EFFECT OF PROCESSING CONDITION ON EARING BEHAVIOR IN ANNEALED SHEET OF AN AL-MN-MG ALLOY

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ABSTRACT Partial annealing and subsequent light cold rolling was applied to heavily cold rolled sheets of Al-Mn-Mg alloys, and the effects of the processing conditions on earing behavior of the subsequently complete-annealed sheets were examined in detail. A low complete annealing temperature results in a duplex structure that contains coarse grains with very fine grains and high 0 - 90° earing. An additional annealing at a higher temperature to the low temperature annealed sheets results in consumption of the fine grains and further increases in the 0 - 90° earing. A low hot roll finishing temperature and a large cold reduction prior to the partial annealing also enhance the tendency toward the 0 - 90 earing.

Keywords: *Al Mn Mg wrought alloys, beverage can, earing, heat treatment, recrystallization*

1. INTRODUCTION

The aluminum beverage can body is generally produced from hard sheets of Al-Mn-Mg alloys such as AA3004. " Earing " during the drawing and ironing process or necking process is undesirable because it is considered to cause the many problems such as material loss, tear-offs due to clipped ears, out-of-round cans, variation in flange width, etc.

Final cold rolling introduces a deformation texture, which tends to induce earing on drawn cups situated at about 45° to the sheet rolling direction. To suppress this trend, it is generally adopted to attain the proper amount of cube texture, which induces a tendency for 0-90° earing, during the recrystallization prior to final cold rolling. It has been reported that a strong cube texture can be obtained in the recrystallized hot rolled sheets with the thickness of 2 - 3 mm which has been processed by a finishing tandem mill with 3 - 4 stands. Cold rolling of these hot rolled sheets to the final thickness of about 0.3 mm with the reduction of 85 - 90 % can be applied to the commercial production of can body stocks.

On the contrary, an intermediate annealing of the cold rolled sheets is required if the thickness of the hot rolled sheet is larger than the adequate range. In this case, a sufficient strength of the cube texture was not easily obtained by the intermediate annealing.

A partial annealing and subsequent light cold rolling of hot rolled sheets [1] or cold rolled sheets [2] is reported to increase the strength of the cube texture after subsequent annealing. In the present investigation, this method is applied to the sheets which were cold rolled more than 60%, and the effects of various process parameters on the earing behavior was examined in detail.

2. EXPERIMENTAL

Cold rolled sheets of Al-Mn-Mg alloys used in this investigation were prepared at the Fuji Plant of Mitsubishi Aluminum. Typical compositions of the alloys are listed in Table 1. Both alloys have considerably higher contents of Si and Cu. These alloys annealed by a continuous annealing line (CAL) at a high temperature exhibit a high bake-hardenability, and the relatively low final cold reduction is required to achieve an adequate strength required for the can body stocks.

The alloys were DC cast, scalped, homogenized, and subsequently subjected to hot rolling. Homogenization was mainly carried out at 838 K for 28.8 ks. Hot rolling was carried out using a reversing mill to a final thickness of 6.5 - 8 mm. The total number of the hot rolling paths was 17

Table 1. Typical compositions of the alloys

	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
alloy A	0.30	0.44	0.28	1.00	1.25	0.02	0.08	0.03	bal.
alloy B	0.30	0.44	0.21	1.00	1.02	0.02	0.08	0.03	bal.

- 21. The final rolling temperature, as measured immediately after coiling, was mainly controlled by the speed of the final rolling path and was mainly about 600 K. The hot rolled coil was cooled to ambient temperature and cold rolled to a thickness within the range of 0.82 - 2.2 mm.

A further process involving these sheets was carried out in the laboratory. Partial annealing was mainly carried out in an air furnace. The cold rolled sheet was heated at the rate of about 0.03 K/s to the given temperature and held at that temperature for 14.4 ks and then furnace-cooled.

The partial annealed sheets were cold rolled in a direction parallel to the original rolling direction with various reductions. Two types of complete annealings were performed after the intermediate cold rolling. The type I treatment is to simulate batch annealing in which the specimen is heated at the rate of about 0.03K/s to the given temperature and held at that temperature for 14.4 ks and furnace-cooled using an air furnace. In the type II treatment, the sheets subjected to the same batch annealing of the type I were subsequently immersed in a salt bath at a temperature of 520 ℃ for 20 s. The immersion in the salt bath is carried out to simulate the annealing by CAL.

After the complete annealing, the sheets were subjected to deep drawing. The drawing ratio of 1.75 and the punch diameter of 33mm were used. The earing ratio of the drawn cup was measured using a Erichsen Model 126 tester. This instrument assumes that a cup has four ears and four valleys around the cup wall. The earing ratio is defined as ±(height of ears - height of valleys) / height of valleys x 100 (%), where the mean value of the four ears or four valleys is used. The positive sign is used for a 45°earing, and the negative sign is used for the 0 - 90° earing. In the case when a cup had both 45° and 0 - 90° ears, the lower ears were ignored, i.e., the measurement was carried out in the same way as in the case when valleys were situated at the positions of the lower ears.

Examples of earing ratios of the sheets, which were recrystallized by the single step annealing, are shown in Table 2.

Table 2. Earing ratios of the single step annealed sheets of the alloy A

thickness	623K for 14.4ks	793K for 20s
1.8 mm	1 %	1.3 %
1.3 mm	0.7 %	1.0 %
0.82 mm	0.6 %	1.4 %

3. RESULTS

3.1. The effects of partial annealing conditions

Isochronal annealing curves of cold rolled sheets of alloys A and B with the thickness of 1.3 -2.2 mm are shown in Fig. 1. The strength gradually decreases with increasing annealing temperature up to about 530 K, and decreases steeply between about 530 and 560 K. The strength has an almost constant value beyond 560 K. A recrystallization temperature becomes somewhat lower with cold reduction prior to annealing.

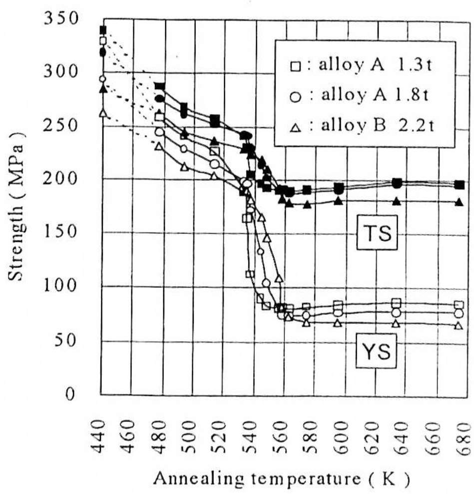

Fig. 1 Isochronal annealing curves of cold rolled sheets. Annealing time is 14.4ks.

The cold rolled sheets of alloy A with a thickness of 1.8 mm were annealed at 523 - 547 K for 14.4ks, and then cold rolled 10 %, and subsequently subjected to complete annealing. The temperature of the batch annealing in the type I and type II treatments was 573 K. The earing ratios of the drawing cups of these annealed sheets are shown in Fig. 2.

In the type I treatment, the sheets partial annealed at 523 - 539 K exhibit apparent 0-90 ° earing, but the sheet annealed at 547 K exhibits 45° earing. In the type II treatment, the additional salt bath annealing increases the 0- 90 ° earing of the sheet partially annealed at 539 K and decreases the 45° earing of the sheet annealed at 547 K.

The cold rolled sheets of alloy B with the thickness of 2.2 mm were partial annealed at 542 K with various conditions. To ascertain the effect of the heating rate, it was varied within the range of 0.006 - 0.1 K/s. A salt bath is used for the highest heating rate of about 5 K/s. The holding time was varied in the range of 0 - 28.8 ks. Some samples were air-cooled after the annealing. The use of combinations of the above conditions results in a yield strength ranging from 135 to 185 MPa after partial annealing. Subsequently, the partially annealed sheets were cold rolled 10% and subjected to the complete annealing under the same conditions in Fig. 2.

Earing ratios of the completely annealed sheets are shown in Fig 3 as a function of the yield strength at the partial annealed state. The effects of the partial annealing conditions on the earing ratio are almost represented by the yield strength of the partially annealed sheets. In the type II treatment, the enhancement of the 0- 90° earing by the additional salt bath annealing is remarkable for the samples annealed to lower yield strengths by the partial annealing.

3.2. The effect of the intermediate cold reduction

The cold rolled sheets of alloy A with the thickness of 1.3 mm were partial annealed at 538 K, and cold rolled 5 - 40 %, and completely annealed at 623 K for 14.4 ks (type I). Earing ratios are shown in Fig. 4 as a function of the intermediate cold reduction. The most appro-

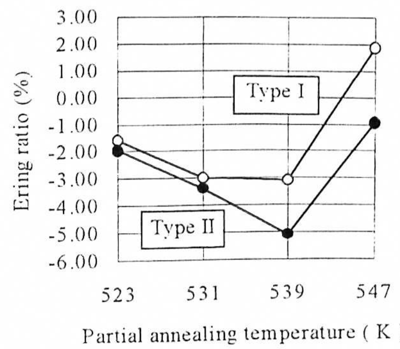

Fig. 2 Effect of partial annealing temperature on earing ratio of completely annealed sheets.

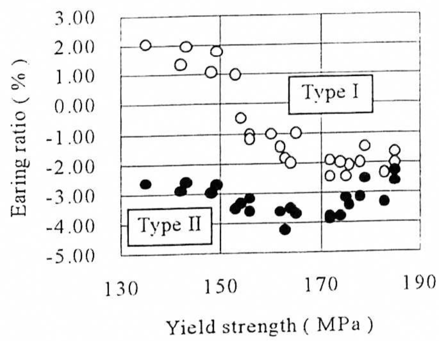

Fig. 3 Earing ratios of the completely annealed sheets as a function of the yield strength of the partially annealed sheets.

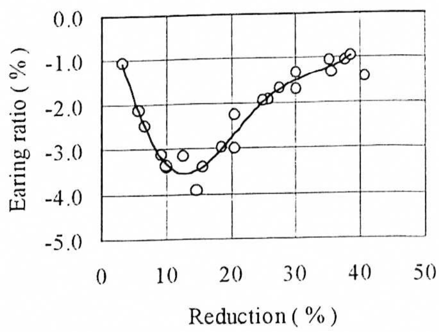

Fig. 4 Effect of the intermediate cold reduction on the earing ratio of the completely annealed sheet.

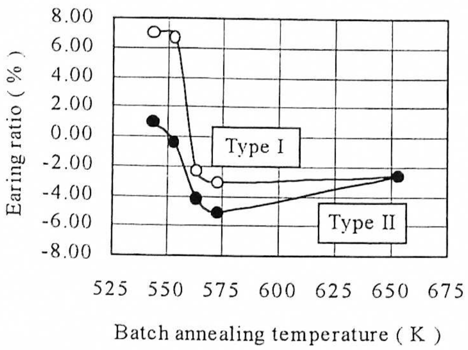

Fig. 5 Effect of the temperature of batch annealing in the type I and II treatments.

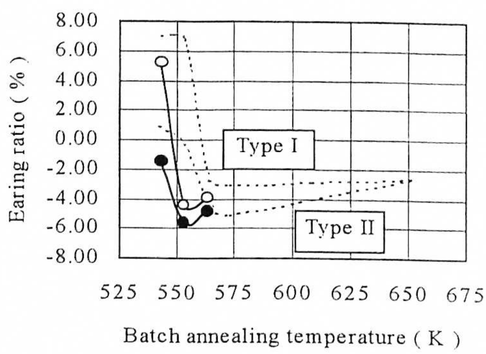

Fig. 6 Effect of the batch annealing at lower temperature for the longer time of 86.4 ks. Dotted lines show the results of the 14.4ks holding time in Fig. 5.

priate reduction to enhance the 0- 90° earing is 10 - 20 %.

3.3. The effect of complete annealing conditions

The cold rolled sheets of alloy A with the thickness of 1.8 mm were partial annealed at 538 K, cold rolled 10 %, and annealed at 543 - 653 K. The type II treatment was also carried out. Earing ratios of the annealed sheets are shown in Fig. 5. In the type I treatment, annealing at a temperature lower than 553 K does not result in complete recrystallization. At a temperature higher than 563K, the recrystallization takes place and 0 - 90° earing is obtained. In the type II treatment, the enhancement of the 0 - 90° earing by the additional salt bath annealing is obvious in the lower temperature range of 563 - 573 K. On the other hand, no effect of salt bath annealing is observed at the higher temperature of 653K.

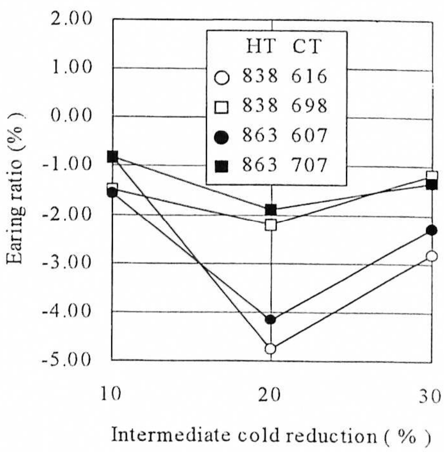

Fig. 7 Effects of homogenization temperature (HT) and hot roll coiling temperature (CT).

It appears that batch annealing at a lower temperature for enough time for the sheet to recrystallize enhances the 0 - 90° earing. Annealing at a temperature lower than 563 K for the longer time of 86.4 ks was carried out, and the results are shown in Fig. 6. It is evident that lower annealing temperature is favorable for the higher 0 - 90° earing in both the type I and type II treatments.

3.4. Other factors

The effects of homogenizing temperature and hot roll coiling temperature are shown in Fig. 7. Homogenization temperature has little effect on the earing level in this case. The hot roll coiling temperature has a considerable effect on the 0 - 90 earing level. The effect of cold reduction from hot band to partial annealing thickness is summarized in Fig. 8. Within the limited conditions examined, it appears that a higher reduction is favorable for higher 0 - 90° earing.

4. DISCUSSION

The application of partial annealing and light cold rolling to heavily cold rolled sheets of Al-Mn-Mg alloys is confirmed to increase the tendency of the 0 - 90° earing of the sheets subjected to subsequent complete annealing. The favorable condition of partial annealing is almost represented by the yield strength level after partial annealing. This yield strength level is considered to correspond to the annealed state where the nucleation of the recrystallized grain has been completed, but the recrystallization was not completed. Little effect of heating rate, holding time and cooling rate was observed.

These results seem to be essentially the same results previously reported [1] in which partial annealing and light cold rolling was applied to hot rolled sheets. In the present investigation, the same treatment was applied to the various cold rolled sheets, and several processing conditions prior to partial annealing are confirmed to affect the earing behavior. The effect of the hot roll coiling temperature must be due to the lack of deformation texture in the hot rolled sheet that is coiled at a higher temperature in which the recrystallization takes place during the period of the coil cooling. The effect of the cold rolling reduction prior to partial annealing is considered to be related to the degree of the development of the cold rolling texture.

In the present investigation, the condition of complete annealing was also examined in detail. The results indicate that the annealing at the lower temperature for enough time to allow almost complete recrystallization of the sheets is effective for higher 0 - 90° earing. In these conditions, an additional CAL type annealing further enhances the 0 - 90° earing. The low temperature annealing results in the duplex grain structure where the coarse grains coexist with the very fine grains as shown in Fig. 9. Additional CAL type annealing eliminates these fine grains and increases the level of 0 - 90° earing. Similar results were reported in the studies on the annealing texture of the hot rolled sheets of an Al-Mn-Mg alloy[3, 4]. It seemed that particle stimulated nucleation was less likely to occur at a low annealing temperature, so that the recrystallized grains grew for a long time to a

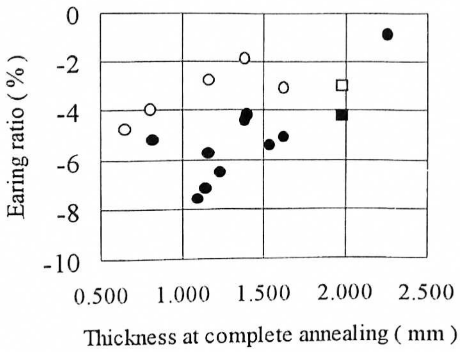

Fig. 8 Earing ratios obtained using the process of partial annealing and light cold rolling. An intermediate cold reduction: 10 - 30 %. open: the type I, solid : the type II. circle: the alloy A, square: the alloy B.

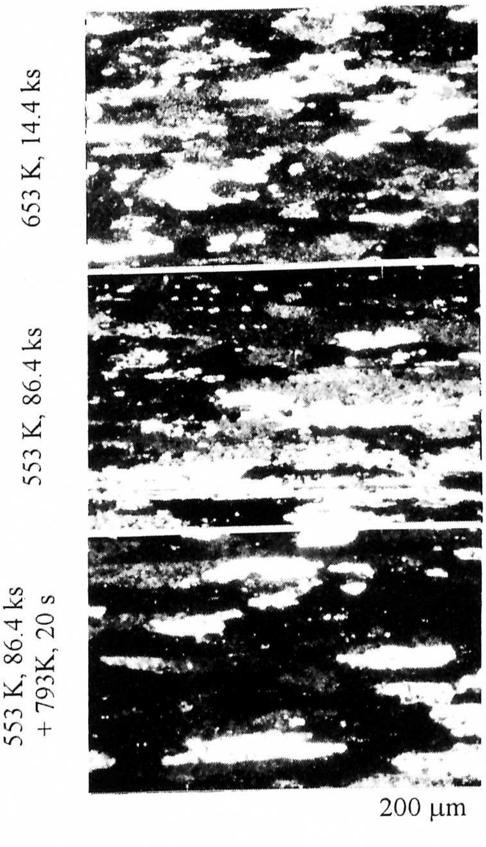

Fig. 9 Annealed structures of the specimens partially annealed at 538k for 14.4 ks, cold rolled 10% and subsequently annealed under the indicated conditions

coarse grain size [3, 4]. On the other hand, complete consumption of the residual deformation texture was not attained within the limited time at low temperature, so that the resultant structure contained fine fragments of the residual deformation textures. Additional CAL type annealing at higher temperature causes the recrystallized grains to consume the fine fragments of the residual deformation texture [4].

CONCLUSIONS

The sequential processing of partial annealing and light cold rolling and subsequent complete annealing was applied to Al-Mn-Mg alloy sheets which were cold rolled more than 60% from the hot rolled condition. The effect of the processing conditions on the earing behavior of the completely annealed sheets was examined in detail.

(1) The effect of the partial annealing condition on the earing behavior is almost represented by the yield strength of the partially annealed sheets. The effects of heating rate, holding time and cooling rate are due to the effects of these variables on the degree of softening.

(2) The favorable yield strength range after partial annealing for higher 0 - 90° earing is within the range between where the steeply drop in the yield strength just before starts and where the complete softening has not occurred.

(3) Concerning the complete annealing condition, low temperature batch type annealing for enough time to have almost complete recrystallization is effective for higher 0 -90° earing. Additional high temperature CAL type annealing further increases the 0 -90°earing of the sheets annealed under the above conditions.

(4) A higher hot roll coiling temperature, which causes recrystallization of the hot rolled sheet, decreases the tendency of 0 - 90°earing. Higher cold reduction from hot rolled sheets to partial annealing thickness increases the tendency of 0 -90° earing.

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