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EXAMINATION OF SOME PROCESSING VARIABLES TO IMPROVE THE PRESS-FORMABILITY OF ALUMINIUM SHEETS

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Abstract

The effects of some processing variables, the surface-friction during cold-rolling, the skin-pass reduction, and the annealing condition prior to cold-rolling, to improve the press-formability of commercially pure aluminium sheets (JIS-A, 1050) are examined.

The high-friction cold-rolling is not a rewarding process to improve the press-formability of aluminium sheets. However, some increase in the r-value may be expected when high-friction is applied during a final moderate reduction.

Aluminium sheets heavily cold-rolled directly after hot-rolling applying good lubricating condition and then fully annealed, possess the optimum press-formability among other sheets similarly processed but subjected to different annealing conditions at the intermediate stage between the hot-rolling and cold-rolling processes.

1. Introduction

The improvement of the press-formability of aluminium sheets can be achieved by means of controlling the processing variables. In previous works,[1,2] the effects of cold-reduction prior to annealing and final annealing conditions on the tensile properties, press-formability, and textures of commercially pure aluminium sheets (JIS-A, 1050), and the correlation among these properties have been carefully examined. It was essential for improving the press-formability that aluminium sheets are cold-rolled with as heavy a reduction as possible (larger than 90%), and then fully annealed.[2] An attempt to evaluate the effects of surface-friction during cold-rolling was also carried out.[2] The high surface-friction was found to have a

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little effect on both r-value and texture as the cold-rolling was performed with degreased rolls in the last two passes only.

In the surface-layer of aluminium sheets cold-rolled under high-friction conditions, surface textures of the type (100) and (111) were identified;[3] while the texture of the center was the usual pure-metal type fcc rolling texture. Kamijo et al.[4] found that under conditions of cold-rolling, very high-friction, and low one pass reduction, (100) surface texture was markedly developed with increasing total reduction. On recrystallization,[5] (100) intensity decreased, while (123) component was mainly developed. This led them to indicate that the press-formability of the recrystallized sheet is expected to improve.

It was found[1] that the development of a sandwich-like structure through thickness of sheet metal, i. e. a surface-layer with most of the grains in the fully-recrystallized state and a mid-thickness one with grains in the as-cold-rolled state, was necessary for obtaining high r-values. The formation of surface-layer is likely due to the severe surface deformation produced by the frictional shear stresses.[6] The nonuniform distribution of temperature through slab thickness during hot-rolling may also contribute to the formation of the surface layer.

Therefore, there are three parameters, which may affect the formation of the surface layer, remain to be examined The first is the surface-friction during cold-rolling, and the second is the annealing condition at the stage between the hot-rolling and cold-rolling processes. The third is the partial annealing prior to final cold-rolling.

Relatively high peak r_{45}-and $\bar{r}$-values* and better limiting drawing rotio (LDR) obtained with a flat-headed punch were gained[1] for sheets partially annealed (275℃ X 1 hr.). Also, high peak intensity ratio of the (112) texture component was developed in the surface layer of these sheets. It was thought that further cold-rolling and annealing sequences would stimulate the formation of the surface layer, the (112) component could be further developed, and hence high r-values could de gained. This point, i. e. the third parameter, along with the other two parameters mentioned above will be investigated in this work.

2. Experimental Procedure

The material used is high purity aluminium sheets hot-rolled to 12 mm thick (JIS-A, 1050), the chemical and mechanical properties of which are given in Table 1.

The metal, started from a single ingot, was submitted to soaking at 540℃ X 3 hrs, hot-rolling started at 500℃ and finished at 350℃, and annealing. The finished sheets (12 mm thick) were subjected to cold-rolling with an experimental two-high mill under different conditions as given in Table 2.

Tensile tests were made on 200 mm ISO-type tensile testpieces employing a gauge length of 50 mm and gauge width of 12.5 mm at 10 mm/min. testing speed. A 5-ton Instron-type universal testing machine was used. r-values were measured at 15% nominal strain.

Deep-drawability was evaluated as the limiting drawing ratio (LDR) following

* The average value of any property $\bar{x}=(x_0+2x_{45}+x_{90})/4$; 0°, 45°, and 90° are the directions of the tension axis to the rolling direction in the plane of the sheet.

Table (1-a) : Chemical composition (wt. %), JIS H4000 A1050P-R.

	Cu	*Si*	*Fe*	*Mn*	*Mg*	*Zn*	*Ti*	*Al*
allowable	≦0.05	≦0.25	≦0.40	≦0.05	≦0.05	≦0.05	≦0.03	≧99.50
tested	<0.01	0.10	0.32	<0.01	<0.01	<0.01	0.01	99.61

Table (1-b) : Mechanical properties.

	σ_u kg/mm^2	totale elong. %	r-values of supplied sheets, annealed: 350℃ X 1 hr.			
allowable	≧7	≧16	r_0	r_{45}	r_{90}	$\bar{r}$
tested	8	54	0.40	0.9	0.38	0.645

Table 2. Processing of Aluminium Sheets.

Process schedule		Annealing after hot-rolling	Cold-rolling	Annealing	Cold-rolling	Total reduction	Annealing
A	1	350°c X 1hr.	95% * L	- - -	a. 36.7% L b. 10% + 25%] D c. 45% R in 8 passes	96.8% 96.8% 97.3%	350°c X 1hr.
	2	350°c X 1hr.	95% * L	350°c X 1hr.	a. 5.2%L ┐same b. 5.1%D │gap c. 3.1%R ┘ d. 8.2%R	- - - -	- - - -
	3	350°c X 1hr.	95%*R	350°cX1hr.	-	-	-
	4		96.8%*R	350°cX1hr.	-	-	-
B	1 2 3 4	- 350°cX1hr. 500°cX2hrs. 600°cX2hrs.	95% * L	350°c X 1hr.	- - - -	- - - -	- - - -
C	1	350°c X 1hr.	95% * L	275°c X 1hr.	a. 4.3% L b. 13.7% L c. 29.5% L	- - -	350°c X 1hr.

Key:
* : Cold-reduction per pass is about 11%.
L : Lubricated rolls [Mineral oil + Oleic acid 1%; Viscosity: 11.96 cSt/100°F, μ= 0.122]
D : Degreased rolls.
R : Rosin is sprayed on the rolls' surfaces and used as a considerably high-friction rolling lubricant.

the procedure adopted by Kawai et al, and the stretch-formability by the Erichsen and the pure-stretch values. The pure-stretch value is the critical depth of a partially drawn positively clamped (by means of beads) blank at the onset of fracture. These tests were carried out using a 12-ton, TF-102 Deep-drawing testing machine manufactured by Tokyo KOKI Co. Ltd, Japan.

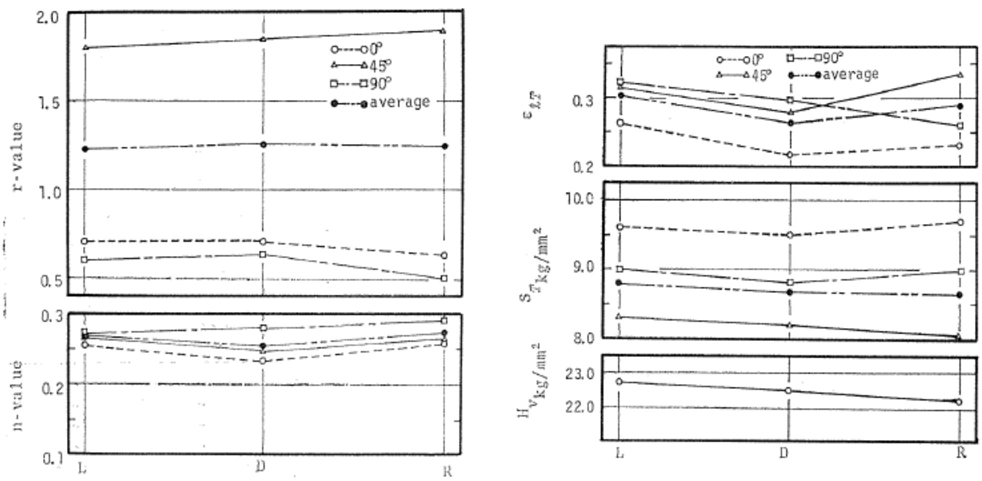
The annealing of testpieces cut off from the finished sheets was carried out in a salt bath to within ±1℃, while that of sheets was carried out in an air circulated electric-furnace to within ±5℃.

3. Experimental Results

3. 1. Effect of surface-friction during cold-rolling:

Aluminium sheets hot-rolled to 12 mm thickness, were fully annealed (350℃ X 1 hr.), then subjected to further processing as given in Table 2.

Fig. 1 shows the r-values of sheets processed according to part A-1, Table 2. r_{45} slightly increases, r_0 and r_{90} decrease when using rosin; $\bar{r}$ shows no change.



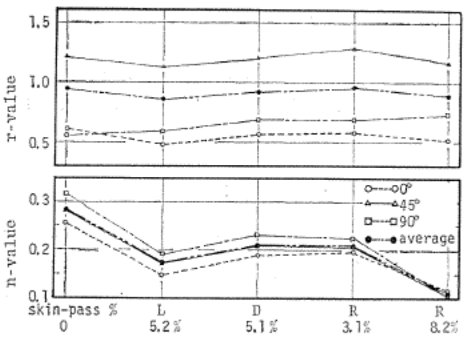
(a) r-and n-value.

(b) total natural strain, ultimate. tensile strength and Vicker' s hardness.

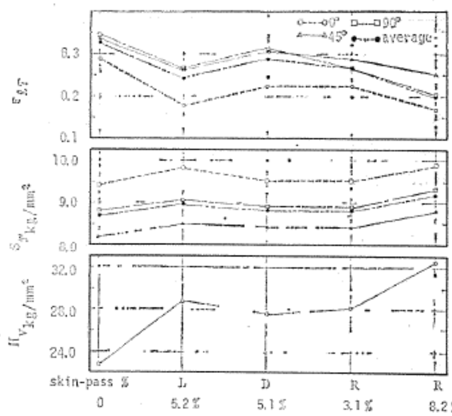
Fig. 1. Effect of friction in cold-reduction of final eight passes prior to annealing on tensil properties.

In this experiment the surface friction has approximately no effect as the material was heavily work-hardened in the first stage of cold-rolling applying good lubricant. Therefore, in order to eliminate the effect of work-hardening and to increase the effect of surface-friction, the material previously cold-rolled to 95% (L) was fully annealed and processed as given in part A-2, Table 2. The r-values show approximately no change as shown in Fig. 2.

Another attempt to evaluate the role of high-friction during cold-rolling was carried out. The hot-rolled sheets were fully annealed, then cold-rolled, applying rosin as a high-friction rolling lubricant, to 95% reduction and further to 96.8% reduction and then fully annealed (part A-3 and 4, Table 2). r-values of those sheets are shown in Fig. 3, in which r-values of sheets cold-rolled to 95% and 96.8% reductions under good lubricating condition are reproduced from previous papers (References 1 and 2 respectively). The figure shows that the high-friction throughout the cold-rolling deteriorate the r-value. It is to be noted that for very high reductions (higher than 95%) the surface-friction condition has no effect, and the cold-reduction is the main factor which influences the variation in r-value.



(a) r- and n-value.



(b) total natural strain, ultimate tensile strength and Vicker's hardness.

Fig. 2. Effect of friction in skin-pass on tensile properties.

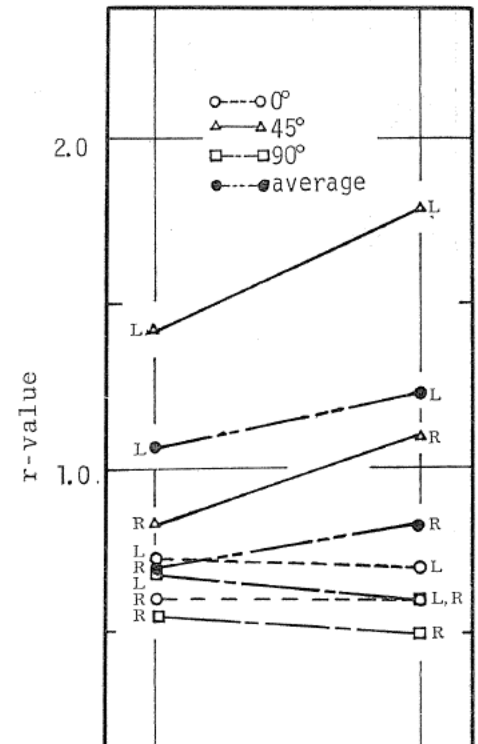


Fig. 3. Effect of friction in cold-reduction prior to annealing on r-value.

This can be understood from Fig. 3 where the tendencies of the variation in r-values are approximately the same for the two surface-friction conditions examined as the reduction increased from 95% to 96.8% reduction.

From the results mentioned above it can be concluded that the high-friction cold-rolling is not a rewarding process to improve r-value. However, some increase in the r-value may be expected when high-friction is applied during a final moderate reduction.

3. 2. Effect of annealing condition prior to cold-rolling:

The second parameter examined was the annealing condition at the intermediate stage between the hot-rolling and cold-rolling process.

The hot-rolled sheets were subjected to different annealing conditions, and then cold-rolled (part B, Table 2).

The tensile properties and press-formability of those sheets were examined as shown in Figs. 4, 5, and 6.

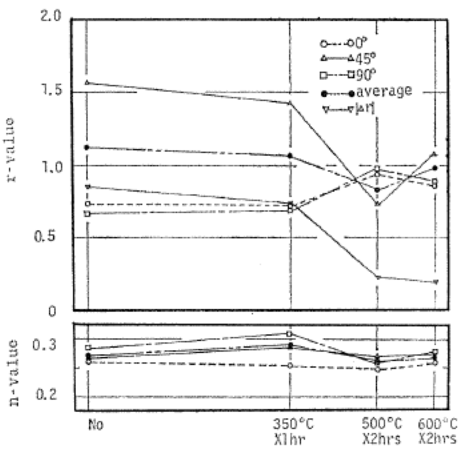


Fig. 4. Effect of anneling condition after hot rolling on r-and n-value.

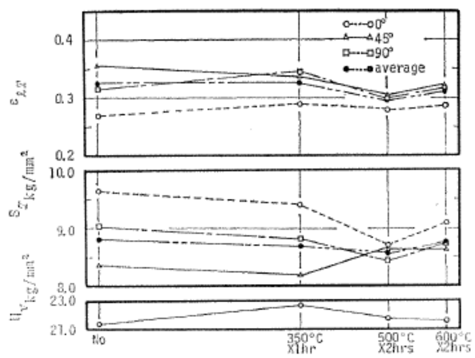


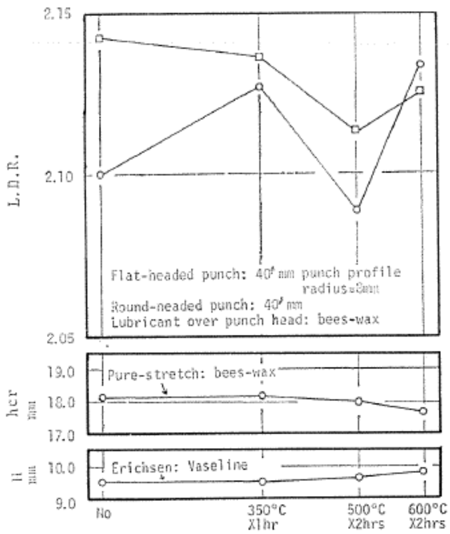
Fig. 5. Effect of annealing condition after hot rolling on total natural strain, ultimate tesile strength and Vicker's hardness.

Both $\bar{r}$ and r_{45}, Fig. 4, decrease reaching a minimum at 500℃ X 2 hrs, then they increase again. r_0 and r_{90} are nearly equal and show no change up to 350℃ X 1 hr. where they increase. They are slightly higher at 500℃ X 2 hrs. condition. The indicator of planar anisotropy $|\Delta r|$* decreases as the annealing condition prior to cold-rolling changes from the no annealing to the 600℃ X 2 hrs. condition. The order of r-value changes from $r_{45} > r_0 > r_{90}$ to $r_{90} > r_0 > r_{45}$ at 500℃ X 2 hrs. then changes to $r_{45} > r_{90} > r_0$ at 600℃ X 2 hrs. condition.

n_{90}-, n_{45}-, and $\bar{n}$-values, Fig. 4, are highest at 350℃ X 1 hr; n_0 approximately unchanges and is lowest at 500℃ X 2 hrs. state. At 350℃ X 1 hr, the differences between n-values in the 0°, 45°, and 90° directions are largest.

As shown in Fig. 5, the total natural strain ε_{lT} has a nearly same tendency as that of n-value in Fig. 4. The ultimate tensile strengths S_{T0}, S_{T90}, and S_T, show

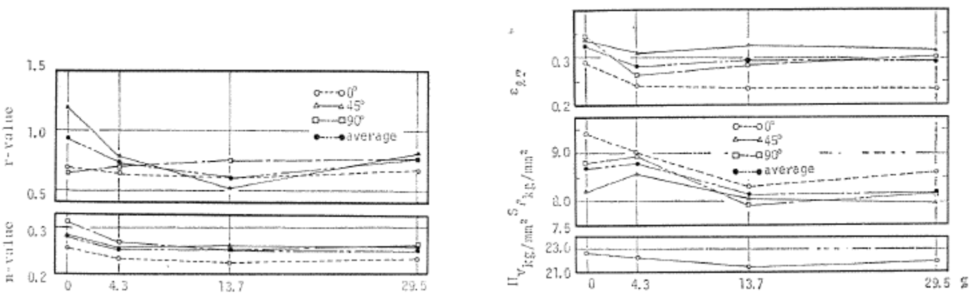
* $\Delta r = [(r_0 + r_{90})/2 - r_{45}]$



Eig. 6. Effect of annenling condition after hot rolling on press-formability.

no change up to 350℃ X 1 hr. they decrease at 500℃ X 2 hrs. then increase slightly at 600℃ X 2 hrs. S_{T45} slightly increases as the annealing condition prior to cold-rolling changes from the no annealing to the 600℃ X 2 hrs. condition.

LDR value obtained with a flat-headed punch applying bees-wax as a good lubricant over punch head is highest for sheets cold-rolled directly after hot-rolling, Fig. 6. It decreases as the annealing condition changes from the no annealing to the 600℃ X 2 hrs. condition. It is lowest at the 500℃ X 2 hrs. state. This variation corresponds to that of $\bar{r}$-value (Fig. 4). LDR obtained with round-headed punch and applying bees-wax increases as the annealing condition is changed to the 600℃ X 2 hrs. state, but is lowest at the 500℃ X 2 hrs. among the other conditions. This seems to be consistent with the variation of the n-value, though influenced likely also by the r-value. The Erichsen value is approximately equal at the differefnt annealing conditions prior to cold-rolling.



(a) r- and n-value.

(b) total natural strain, ultimate tensile strength and Vicker's hardness

Fig. 7. Effect of cold-reduction after partial annealing of sheets cold-rolled to 95% reduction then fully annealed (Part C, Table 2).

3. 3. Effect of partial annealing prior to final cold-rolling:

As shown in part *C*, Table 2, hot-rolled sheets annealed and then cold-rolled to 95% reduction with lubricated rolls were partially annealed (275℃ X 1hr.). These sheets were subjected to further cold-rolling in one pass (low, medium, and heavy passes) then fully annealed. Both r- and n-values are approximately equal for the three reductions per pass, Fig. 7. n-values, r_{45}, and $\bar{r}$ are decreased compared with those values of sheets cold-rolled to 95% reduction and then fully annealed.

4. Conclusions

In this work, the effects of some processing variables, the surface-friction during cold-rolling, the skin-pass reduction, and the annealing condition prior to cold-rolling, to improve the press-formability of aluminium sheets were examined. The followings can be concluded:

1) The high-friction cold-rolling is not a rewarding process to improve the press-formability of aluminium sheets. But, some increase of the r-value may be expected when high-friction is applied during a final moderate reduction. In order to stimulate the formation of the surface-layer with the suitable (112) and (123) texture components for good press-formability, another way of processing aluminium sheets is to be followed. The sheet drawing of heavily cold-rolled sheets, while studying the effects of cold-reduction per pass, the surface-friction condition, and annealing sequences, would be a benefitable technique to obtain higher r-values.

2) Aluminium sheets cold-rolled directly after hot-rolling under conditions of good lubrication and then fully annealed possess the optimum press-formability among the other sheets similarly processed but annealed at different annealing conditions at the intermediate stage between the hot-rolling and cold-rolling processes.

5. References

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