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Mechanical Properties of 5083 Aluminum Alloy Sheets Produced by Isothermal Rolling

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The microstructure and mechanical properties of AA5083 aluminum alloy sheets consisting of well developed β-fiber texture were investigated. In order to maintain rolling textures after final annealing, the materials were rolled isothermally at 623 K by making use of heated rolls and reheating process every pass up to final thickness of 1 mm. The isothermal rolled sheets consisted of fine subgrain structures through the thickness with a high proportion of low angle boundary less than 15°. Tensile properties showed anisotropy clearly regarding elongation and Lankford value. In the isothermal rolled sheets, the elongation of 0° to rolling direction was below 20% and Lankford value of 45° to rolling direction was over 1.5. Therefore, the average Lankford value showed 1.0. The yield strength of the isothermal rolled sheets was about 40% higher than that of the cold rolled sheets because of subgrain structures. The low ductility of 0° to rolling direction on the isothermal rolled sheets seemed to reduce drawability at room temperature. The warm drawability of the isothermal rolled sheets improved and was superior to the cold rolled sheets because of increasing ductility and keeping higher strength than the cold rolled sheets.
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1. Introduction

It was known in low-carbon steels that Lankford (r) value had a good relationship with drawing formability.[1)] High Lankford value leads to excellent deep-drawability. It was also known that Lankford value was related to texture strongly in aluminum alloy sheets[2)] as well as low-carbon steels.[3)] Generally, main component in O-temper of aluminum alloy sheets is a $\{001\}\langle 100\rangle$ Cube component. In such case, it is predicted by Taylor model that Lankford value is below 1.0, especially a significantly smaller one of 45° to rolling direction.[2)] Meantime, the texture consisted of the β-fiber ($\{011\}\langle 211\rangle - \{123\}\langle 634\rangle - \{112\}\langle 111\rangle$) after cold rolling in aluminum alloy sheets,[4,5)] and it was expected according to Taylor model that the β-fiber increased Lankford value of 45° to rolling direction.[2)] Such cold rolled sheets are not suitable for press forming because of low ductility. If a sheet is prepared with thermal stability in microstructure, high Lankford value with adequate ductility is gained by remaining β-fiber after a specified heat treatment.

In prior studies,[6,7)] it was revealed that AA7475 based aluminum alloy sheets containing zirconium by controlled warm rolling have the strong $\{011\}\langle 211\rangle$ Brass component after the solution heat treatment at 753 K. These sheets had high Lankford values of 45° to rolling direction and increased strength by subgrain structure less than 3 µm. It is hard to examine formability on heat-treatable alloy such as AA7475 aluminum alloy. The thermal stability of AA5083 aluminum alloys has been investigated by making use of plane strain compression test.[8)] Due to this study, it was found that AA5083 aluminum alloy sheets deformed at not lower than 623 K and under control of strain rate in $5\,s^{-1}$ and below have the property of thermal stability.

In the present work, AA5083 aluminum alloy sheets were prepared under control of temperature and strain rate according to the above results of the plane strain compression test. These materials were also investigated about microstructures and drawing formability comparing with conventional AA5083 aluminum alloy sheets produced by cold rolling.

2. Experimental Procedures

Samples of AA5083, of which the composition is given in Table 1, were prepared according to the procedure shown in Table 2. The alloy AA5083 was cast into slabs by a standard semi-continuous direct chill technique. The slab was homogenized at 738 K for 43.2 ks followed by machining with dimensions of 30 mm high, 170 mm wide and 170 mm long. The rolling equipment used in this work has two ϕ260 mm work rolls mounted eight cylindrical heaters per roll[9)] to keep roll temperature near sample temperature. In this experiment, the peripheral velocity of the work rolls was 5 m/min, and the rolls were heated at 643 K ± 15 K in order to manufacture sheets isothermally to the final thickness of 1 mm. The above material machined was rolled at 623 K with re-heating at 623 K for about 900 s after every pass. Average strain rate of every pass was calculated roughly by the following equation.[10)]

$$\dot{\varepsilon} = \frac{U_R}{\sqrt{R' h_0}} \cdot \frac{2\sqrt{r}}{2 - r} \tag{1}$$

Here, U_R is the peripheral velocity of roll (m/s), R' is the radius of roll (m), h_0 is the sample thickness before rolling (m) and r is the rolling reduction per pass. Then, the average strain rate per pass should be under $5\,s^{-1}$. Commercial machine oil was used in the isothermal rolling process. In

Table 1 Chemical composition of specimens (mass%).

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.04	0.05	<0.01	0.63	4.38	0.16	<0.01	0.02	Bal.

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Table 2 Experimental procedure of the isothermal rolling.

Stage	Condition
Casting	Semicontinuous direct chill techniques into slab 100 mm × 175 mm × 175 mm
Homogenization	738 K–43.2 ks
Machining	30 mm × 170 mm × 170 mm
Isothermal rolling	
Roll temperature	643 K ± 15 K
Plate temperature	613∼623 K
Average strain rate per pass	$<5\,s^{-1}$
Total reduction	96.7% (30 → 1 mm)
Annealing	623 K–3.6 ks F.C.

Table 3 Drawing test condition at room temperature.

Lubricant	Castrol No. 700 (Grease)
Punch	ϕ50 mm (flat)
Die	ϕ53 mm
Blank diameter	ϕ110 mm
BHF	10 kN
Punch speed	120 mm/min

Table 4 Drawing test condition at warm temperature.

Lubricant	MOLYKOTE (Molybdenum disulphide)
Punch	ϕ50 mm (flat)
Die	ϕ53 mm
Temperature	473–573 K
BHF	6 kN
Punch speed	120 mm/min

order to prepare conventional materials, hot rolling, intermediate annealing and cold rolling were carried out. Final annealing was carried out to the isothermal rolled samples and cold rolled samples at 623 K for 3600 s.

Microstructure was observed using an optical microscope and a transmission electron microscope (TEM). Misorientation angles between grains were measured using electron backscattered diffraction (EBSD) equipment with a scanning electron microscope (SEM). Measurement points on EBSD analysis were set at an interval of 0.5 µm. X-ray diffraction method was used to describe incomplete pole figures, and orientation distribution functions (ODFs) were calculated from three incomplete pole figures of {111}, {110} and {100} by the harmonic method.[11] The ODFs were displayed using Bunge's system.[11] The mechanical properties of the samples after the final annealing were investigated. Tensile test specimens were got from the orientations of 0°, 45° and 90° to the rolling direction. Drawing formability at room temperature was investigated according to the conditions given in Table 3. Additionally, warm drawing test shown in Table 4 and Fig. 1 was carried out with a punch of 50 mm in diameter in blank holding force of 6 kN. In order to distinguish warm drawability between the isothermal rolled sheets and conventional sheets, the punch of the test machine was not cooled. Therefore, the punch temperature was about 60 K lower than specimen temperature.

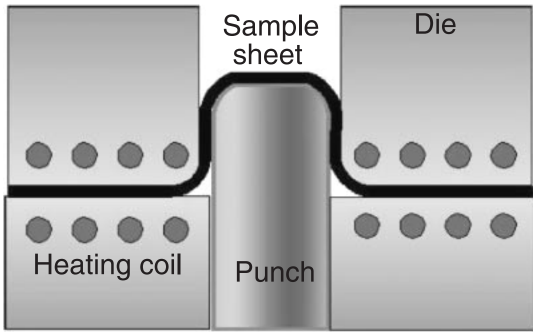

Fig. 1 Method for measuring of warm drawability.

3. Results

3.1 Isothermal rolling condition

Sample temperature was measured during heating in a furnace, and immediately after rolling. Sample thickness was also measured after rolling in order to derive strain rate every pass. These results are shown in Fig. 2. It is found that the rolling process was carried out in the range from 613 K to 623 K, and the strain rate per pass was kept below $5\,s^{-1}$ through the process. Sample temperature maintained to a final thickness of 1 mm as the heated rolls were used.

3.2 Microstructures after final annealing

Figure 3 shows optical micrographs in L-LT section and TEM images after the final annealing in order to compare the isothermal rolled sheet (IR) with the cold rolled sheet (CR). In optical micrographs, it is found that the cold rolled sheet consists of equiaxial grains about 30 µm in diameter, whereas the isothermal rolled sheet maintains rolled structure. In TEM images, it is revealed the isothermal rolled sheet consists of fine grains whose average diameter is approximately 3 µm. Fine particles would contain manganese or Chromium as Al_6Mn and $Al_{18}Cr_2Mg_3$ by reference to the previous work.[12]

3.3 Distribution of grain boundary misorientation angle after the final annealing

Figure 4 shows misorientation angle histograms taken

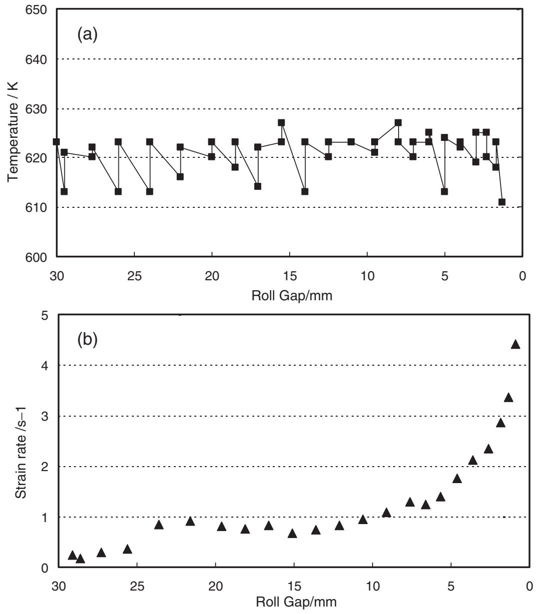

Fig. 2 The results of the isothermal rolling, (a) sample temperature, (b) strain rate per pass.

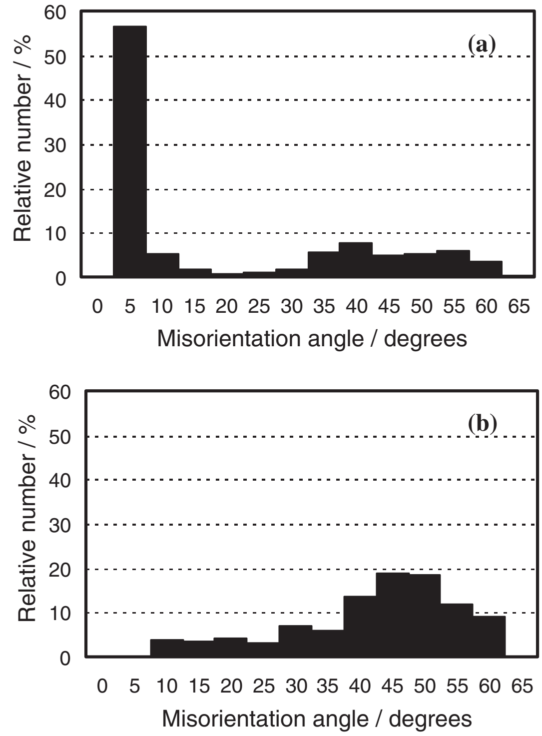

Fig. 4 Misorientation angle histograms after annealing at 623 K for 3.6 ks, (a) isothermal rolled sheets, (b) cold rolled sheets.

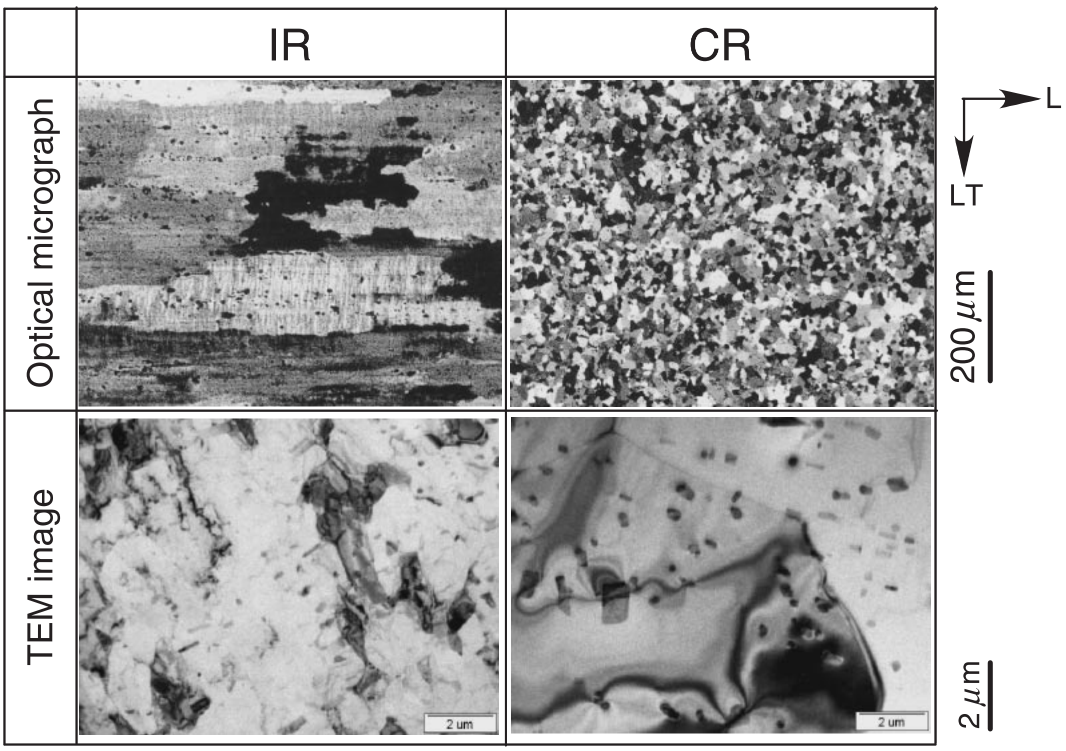

Fig. 3 Optical and TEM micrographs after annealing at 623 K for 3.6 ks. IR: isothermal rolled sheets, CR: cold rolled sheets.

from SEM-EBSD measurements. The measured area in this work was 100 × 100 μm. The isothermal rolled sheets have a high proportion of low angle boundary less than 15°, whereas the cold rolled sheets show a lower proportion of the low angle boundary. According to the above results, it is clear that the isothermal rolled sheets consists of subgrain structures.

3.4 ODF analysis

Figure 5 gives the ODFs at the surface and center layers of the materials after the final annealing. In the isothermal rolled sheets, the β-fiber, especially {011}⟨211⟩ Brass component is recognized clearly through the thickness of it. The cold rolled sheets have a weak peak of {001}⟨100⟩ Cube component. In

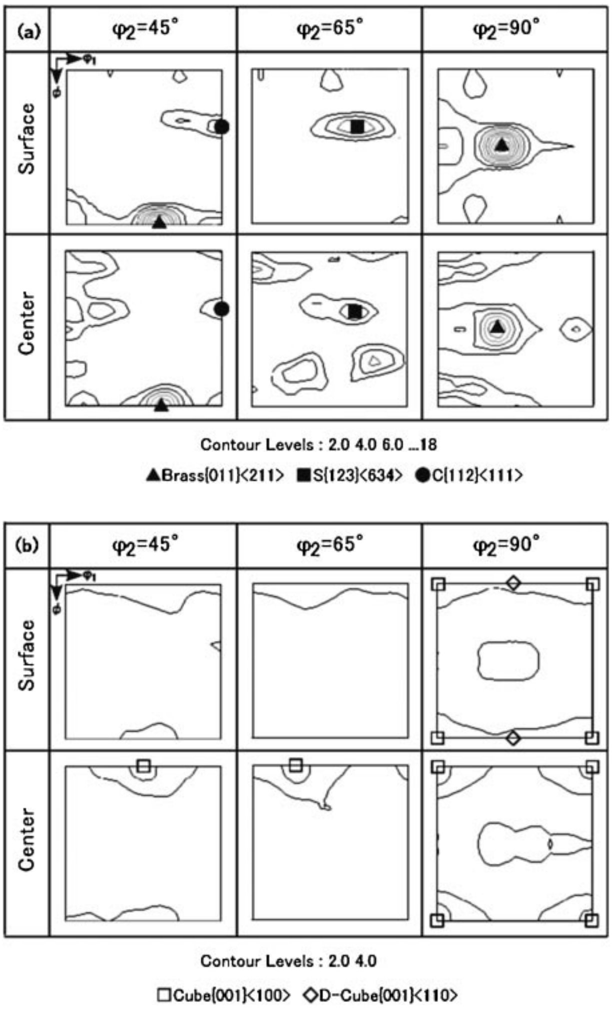

Fig. 5 ODFs after annealing at 623 K for 3.6 ks, (a) isothermal rolled sheets, (b) cold rolled sheets.

other words, the texture of the cold rolled sheets was randomized after recrystallization.

3.5 Tensile properties

Table 5 summarizes the tensile properties after the final annealing. The yield strength of the isothermal rolled sheets is about 40% higher in orientations of 0° and 90° to rolling direction than that of the cold rolled sheets. The properties of the isothermal rolled sheets on ductility and Lankford value measured at 10% elongation show anisotropy whereas the cold rolled sheets tend to be isotropic. Regarding the isothermal rolled sheets, the elongation of 0° to rolling direction is below 20% and Lankford value of 45° to rolling direction is very high. Due to this property on Lankford value, the average value is over 1. The average Lankford value of the cold rolled sheets is lower than that of the isothermal rolled sheets.

3.6 Drawing formability

At room temperature, the drawability of the isothermal rolled sheets seems to be superior to the cold rolled sheets as shown in Fig. 6. Breaking points in this test were different between the two materials. The cold rolled sheets broke at corner of the punch. Meanwhile, the isothermal rolled sheets broke at side surface of 0° to rolling direction. The drawability at room temperature will be discussed later.

The limiting draw ratio (LDR) measured between 473 K and 573 K is shown in Fig. 7. Up to 523 K, the isothermal rolled sheets show higher LDR than the cold rolled sheets. Then, at 573 K, the both materials show same level on LDR. Figure 8 indicates the effect of blank holding force (BHF) at 523 K. Generally, low BHF leads wrinkling matter and high BHF reduces DR.[13)] In the cold rolled sheets, the range of BHF to carry out drawing successfully is very limited at the draw ratio of 2.2. On the other hand, the isothermal rolled sheets have somewhat large range of BHF to carry out drawing successfully at the draw ratio of 2.3. The above results show the isothermal rolled sheets have good drawability at 523 K or so. In the warm drawing, the break points of the isothermal rolled sheets were at corner of the punch.

4. Discussions

In the present work, it was found that the isothermal rolling is able to form β-fiber strongly through the thickness of a sheet. This means rolling deformation was carried out sufficiently into the center of a sheet as well as the surface area in the isothermal rolling process.[14)] The materials produced by the isothermal rolling maintained the β-fiber after the final annealing, whose texture made Lankford value of 45° to rolling direction increase whereas the anisotropy of mechanical properties became marked. This trend agrees with the previous work[2)] which argued the anisotropy of Lankford value by making use of Taylor model. Regarding the ductility, it was found that the elongation of 0° to rolling direction on the isothermal rolled sheets decreases signifi-

Table 5 Mechanical properties after 623 K annealing.

Condition	Angle to RD	Tensile strength (MPa)	Yield strength (MPa)	Elongation (%)	r-value	ave.r	Δr
5083 IR	0°	351	207	16	0.41	1.09	−0.91
	45°	328	192	26	1.54		
	90°	348	204	21	0.85		
5083 CR	0°	315	149	24	0.76	0.67	0.13
	45°	302	145	28	0.60		
	90°	300	145	25	0.70		

IR: isothermal rolling CR: cold rolling

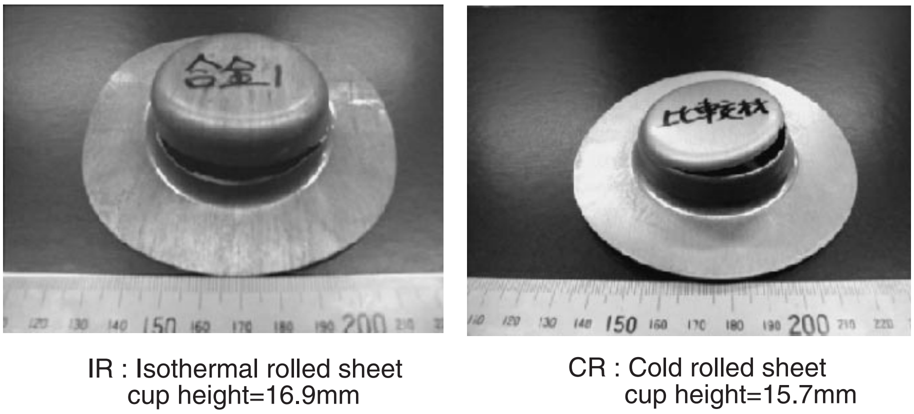

Fig. 6 Appearance of specimens drawn at room temperature. Cup height: IR = 16.9 mm, CR = 15.7 mm.

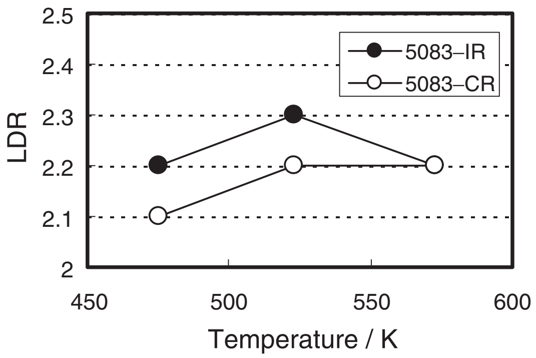

Fig. 7 Limiting draw ratio at warm temperature. IR: isothermal rolled sheets, CR: cold rolled sheets.

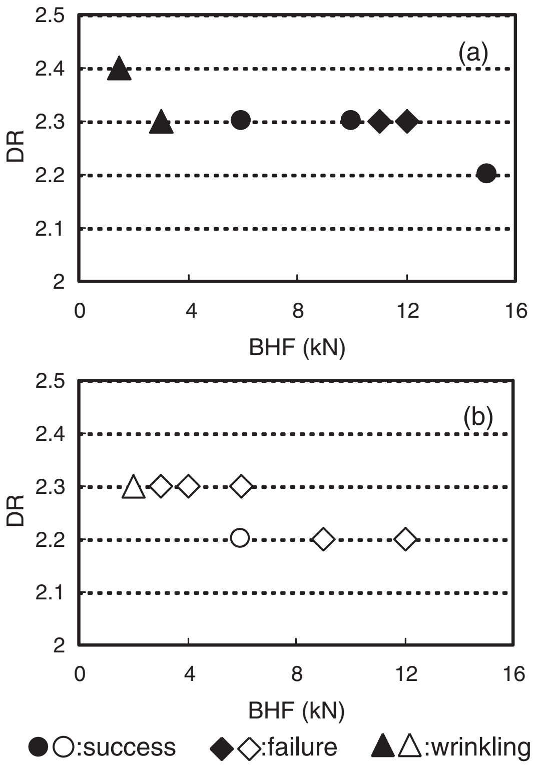

Fig. 8 Warm drawability at 523 K, (a) isothermal rolled sheets, (b) cold rolled sheets.

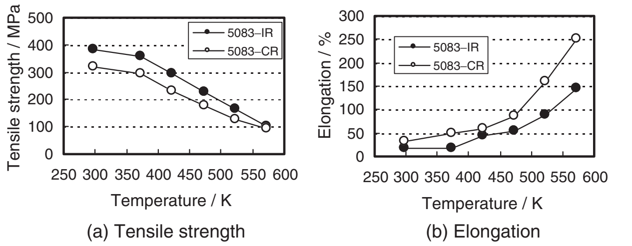

Fig. 9 Tensile strength (a) and elongation (b) versus tensile temperature. IR: isothermal rolled sheets, CR: cold rolled sheets.

cantly. In the drawing test at room temperature, the reason of breaking point at side surface of 0° to rolling direction on the isothermal rolled sheets seems to be ascribable to the above decrease of the elongation. The property of LDR at room temperature on the isothermal rolled sheets was not superior to the cold rolled sheets, which may be related to the small ductility of 0° to rolling direction. Further examination should be required to consider the relationship between tensile properties and drawability at room temperature. The breaking of the isothermal rolled sheets occurred at corner of the punch in the warm drawing. In order to consider the change on above breaking points, tensile properties of 0° to rolling direction were checked (Fig. 9) at elevated temperatures. The ductility of the isothermal rolled sheets increases in a temperature range over 400 K, which seems to be a reason to change location of break point at the warm drawing. The isothermal rolled sheets have higher tensile strength up to 523 K than the cold rolled sheets. This tendency may lead the isothermal rolled sheets to good warm drawability up to 523 K. At 573 K, the both materials show the same tensile strength. Figure 10 indicates TEM images when the both materials were heated to each temperature of the warm drawability test. The isothermal rolled sheets maintained subgrain structures up to 573 K, though their tensile strength was almost the same as that of the cold rolled sheets consisting of a normal recrystallized structure. It seems that the summation of the work hardening and softening by restoration process in the isothermal rolled sheets is the same level as the cold rolled sheets at 573 K. This tendency may reduce the LDR of the isothermal rolled sheets at 573 K.

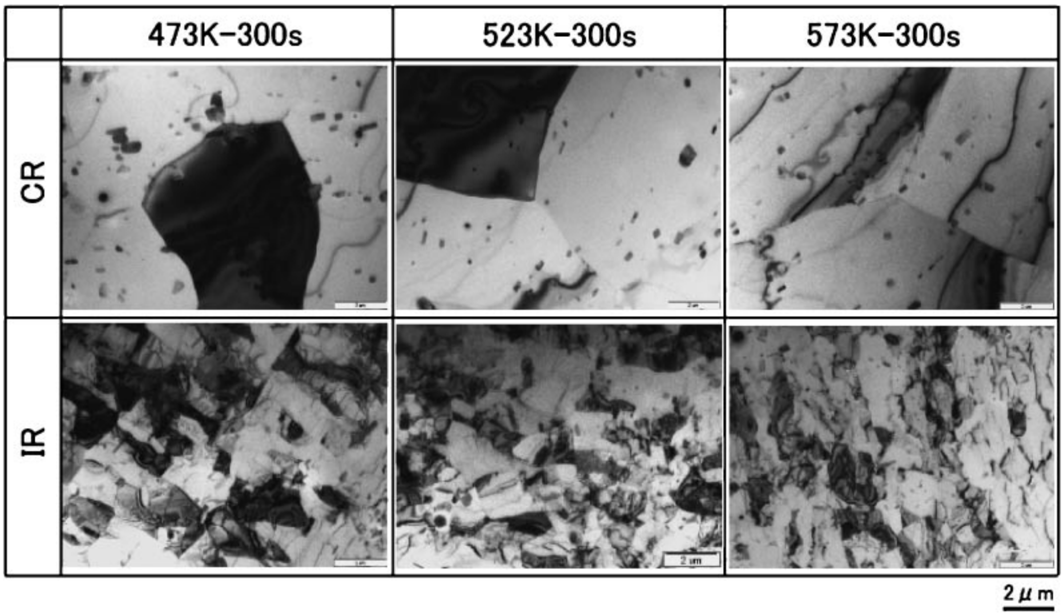

Fig. 10 TEM images at start of warm drawing. IR: isothermal rolled sheets, CR: cold rolled sheets.

5. Conclusions

The microstructures and drawing formability of AA5083 aluminum alloy sheets prepared by isothermal rolling which controls temperature and strain rate were investigated comparing with conventional AA5083 aluminum alloy ones produced by cold rolling. The conclusions obtained are as follows.

(1) Due to the isothermal rolling under the control of sample temperature and strain rate, the β-fiber, especially $\{011\}\langle 211\rangle$ Brass component is formed clearly through the thickness of a sheet after 623 K annealing.

(2) The isothermal rolled sheets have anisotropy on mechanical properties, which show the elongation of 0° to rolling direction is below 20% and Lankford value of 45° to rolling direction over 1.5. And, the yield strength of the isothermal rolled sheets is about 40% higher in orientations of 0° and 90° to rolling direction than that of the cold rolled sheets because of subgrain structures.

(3) The low ductility of 0° to rolling direction on the isothermal rolled sheets seems to reduce drawability at room temperature. The warm drawability of the isothermal rolled sheets improves and is superior to the cold rolled sheets.

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REFERENCES

1) R. L. Whiteley, D. E. Wise and D. J. Blickwede: Sheet Metal Industries **38** (1961) 349–358.
2) H. Inoue and N. Inakazu: Journal of Japan Institute of Light Metals **44** (1994) 97–103.
3) R. S. Burns and R. H. Heyer: Sheet Metal Industries **35** (1958) 261–275.
4) K. Ito, R. Musick and K. Lücke: Acta Metall. **31** (1983) 2137–2149.
5) J. Hirsch and K. Lücke: Acta Metall. **33** (1985) 1927–1938.
6) H. Tanaka, T. Minoda, H. Esaki, K. Shibue and H. Yoshida: Journal of Japan Institute of Light Metals **52** (2002) 29–33.
7) H. Tanaka, H. Esaki, K. Yamada, K. Shibue and H. Yoshida: Mater. Trans. **45** (2004) 69–74.
8) Y. Nagai, H. Tanaka and H. Yoshida: Proc. of 110th Conf. of Japan Institute of Light Metals, Kitakyusyu (2006) 237–238.
9) H. Esaki, H. Tanaka, K. Shibue, M. Kamitori and H. Yoshida: Sumitomo Light Metal Technical Reports **42** (2001) 175–180.
10) The Iron and Steel Institute of Japan: *Rolling theory and its applications*, (1969) p. 317.
11) H. J. Bunge: *Texture analysis in materials science*, (Butterworths, 1982).
12) L. F. Modolfo: *Aluminum Alloys, Structure and Properties*, (1976) p. 806.
13) Y. Takeshima, T. Hikida and H. Uto: Sumitomo Light Metal Technical Reports **32** (1991) 39–55.
14) H. Tanaka, H. Esaki, T. Minoda, K. Shibue and H. Yoshida: Journal of Japan Institute of Light Metals **52** (2002) 231–235.