Proceedings of the 12th International Conference on
Aluminium Alloys, September 5-9, 2010, Yokohama, Japan

pp. 1225-1230

Improvement of Deep Drawability of Al-Mg-Si Alloy Sheets for Automotive Panel by Asymmetric Warm Rolling

Yoshiki Miki, Osamu Noguchi, Yoichi Ueno, Yoshikazu Suzuki, Katsumi Koyama and Toshio Komatsubara

Furukawa-Sky Aluminum Corporation, 1351 Uwanodai, Fukaya-City, Saitama 366-8511, Japan

Weight reduction of automobiles is crucial for improving fuel efficiency and reducing carbon-dioxide emission. There is considerable attention regarding the use of aluminum alloy sheets as alternative lightweight materials. These are expected to reduce automobile weight drastically. However, it is difficult to use aluminum alloy sheets for automobile body parts because they have low deep drawability resulting from the presence of a specific texture: the cube orientation. The authors attempt to control the texture of an aluminum alloy sheet by asymmetric warm rolling (AWR), which, in turn, can produce shear deformation in the entire thickness of the sheet. An asymmetric warm-rolled aluminum alloy sheet has a small amount of {111}//ND orientation, which is similar to the recrystallized texture of a low-carbon steel sheet and suitable for deep drawing; this orientation is maintained even after recrystallization annealing. In addition, the cube orientation, which is unsuitable for deep drawing, is not observed in the asymmetric warm-rolled aluminum alloy sheet. An increase in the Lankford value (r-value) is also confirmed. In this study, using the improved AWR process, we provide a stronger shear than that provided in previous study and attained an average r-value of 1.23. The limiting drawing ratio (LDR) of the asymmetric warm-rolled aluminum alloy sheet increased from 2.06, which is the LDR of the conventional cold-rolled sheet, to 2.24. In fact, the result of a test conducted on a formed a model of a fender from the asymmetric warm-rolled sheet showed that it is superior to the conventional cold-rolled sheet.

Keywords: *texture, asymmetric warm rolling, Lankford value, forming, automobiles*

1. Introduction

Automobiles are required to have improved fuel efficiency in order to comply with the regulations of the Kyoto protocol, ratified in 1997, which introduced carbon-dioxide-reducing obligations in order to control global warming. Lightweighting technology for autobodies provides a very effective means for improving the fuel efficiency of automobiles. That is, instead of steel sheets, if autobodies are predominantly made of lightweight materials such as aluminum alloy sheets, which have the merits of lightness, high strength, and recyclability, then it is possible to reduce the emissions of carbon-dioxide gas drastically. In order to advance the adoption of aluminum alloy sheets to fabricate autobodies, the research project “Aluminum Production and Fabrication Technology Development Useful for Automotive Light-weighting” was carried out in 2002–2006 by NEDO (New Energy and Industrial Technology Development Organization). The purpose of this study, supported by NEDO, is to develop aluminum alloy sheets with high formability.

The formability of a metal sheet strongly depends on its texture [1]. The rolling texture of FCC metals such as aluminum alloys is typically characterized by the β-fiber through copper orientation (Cu :{ 112} <111>) and S orientation (S :{ 123} <634>) to brass orientation (Br :{ 011} <211>), and the recrystallized texture mainly consists of a cube orientation (Cube :{ 001} <100>), which negatively affects the deep drawability of FCC metals. On the other hand, the rolling texture of BCC metals such as low-carbon steel is typically characterized by the α-fiber through {001}<110> and {112}<110> to {111}<110>, and the recrystallized texture consists of the γ-fiber {111}//ND, which has a positive effect on the deep drawability of BCC metals. The {111}//ND orientation was not observed in the conventional cold-rolled and recrystallized aluminum alloy sheet.

However, it has been reported that the {111}//ND orientation occur in recrystallized aluminum alloy sheets by inducing shear texture [2-4]. The {111}//ND orientation could be observed in the surface layer of warm-rolled Aluminum alloy sheets, and the Lankford value (r-value), which is one of the indicators of formability, was found to have increased [5-7]. In a previous study, the present authors tried to control the texture of Al-Mg-Si alloy sheets by asymmetric warm rolling, which can produce shear deformation in the entire thickness of the aluminum alloy sheet. It was confirmed that the average r-value increased from 0.62 to 0.80[8].

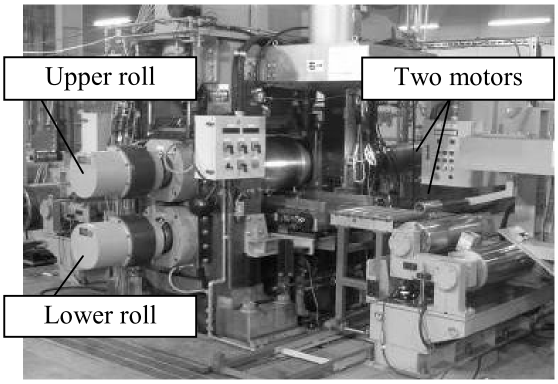
In this study, asymmetric warm rolling was carried out to reduce a 100mm-thick slab of aluminum alloy to a 1mm-thick sheet at 523 K to obtain a stronger shear texture and a higher r-value. Additionally, the formability test of an asymmetric warm-rolled sheet was conducted to investigate its mechanical properties and evaluate its formability.

2. Experimental

The specimen, AA6022-alloy slab, was DC cast and soaked and scalped to 100mm-thick in the laboratory. Its chemical composition is shown in Table 1. An asymmetric warm-rolling mill and its parameters are shown in Fig. 1. The asymmetric warm-rolling mill was designed with each roll being independently driven by two motors; the rolls were heated by cartridge heaters, which were inserted in the rolls. Both the alloy material and the rolls could be heated.

Table 1 Chemical composition of AA6022 (mass%)

Si	Fe	Cu	Mn	Mg	Ti	Al
1.00	0.10	0.01	0.05	0.55	0.01	Bal.



Mill construction	2Hi reversible mill
Roll driving	Independently driven by two motors
Roll size	ϕ 450mm, 600mm wide
Roll speed	Maximum 50m/min
Roll heating	Cartridge heaters inserted in rolls
Roll temperature	Maximum 600K
Asymmetric ratio	Maximum 250%

Fig. 1 Asymmetric warm-rolling mill

Asymmetric warm rolling was carried out at an asymmetric ratio of 150%, and the thickness was reduced from 100 mm to 6 mm at 523 K. Subsequently, it was carried out at an asymmetric ratio of 150–250%, and the thickness was further reduced from 6 mm to 1 mm at 523 K. For comparison, a conventional cold-rolled AA6022 sheet, produced on the basis of a conventional process in an industrial plant, was used. The conventional cold-rolled AA6022 sheet was DC cast and hot-rolled to a thickness of 6 mm in plant and then cold-rolled to 1 mm in laboratory. Solution treatment involving recrystallization was carried out at 823 K for 300 s followed by water spray quenching.

The texture analysis of the asymmetric warm-rolled AA6022 sheet was carried out by X-ray diffraction of the upper surface of the sheet. The orientation distribution functions (ODFs) were calculated from {111}, {200}, and {220} incomplete pole figures according to Bunge's series-expansion method (lmax = 22) with ghost correction.

To investigate the mechanical properties of the asymmetric warm-rolled AA6022 sheet, solution-treated specimens were tensile-tested 0°, 45°, and 90° to the rolling direction. The r-value, which is the ratio between the plastic strain in the width direction and the through-the-thickness, was measured at 7.5% plastic strain.

To evaluate the formability of the asymmetric warm-rolled AA6022 sheet, a circular deep-drawing test of the sheet was conducted. The limiting drawing ratio (LDR), one of the indicators of formability, was measured. The LDR is given by the ratio of the maximum blank diameter D_0 to the punch diameter D_p. It was calculated from Eq. 1:

$$\text{LDR} = \text{Maximum blank diameter } D_0/\text{Punch Diameter } D_p. \qquad (1)$$

Moreover, to practically establish formability, a test involving the fabrication of a model of a fender (hereafter referred to as a fender model) was carried out. The formed fender model of the asymmetric warm-rolled AA6022 sheet is shown in Fig. 2. We determined the success or failure of this model on the basis of the presence of cracks.

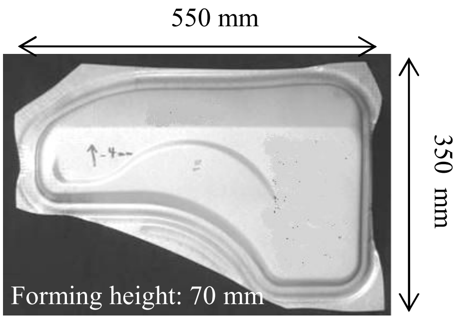


Fig. 2 Formed fender-parts model used in formability test

3. Results and discussions

3.1 Textures of asymmetric warm-rolled AA6022 sheets

The as-rolled and post-solution treatment ODFs of both asymmetric warm-rolled and conventional cold-rolled sheets were obtained, as shown in Fig. 3.

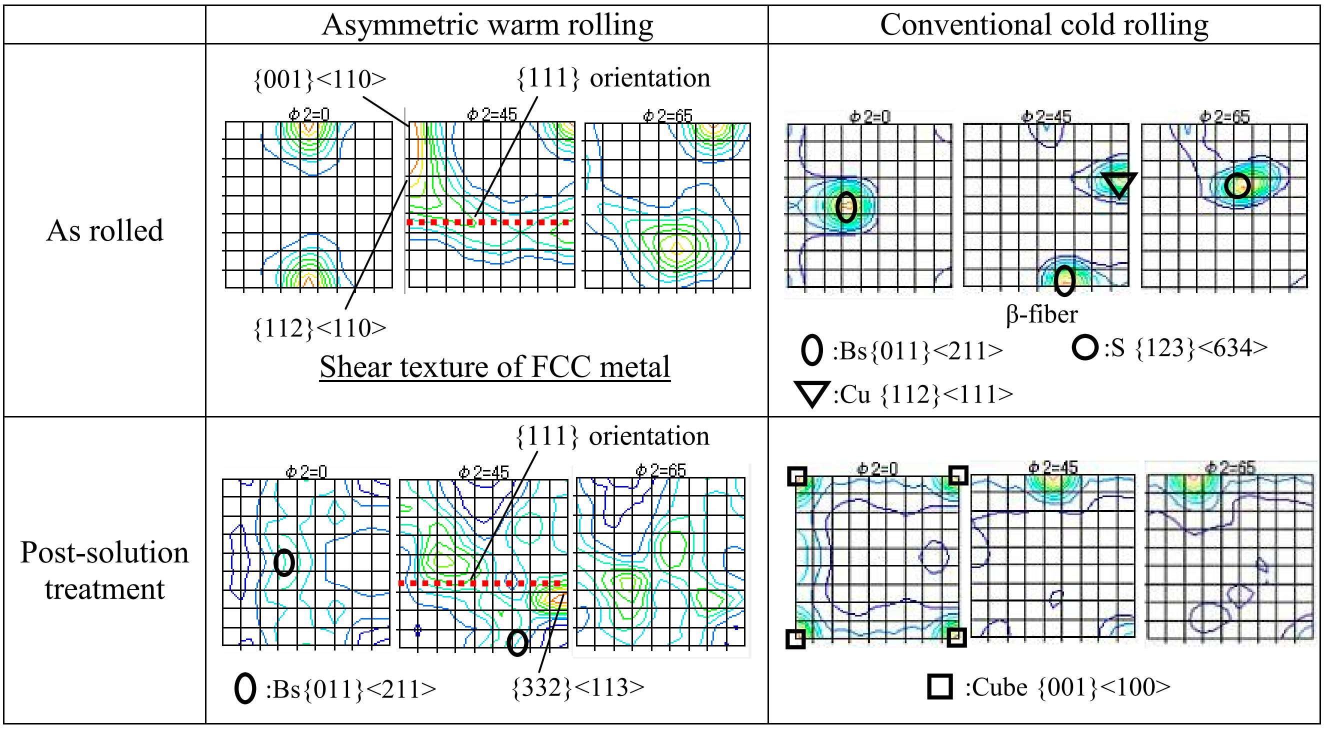


Fig. 3 As-rolled and post-solution treatment ODFs of asymmetric warm-rolled and conventional cold-rolled sheets

ODFs of the conventional cold-rolled specimen consisted of the β-fiber, and a strong accumulation of cube texture {001}<100> could be observed after recrystallization. On the other hand, ODFs of the asymmetric warm-rolled AA6022 specimens comprise {001}<110> and {112}<110> to {111}<110> fiber textures which are the typical shear textures of FCC metals, and the β-fiber components are seldom seen. After solution treatment, a nearly {111} orientation such as {332}<113> and a small amount of Bs orientation {011}<211>, which are thought to be the texture suitable for deep drawability, are observed. In addition, the cube texture, which is unsuitable for deep drawability, was seldom seen.

3.2 Mechanical properties of asymmetric warm-rolled AA6022 sheets

The mechanical properties of the asymmetric warm-rolled and conventional cold-rolled sheets are listed in Table 2. Additionally, the relationship between the r-value and the rolling direction is shown in Fig. 4 The average r-value of the asymmetric warm-rolled and conventional cold-rolled AA6022 sheets is shown in Fig. 5.

Table 2 Mechanical properties of asymmetric warm-rolled and conventional cold-rolled AA6022 sheets.

	Angle to rolling direction (°)	TS (MPa)	YS (MPa)	EL (%)	r-value
Asymmetric warm-rolled sheet	0	288	115	29	0.97
	45	232	112	31	1.41
	90	238	119	30	1.13
	Ave.	**233**	**115**	**30**	**1.23**
Conventional cold-rolled sheet	0	231	120	28	0.73
	45	230	118	29	0.50
	90	230	118	27	0.75
	Ave.	**230**	**119**	**28**	**0.62**

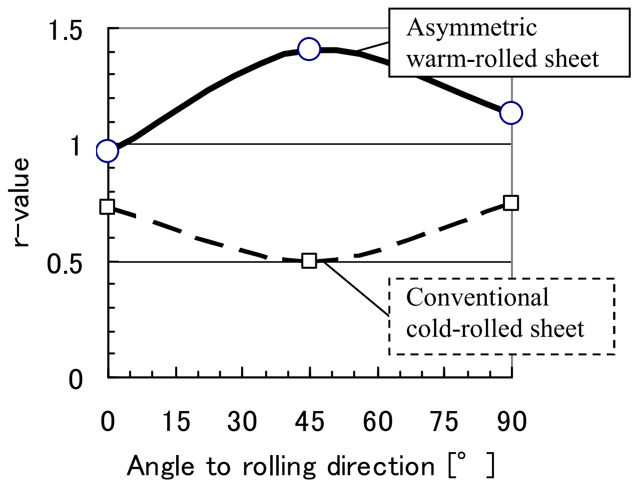


Fig. 4 Relationship between r-value and rolling direction for asymmetric warm-rolled and conventional cold-rolled AA6022 sheets

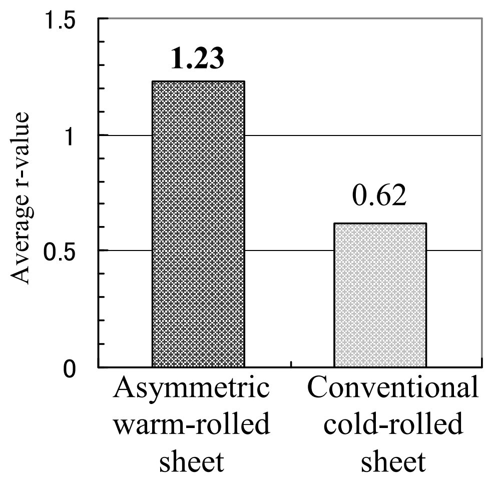


Fig. 5 Average r-value for asymmetric warm-rolled and conventional cold-rolled AA6022 sheets

There is a significant increase in the r-value of the asymmetric warm-rolled sheet. Particularly, the r-value 45° to the rolling direction increased to 1.41, as shown in Fig. 4. Therefore, the average r-value increased by approximately 0.6 and attained a value of 1.23 as a result of the asymmetric warm rolling. However, other mechanical properties such as yield stress, tensile stress, and elongation were nearly similar to those of the conventional cold-rolled sheet.

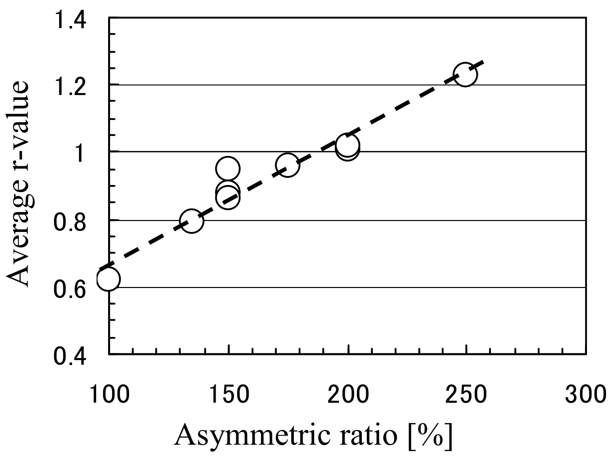


Fig. 6 Relationship between asymmetric ratio and average r-value for asymmetric warm-rolled AA6022 sheet

The dependence of the r-value on rolling condition was also confirmed. The relationship between the asymmetric ratio and the average r-value of an AA6022 sheet that was asymmetrically warm-rolled from 6 mm to 1 mm in thickness at 523 K and solution treated is shown in Fig. 6. The average r-value depends on the asymmetric ratio. In a previous study, it was confirmed that shear strain increased with the asymmetric ratio [9]. It is thought that the increase in the average r-value after solution treatment depends strongly on the growth of the shear texture caused by asymmetric warm rolling.

3.3 Formabilities of asymmetric warm-rolled AA6022 sheets

The results of the circular deep-drawing test are listed in Table 3. Shaped cups of the asymmetric warm-rolled and conventional cold-rolled AA6022 sheets are shown in Fig. 7.

Table 3 LDR of asymmetric warm-rolled and conventional cold-rolled AA6022 sheets

	Asymmetric warm-rolled sheet	Conventional cold-rolled sheet
Ave. r-value	1.23	0.62
LDR	2.24	2.06

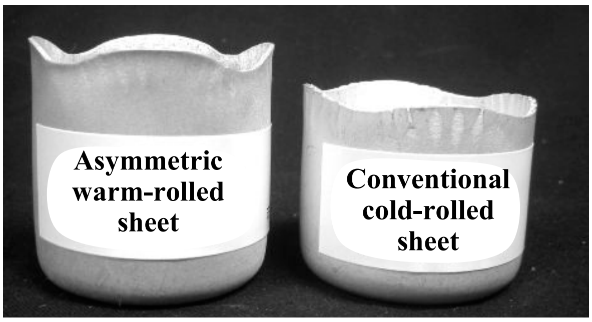


Fig. 7 Shaped cups of asymmetric warm-rolled and conventional cold-rolled AA6022 sheets.

The asymmetric warm-rolled AA6022 sheet was successful in the deep-drawing test when a blank sheet larger than that used for conventional cold rolling was used. The LDR of the asymmetric warm-rolled sheet reached 2.24 eventually. As shown in Fig. 7, a significant improvement in deep drawability was confirmed. It is believed that the improvement was caused by an increase in the r-value resulting from a change in the texture of the sheet. This texture, which is suitable for deep drawability, was produced by asymmetric warm rolling.

Moreover, to practically establish the formabilities of aluminum alloy sheets, a fender model formed from asymmetric warm-rolled and conventional cold-rolled sheets were tested. The results of the formability test are listed in Table 4. We determined the success or failure of formed fender on the basis of the presence of cracks.

Table 4 Results of test on formed fender model of asymmetric warm-rolled and conventional cold-rolled AA6022 sheets

	Average r-value	Die cushion load (kN)				
		200	250	300	350	400
Asymmetric warm-rolled sheet	1.23	○	○	○	○	○
Conventional cold-rolled sheet	0.62	×	×	×	-	-

The asymmetric warm-rolled AA6022 sheet was successful in forming fender model in low and high die-cushion-load conditions. On the other hand, the conventional cold-rolled sheet ruptured under both conditions. The superior formability of the asymmetric warm-rolled sheet was evidently established. These results correspond to the mechanical properties and results of the deep-drawing test.

4. Conclusions

The development of aluminum alloy sheets with high formability was attempted using asymmetric warm rolling, and the textures, mechanical properties, and formabilities of the so-formed sheet were investigated. The results obtained in this study are as follows:

- The asymmetric warm-rolled AA6022 sheets exhibited the shear texture observed in FCC metals. After solution treatment, a nearly {111} orientation such as {332}<113> and a small amount of Bs orientation, which are considered to be the texture suitable for deep drawability, are observed. On the other hand, the cube texture which is unsuitable for deep drawability, was seldom seen.

- There is a significant increase in the r-value of the asymmetric warm-rolled sheet. In particular, the r-value 45° to the rolling direction increased to 1.41, and the average r-value attained was 1.23.

- The limiting drawing ratio (LDR) of the asymmetric warm-rolled sheet increased from 2.06, which is the LDR of the conventional cold-rolled sheet, to 2.24. Additionally, in the formability test, the asymmetric warm-rolled sheet was successful in forming fender model. The superior formability of asymmetric warm-rolled sheet was, thus, evidently established.

5. Acknowledgements

The authors acknowledge NEDO for their support toward the research project titled "Aluminum Production and Fabrication Technology Development Useful for Automotive Light-weighting."

References

[1] O. Engler, M.Y. Huh and C.N. Tomé, Metall. Mater. Trans. 31A (2000), 2299–2315.
[2] P. H. Lequeu and J. J. Jonas: Metall. Trans. 19A (1988), 105–120.
[3] C. H. Choi, K. H. Kim and D. N. Lee, Mater. Sci. Forum, 273-275, (1998) pp.391-396.
[4] O. Engler, H.C. Kim and M.Y. Huh, Mater. Sci. Technol. Vol.17 (2001), 75-86.
[5] Y. Saito, H. Utsunomiya, H. Suzuki and T. Sakai: Scripta mater. Vol.42, (2000) 1139-1144.
[6] T. Kamijo and H. Fukutomi: Proc. of 16th RISO Int. Sympo. on Mater. Sci., (1995), 377–382.
[7] H. Inoue and T. Takasugi: Material Transactions, Vol.48 No. 8 (2007) 2014-2022.
[8] Y. Miki, K. Koyama, et.al: Mater. Sci. Forum Vol.539-543 (2007) 333-338.
[9] O. Noguchi, T. Komatsubara et al.: Proc. 9th Int. Conf. on Al Alloys, (2004) 758-762.