ANISOTROPY IN MECHANICAL PROPERTIES OF Al-4.5%Mg ALLOY SHEET

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Abstract

The anisotropy in mechanical properties, especially r-values, was controlled in annealed sheet of an Al-4.5%Mg alloy produced by using various combination of cold rolling reduction and annealing. High r-values were obtained in the following method: hot rolling, high reduction of cold rolling, intermediate annealing, appropriate reduction of cold rolling to final gauge and final annealing. Furthermore, the condition required for high $\bar{r}$ with low Δr and low earing was found. The high r-values achieved in this process resulted from the higher r_{45} that remained even after the final annealing, indicating a retention of cold working texture components. In the small cup forming tests, high $\bar{r}$ resulted in an increase in the deep drawing height but a decrease in the stretch forming height.

Introduction

5000 series alloy sheet has been used for various applications. The anisotropy in mechanical proprerties, especially plastic strain ratios, r-values, is one of the most important factors affecting press forming. High r-value materials have been developed in steel in order to obtain better formability, but it is more difficult to process aluminum to this condition. Investigations to obtain the various r-values in aluminum alloys[1~3] showed that deep drawability was affected by r-values[1,2]. In the present study, specimens with various r-values have been obtained by using various combinations of cold rolling reduction and intermediate annealing, and both deep drawing and stretch forming were investigated. The crystallographic texture responsible for this behavior was analyzed and is discussed.

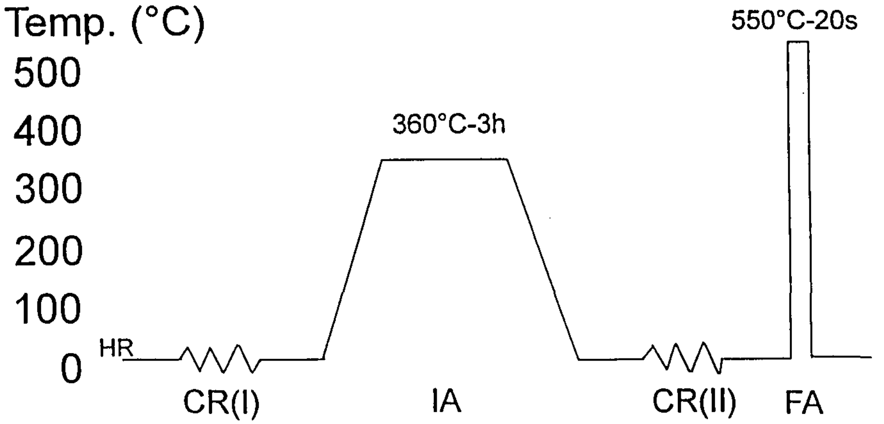
Experimental procedure

Materials

Chemical composition of the test alloy, 5182, is shown in Table 1. The sheet was made from hot rolling sheet produced in the plant. Thermomechanical processing of the specimens after hot rolling are shown in Fig. 1. After hot rolling, specimens were subjected to cold rolling (I), intermediate annealing at 360°C for 3 h, cold rolling (II) and final annealing at 550°C for 20 s in a salt bath followed by air forced cooling.

Table 1 Chemical composition (mass %)

Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
0.04	0.05	0.08	0.23	4.64	<0.01	<0.01	0.03	bal.



HR:Hot Rolling CR:Cold Rolling IA:Intermediate annealing FA:Final Annealing

Fig.1 Thermomechanical processing of the specimens

Evaluations

Tensile tests were carried out on the specimens having reduced parallel sections of 60 mm, and 50 mm gage length and 25 mm width according to Japanese Industrial Standard. Tensile properties were determined in the longitudinal (0°), diagonal (45°) and transverse (90°) directions. Work hardening co-efficients, n-values, were evaluated using tensile specimens at strains between 10% and 15%, and r-values were measured at a 15% elongation. The average and difference of each property, X, were calculated by the formulae below;

$$\overline{X}\,(\text{av.}) = (X_0 + 2X_{45} + X_{90}) / 4 \qquad (1)$$

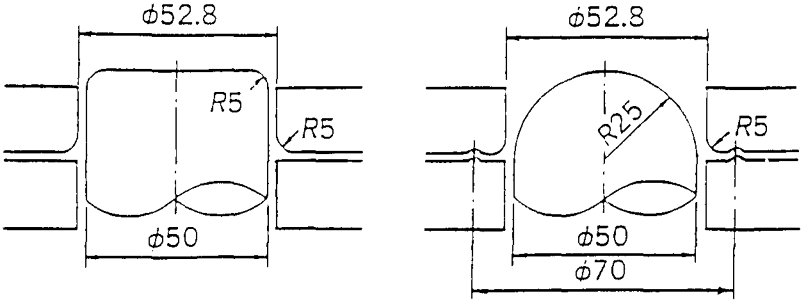
$$\Delta X = (X_0 - 2X_{45} + X_{90}) / 2 \qquad (2)$$

Earing tests were carried out on the specimens with 64 mm diameter using punch with 33 mm diameter. Deep drawing and stretch forming tests were performed using the circular blank and the die shown in Fig. 2. Microstructure was observed using polarized light, and grain size was determined by comparing with ASTM standards. Texture analysis yielding orientation distribution function, ODF, was performed using the pole figure data measured using a Siemens

D5000[4]. Specimens were analyzed at the quarter plane. Volume fractions of texture components were extracted from ODF using a Gaussian spread of 15.0 degrees.

Blank size : ϕ112.5mm
Blank holding force : 34kN
Punch speed : 2mm/s

Blank size : ϕ120mm
Blank holding force : 40kN
Punch speed : 2mm/s



(a) Deep drawing test (b) Stretch forming test

Fig. 2 Deep drawing and stretch forming test

Results and discussion

Tables 2 and 3 and Fig. 3 show the results of the tests studied. Increasing the reduction of initial cold rolling (I) resulted in an increased diagonal plastic strain ratio (r_{45}). The longitudinal plastic strain ratio (r_0) was seen to reach a maximum value at the midpoint of the initial cold rolling (I) reduction range studied. The anisotropy of tensile strength, TS, yield strength, YS, and elongation, E, was low, and earing was lowest at that point. After the point, grain diameter became larger as shown in Table 4, and the anisotropy increased. All specimens had equiaxed recrystallized microstructures, and such an anisotropy is thought to be a product of recrystallization. Table 5 shows the tensile results of the materials produced without cold rolling (II). Final annealing at 360°C for 3 h lead to high r_{45}, while final annealing at 550°C for 20 s after annealing at 360°C lead to an increase in r_0 and r_{90} but a decrease in r_{45}, which means that more recrystallization with crystal rotation occurred in the annealing at 550°C. On the contrary, applying slight reductions of cold rolling (II) seems to restrict the recrystallization with crystal rotation during annealing at 550°C. At higher cold rolling (II) reductions, for example 20%, recrystallization and cold working are balanced and high r-values and low earing are obtained. A much higher reduction of cold rolling (II) seems to promote equiaxed recrystallization with crystal rotation. Thus the anisotropy is thought to be associated with recrystallization due to the reduction of cold rolling (II).

Table 2 Tensile properties of a 5182 alloy

Reduction of CR (I)	Thickness before IA	Reduction of CR (II)	0 degree			45 degree			90 degree					
			TS	YS	E	TS	YS	E	TS	YS	E	ΔTS	ΔYS	ΔE
%	mm	%	MPa	MPa	%	MPa	MPa	%	MPa	MPa	%	MPa	MPa	%
0.0	4.80	79.2	260	110	34	261	110	31	260	107	33	-1	-2	3
20.0	3.84	74.0	259	110	33	261	110	32	263	111	32	0	1	1
50.0	2.40	58.3	260	113	33	263	113	31	263	114	32	-2	1	2
74.0	1.25	20.0	266	112	30	262	108	34	270	114	33	6	5	-3
76.9	1.11	9.9	268	108	26	259	103	34	272	112	31	11	7	-5
78.1	1.05	4.8	263	105	27	253	96	35	275	115	29	16	14	-7

Table 3 n-value, r-value and earing of a 5182 alloy

Reduction of CR (I)	Thickness before IA	Reduction of CR (II)	n-value					r-value					Earing (45°)
			n0	n45	n90	$\bar{n}$	Δn	r0	r45	r90	$\bar{r}$	Δr	
%	mm	%											%
0.0	4.80	79.2	0.37	0.36	0.38	0.37	0.01	0.53	0.66	0.45	0.58	-0.17	2.9
20.0	3.84	74.0	0.38	0.35	0.40	0.37	0.04	0.52	0.69	0.47	0.59	-0.02	2.9
50.0	2.40	58.3	0.37	0.37	0.39	0.37	0.01	0.57	0.68	0.51	0.61	-0.14	2.4
74.0	1.25	20.0	0.38	0.37	0.35	0.37	-0.01	0.64	0.91	0.86	0.83	-0.16	2.1
76.9	1.11	9.9	0.37	0.38	0.33	0.36	-0.03	0.44	1.00	0.80	0.81	-0.38	5.0
78.1	1.05	4.8	0.37	0.38	0.35	0.37	-0.02	0.36	1.24	0.86	0.93	-0.63	6.8

Table 4 Grain size of a 5182 alloy

Reduction of CR (I)	Thickness before IA	Reduction of CR (II)	Grain size	
%	mm	%	ASTM No	(μm)
0.0	4.80	79.2	6	(45)
20.0	3.84	74.0	6	(45)
50.0	2.40	58.3	6.5	(35)
74.0	1.25	20.0	6	(45)
76.9	1.11	9.9	4	(90)
78.1	1.05	4.8	3.5	(110)

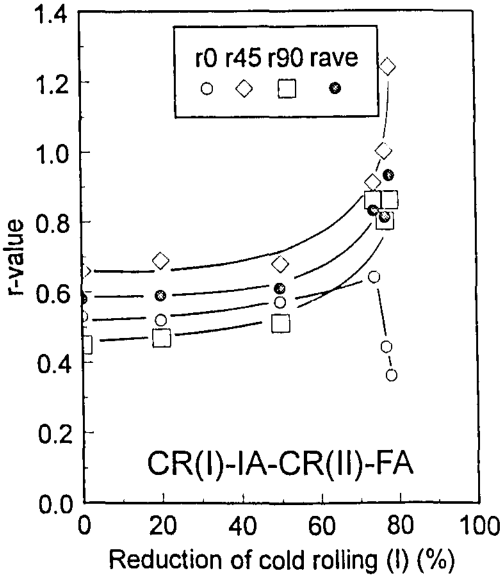


Fig. 3 Relation of r-value versus reduction of cold rolling (I)

Table 5 Results of additional experiments in a 5182 alloy

Reduction of CR (I)	Final annealing	0 degree			45 degree			90 degree			r-value				
		TS	YS	E	TS	YS	E	TS	YS	E	r0	r45	r90	$\bar{r}$	Δr
%		MPa	MPa	%	MPa	MPa	%	MPa	MPa	%					
79.2	360°C-3h	293	147	25	280	142	33	287	152	30	0.59	1.02	0.84	0.87	-0.31
79.2	360°C-3h +550°C-20s	270	112	28	262	110	32	262	107	34	0.70	0.66	1.03	0.76	0.20

Fig. 4 shows the pole figures of some of the specimens. Cold work components, such as Cu, S, and Brass, remained in the structure as shown in Fig. 5. Furthermore, in stead of Cube texture, CH component, (001)[120], appeared in the present study. Saimoto et al. showed that CH components existed in 6000 series alloys for autobody[5]. Hasegawa et al. showed that Cube texture appeared in pure aluminum, while the {310}<132> appeared in an Al-5%Mg alloy[6].

Fig. 6 shows the results of the deep drawing and stretch forming in the specimens with different $\bar{r}$. Increases in $\bar{r}$ increased the deep drawing height but decreased the stretch forming height. Deep drawing was affected by $\bar{r}$ rather than grain diameter. Increases in stretch forming height were associated with increases in CH texture components and/or decreases in cold working components. J.D.Bryant reported in a 2036-T4 alloy for auto body that improved LDH, limited dome height, response was associated with lower r_{90} specimens, which was associated with a decrease in the proportion of Goss texture component measured[7].

Conclusion

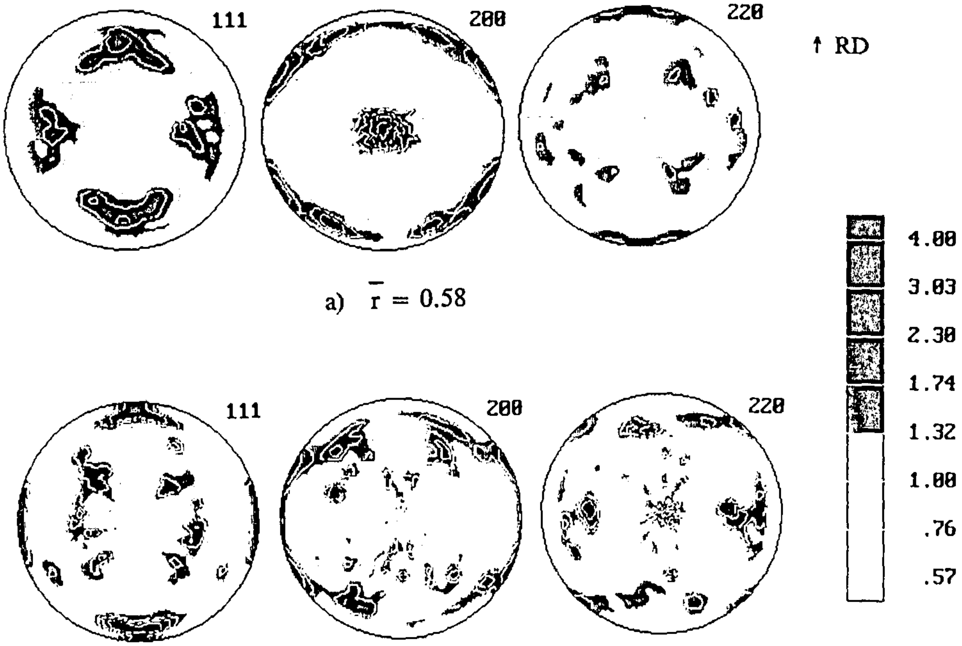
The anisotropy in mechanical properties of Al-4.5%Mg sheet produced using various processes was evaluated.

1) Increasing the reduction of the initial cold rolling(I) resulted in an increased diagonal plastic strain ratio (r_{45}). The condition for obtaining high r-value with low Δr and earing was found, and the anisotropy of tensile properties was minimized.

2) Increases in $\bar{r}$ increased the deep drawing height but decreased the stretch forming height.

3) All specimens had equiaxed recrystallized microstructures. But cold working components, such as Cu, S, and Brass, remained in the structure. Increases in stretch forming height were associated with increases in CH texture components and/or decreases in cold working components.

4) The recrystallization associated with the reduction of cold rolling (II) is an important factor for the anisotropy. Further research is justified to investigate a more precise mechanism.



a) $\bar{r} = 0.58$

b) $\bar{r} = 0.93$

Fig. 4 Pole figures in the quarter thickness plane

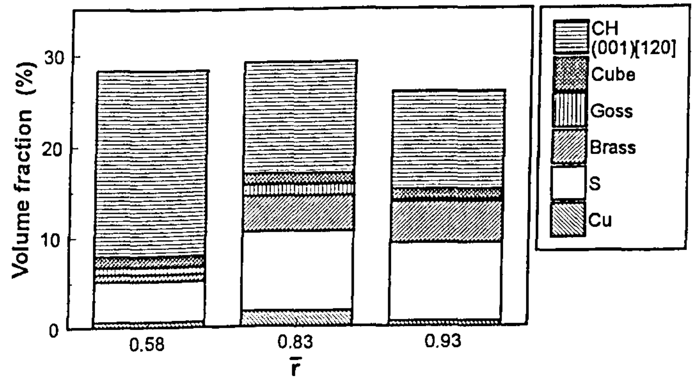


Fig. 5 Results of the texture analysis

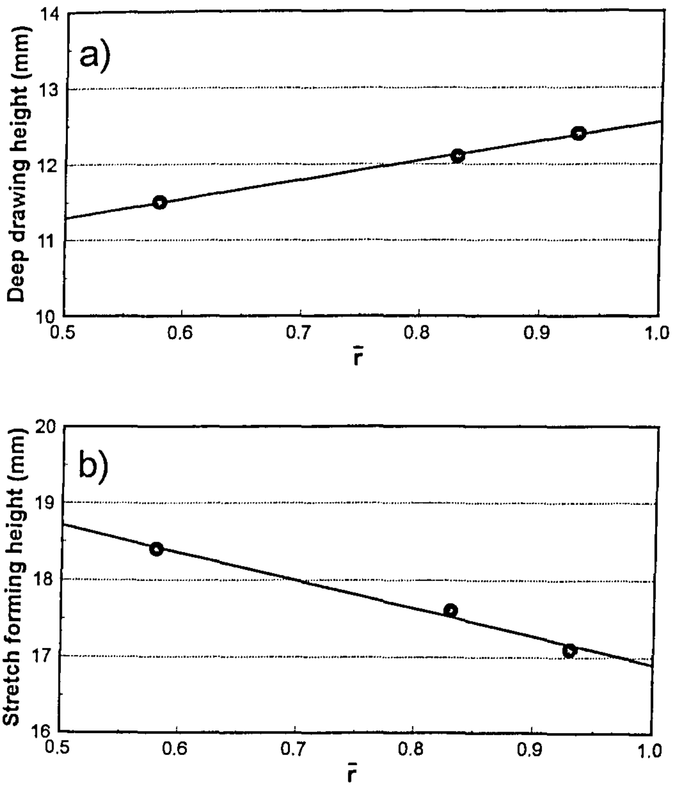


Fig. 6 Relation between forming height and $\bar{r}$

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