 Optical photos showing grain structures in the FLEXCAST3003-B (a) and the DC3003 (b) after kept at 473K for 1000 h.

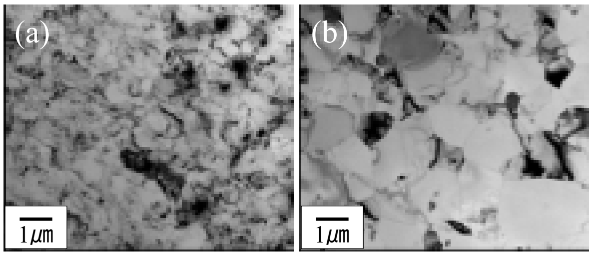

Fig. 8 TEM photos showing precipitates in the FLEXCAST3003-B (a) and the DC3003 (b) after kept at 473K for 1000 h.

In order to understand the difference of UTS between the FLEXCAST3003-B and the DC3003, solid solution amount of Mn was measured and listed in Table 3. The FLEXCAST3003-B has higher solid solution amount of Mn than the DC3003 even they are kept up to 1000 h at 473K.

Table 3 Solid solution amount of Mn (mass%)

Alloy	Keeping time at 473K	Mn
FLEXCAST3003-B	1h	0.78
	1000h	0.57
DC3003	1h	0.12
	1000h	0.09

Fig. 9 shows the correlation between the YS or the UTS at 473K and solid solution amount of Mn. It is said that solid solution amount of Mn affects the YS and the UTS remarkably due to solid solution hardening [6]. As the solid solution amount of Mn increases, the YS or the UTS becomes high.

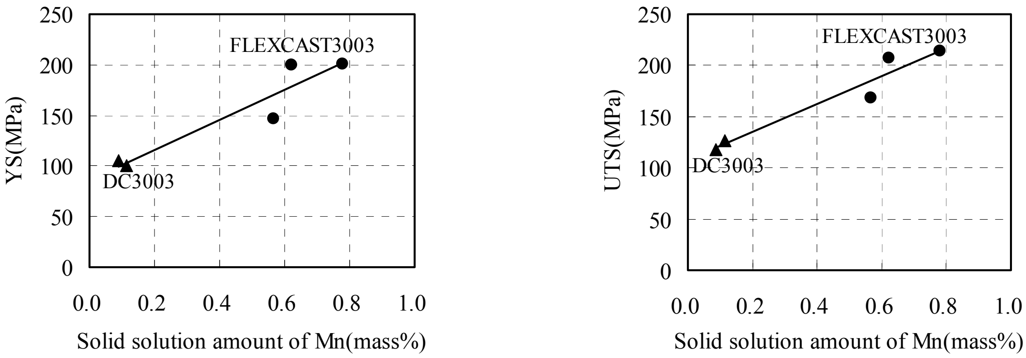

Fig. 9 A correlation between YS or UTS and solid solution amount of Mn.

4. Conclusion

(1) The strength of the FLEXCAST3003 aluminum alloy sheet with H18 temper is twice as high as the DC3003 aluminum alloy sheet at elevated temperature from 473 to 673K. After keeping at 473K up to 1000 h, the strength of the FLEXCAST3003 aluminum alloy sheet is 1.4 times as high as the DC3003 aluminum alloy sheet.

(2) It is found that there is a good correlation between strength at 473K and the solute solution amount of Mn, and fine precipitate of AlMnSi is a very important factor for higher strength at 673K.

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