CONTINUOUS CAST CAN BODY STOCK ALLOY AND PROCESS DEVELOPMENT

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ABSTRACT. A study was conducted to develop an alloy and thermomechanical practice for can body stock using twin-belt cast slab as the feed stock. The slab was industrially cast, hot rolled, and subjected to annealing and cold rolling schedules, followed by microstructure, texture, and mechanical property evaluations. The annealed hot bands were analyzed for (a) manganese content in solid solution (Mn_{SS}), (b) dispersoid size distribution, and (c) quantitative texture. The Mn_{SS} showed a similar decrease at various annealing temperatures; however, the dispersoids were coarser at higher temperatures. The favorable "cube" texture component increased with annealing temperature and provided the necessary balance against the rolling texture for earing control. The effects of cold rolling, intermediate annealing, and stabilization treatments on final sheet properties were studied. The study included commercial-scale can making trials to compare with ingot cast product.

Keywords: *Can body stock, continuous casting, earing, annealing, cold rolling*

INTRODUCTION

Over the years continuous strip casting has been investigated as a lower-cost substitute for ingot casting of aluminum sheet products. Strip casting technology is attractive due to lower capital expenditures and fewer processing steps (no scalping, fewer rolling reductions, etc.), which can result in increased productivity. For surface-critical applications, such as that for can body sheet, strip cast sheet has been less than desirable. However, improvements in surface quality, to the degree of commercial acceptance, have been made, particularly in the block casting methods [1-4]. The other metallurgical challenge in using strip cast can stock is earing, which has been higher than the typical ingot metallurgy product [5-11]. In this study an alloy and a fabrication practice for producing D&I can body stock, using a twin belt cast slab as the feed stock, were investigated and patented [12]. The present paper will discuss microstructure, texture, and mechanical property changes during thermomechanical processing steps and their impact on can making performance.

MATERIAL AND EXPERIMENTAL PROCEDURE

The alloy used in the study is similar to commercial AA3104 can body stock, except for lower manganese and higher copper. The metal was continuously cast on a twin-belt caster and hot rolled to four gauges, i.e., 1.9, 2.2, 2.4, and 3.0 mm, on an industrial scale. Figure 1 shows the processing details from cast slab to final gauge. After each processing step, mechanical properties, microstructure, and crystallographic texture were evaluated. Electrical conductivity was measured to estimate the amount of manganese in solid solution (Mn_{SS}). Constituent and dispersoid identities and size distributions were resolved using transmission and scanning electron microscopy. Pole figures measured at the mid-plane (t/2) of the hot bands were used to calculate the Orientation Distribution Function (ODF) using the Van Houtte software [13]. From the ODF data the volume fractions of various ideal texture components were estimated using a 16° Gaussian spread.

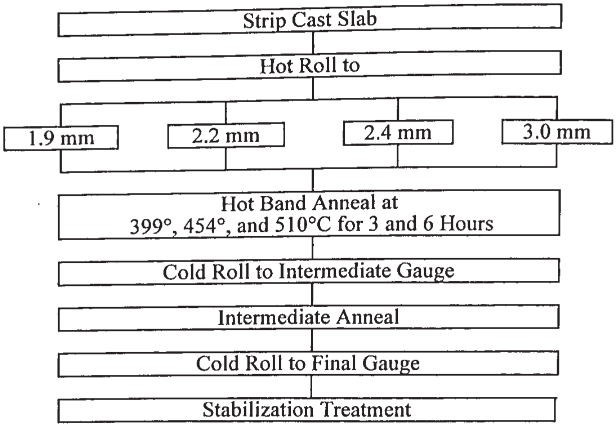

Figure 1. Experimental layout for processing of belt cast hot band.

RESULTS AND DISCUSSION

As-Rolled Hot Band Surface Quality

Control of hot band surface quality is critical for providing acceptable surface in the final sheet. Ingot source hot band surface quality is strictly controlled, and anodizing treatments are used to inspect the surface. Similarly, in this study the hot band samples were subjected to typical anodizing treatments using a sulfuric acid bath. The anodized quality test showed that the hot band with lowest gauge (1.9 mm) had a relatively poorer surface than the other three hot bands. The top and bottom sides of the hot bands also varied in their surface quality, suggesting casting and/or rolling practice differences from top to bottom. The 1.9 mm hot band's poor anodized quality may be partly due to it being the first to be cast and rolled before reaching a true steady state condition, as well as having a higher degree of reduction. However, the SEM examination of the as-rolled hot band samples did not show a high degree of buried oxides (or undercast) typically associated with poor hot band surface quality. A number of hot band samples were milled to remove 0.05-0.10 mm from the surface and anodized. This resulted in extremely good anodized surface quality, suggesting that the poor anodized surface quality is a near-surface phenomenon.

Constituent "banding" or "clustering" on the surface of several of the hot bands was observed, as shown in Figure 2. This was attributed to local variations in the heat transfer at the belt-metal interface, resulting in differential solidification conditions. Typically the bands were up to 100 μm wide and a few hundred μm long. The large constituents (3-5 μm^2) were mainly $Al_6(FeMn)$ and $Al_{12}(FeMn)_3Si$ phases, with some Mg_2Si and AlCuMgSi phases also present. Varying amounts of copper were detected in the $Al_6(FeMn)$ and $Al_{12}(FeMn)_3Si$ phases. The constituent banding can cause cosmetically unappealing "streaking" or "Looper line" type phenomena on the finished cans, especially if the cans have no base coat and have light-colored labels. Some degree of centerline segregation is considered inevitable in a belt cast product. However, its presence can affect can making performance (e.g., increased tear-off rate) when the centerline segregation is a significant fraction of can wall thickness. Shown in Figure 3 is an example of extreme centerline segregation observed in the hot bands of the present study. However, on the whole, the centerline segregation was considered negligible for adversely affecting the can making performance.

Hot Band Thermals

Unlike DC cast ingots, which are subjected to homogenization treatments prior to hot rolling, the continuous cast slabs are directly hot rolled and coiled. These coiled hot bands are subjected to thermal treatments to achieve homogenization and recrystallization. As a result of these thermals, remaining microsegregation from casting is reduced and metal is recrystallized to attain proper texture and microstructure. One of the main objectives is to maximize on the "cube" texture content such that final gauge earing is reduced. Evolution of the cube texture can be assisted by the presence of coarse dispersoids and lower amount of particle stimulated nucleation (PSN) of recrystallized grains. The PSN is affected by the size and number of $Al_6(FeMn)$ and $Al_{12}(FeMn)_3Si$ constituents. In general, continuous cast hot band has lower sized constituents than that from the ingot source. Transformation of $Al_6(FeMn)$ to $Al_{12}(FeMn)_3Si$, which has higher hardness, is considered to improve galling resistance in the body maker. Accordingly, hot bands were annealed at 399°, 454°, and 510°C for 3 and 6 hours at each temperature.

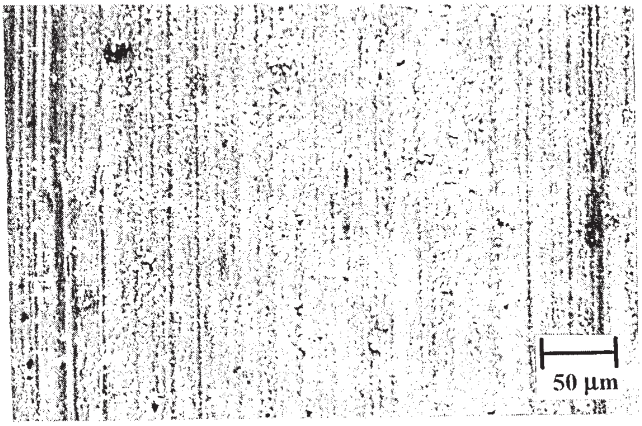

Figure 2. Scanning electron micrograph (backscattered electron image) of the 1.9 mm hot band surface showing banding of the constituents in the rolling plane.

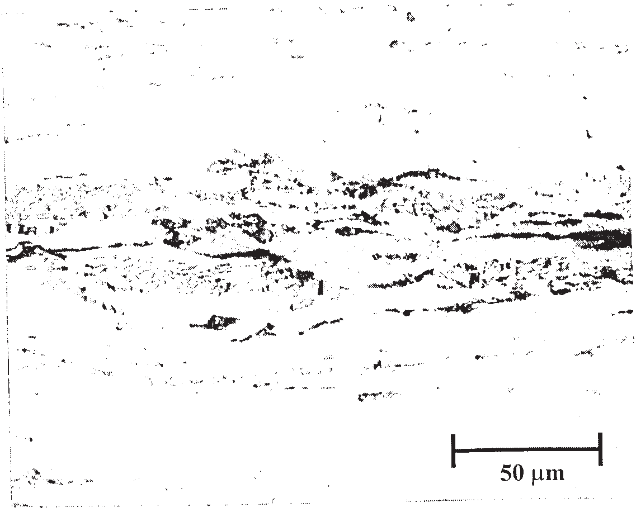

Figure 3. Optical photomicrograph of the 2.2 mm hot band (long transverse plane) showing the presence of centerline segregation as seen in the longitudinal section.

Manganese Retained in Solid Solution

In the manganese-containing alloys, the manganese in solid solution (Mn_{SS}) has the largest effect on electrical conductivity. As shown in Table 2, there is a significant decrease in the Mn_{SS} due to precipitation of the manganese-bearing phases. The anneal at 454°C showed the largest drop, due to a high degree of precipitation resulting from an optimum combination of diffusivity and super saturation. In comparison, for ingot processed 3104 type alloy, the Mn_{SS} of the as-cast alloy is ≅0.75-0.80 weight percent, which, after homogenization, decreases to ≅0.3-0.6 weight percent, depending on the practice [14]. Although Mn_{SS} retards recrystallization, its presence in can stock is critical for providing hard $Al_6(FeMn)$ and $Al_{12}(FeMn)_3Si$ constituents for die-cleaning and imparting strength to the final gauge sheet through solid solution hardening.

Table 2. Mn_{SS} Estimated from Electrical Conductivity (Percent IACS)
Before and *After* Hot Band Anneals [14]

Hot Band (mm)	As-Rolled	399°C		454°C		510°C	
		3 Hours	6 Hours	3 Hours	6 Hours	3 Hours	6 Hours
1.9	0.59	0.28	0.26	0.22	0.21	0.23	0.24
2.2	0.60	0.30	0.27	0.22	0.22	0.24	0.24
2.4	0.61	0.29	0.26	0.22	0.22	0.24	0.24
3.0	0.62	0.29	0.26	0.23	0.22	0.24	0.25
Average	0.61	0.29	0.26	0.22	0.21	0.23	0.24

Annealed Hot Band Microstructure

Optical metallography of the four annealed hot bands showed that, in general, the degree of recrystallization increased with increasing annealing temperature and time. For example, the hot band annealed at 399°C showed highly elongated grains, indicating a low degree of recrystallization. On the other hand, the hot bands annealed at 510°C exhibited grains tending toward equiaxed structure. Unexpectedly, the amount of reduction from hot rolling did not show any direct correlation with extent of recrystallization. The dispersoids (<1 μm^2) were identified to be mainly α-$Al_{12}(FeMn)_3Si$ phase with varying amounts of copper present. The dispersoids were distributed inhomogenously and observed to be either spherical or rod-shaped. In general, the dispersoids became coarser with increasing annealing temperature or time. Shown in Figure 4 are the TEM photomicrographs of dispersoids in hot bands annealed at 399° and 510°C for 6 hours each. Providing coarse dispersoids is especially important for sheet from continuous cast feed stock, as multiple down-stream annealing treatments may be necessary for earing control. Proper recrystallization texture evolution is assisted by coarser dispersoids, which, in turn, aids in lowering the earing of the final gauge sheet.

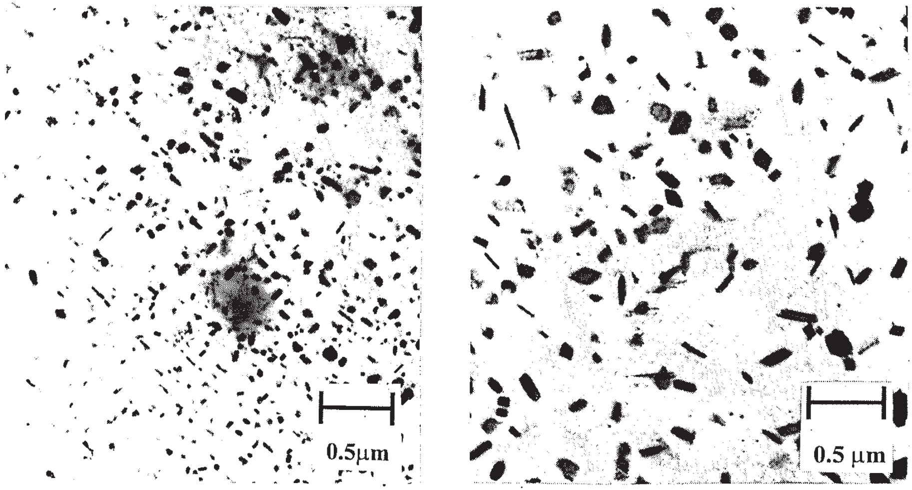

Figure 4. TEM photomicrographs of the 2.2 mm hot band annealed at 399°C (left) and 510°C (right) for 6 hours each, showing dispersoid size distribution.

Annealed Hot Band Crystallographic Texture

Final gauge sheet earing is minimized by balancing the "cube" texture (ears in the 0/90° to rolling direction) with deformation texture (ears at 45° to rolling direction). As-coiled hot band texture components for the four gauges were similar, with weak recrystallization texture components ("cube", Goss, etc.), indicating lack of recrystallization during hot rolling and coiling. The hot bands consisted mainly of deformation texture components (S, Brass, and Cu) typically associated with rolling of face centered cubic (FCC) aluminum.

Since the as-coiled hot band texture and the extent of recrystallization assessed by optical metallography did not vary with gauge, two extreme gauges (1.9 mm and 3.0 mm) were selected for texture analyses. Pole figures were measured on the center (t/2) plane of the samples for all three annealing temperatures. The component of interest, "cube", increased with annealing temperature (Figure 5), with a simultaneous decrease in the Brass, Cu, and S components (Figure 6).

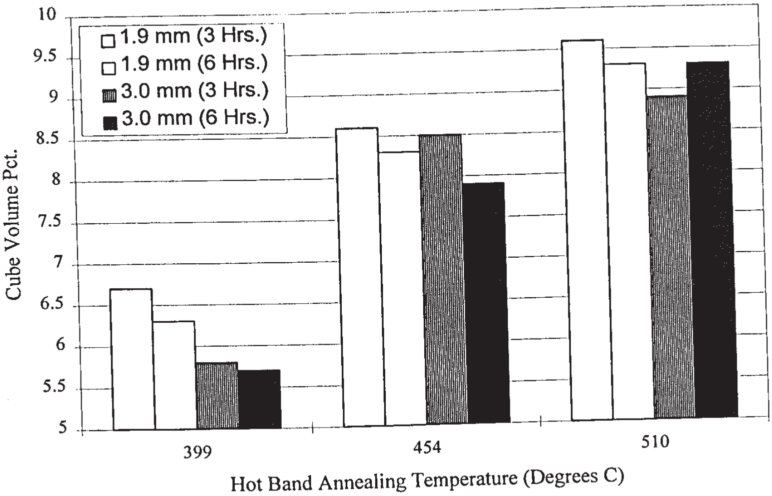

Figure 5. "Cube" texture component as a function of hot band annealing temperature for the 1.9 mm and 3.0 mm hot bands.

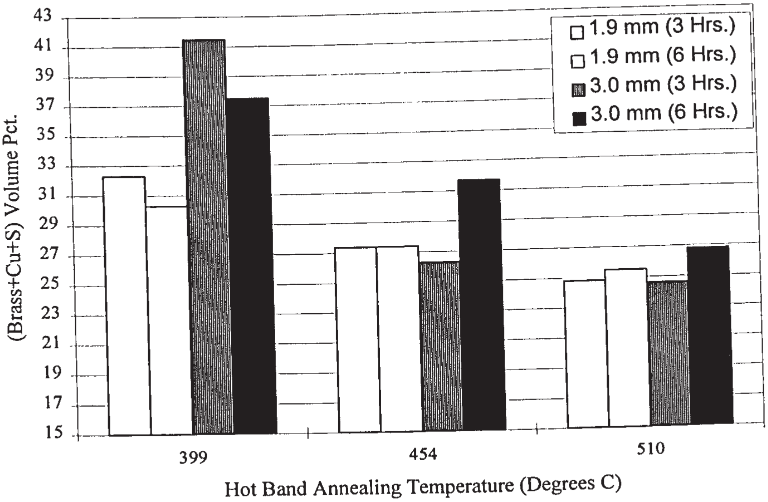

Figure 6. Deformation texture components (Brass+Cu+S) as a function of hot band annealing temperature for the 1.9 mm and 3.0 mm hot bands.

However, the Cu component showed a relatively smaller change than the Brass or S components. A high volume percentage of rolling texture components for the 399°C anneal, particularly for the 3.0 mm hot band, confirmed lower recrystallization observed by metallography. It is likely that the dispersoids, being smaller, were more effective in imposing Zener drag on the recrystallized grain boundaries at the lower annealing temperature due to less available thermal energy.

COLD ROLLING INTERMEDIATE ANNEALING AND COLD ROLLING

Hot band annealed coils were cold rolled to an intermediate gauge of 0.635 mm, providing a cold rolling reduction of approximately 66-78 percent, depending on the hot band gauge. An intermediate annealing step was imposed to control final gauge sheet earing and to prepare the metal for subsequent rolling to final gauge. An intermediate anneal can be expected to provide the necessary amount of "cube" texture to balance the deformation texture and lower earing in the final gauge sheet. The hot band annealing temperature impacted the extent of recrystallization during intermediate annealing. This was attributed to (a) amount of "cube" texture available in the annealed hot band, (b) degree of cold working reduction, and (c) dispersoid size variation resulting from the hot band anneal (Figure 3). Following the intermediate annealing at 371°C, the sheet samples were cold rolled to the final gauge of 0.279 mm, which resulted in a 56 percent cold work and an H16 temper. In order to further improve formability, the final gauge samples were subjected to low temperature "stabilization" at 163°C for 4 hours. The stabilization treatment is similar to that which typical ingot processed coils are occasionally subjected to, for improving formability, especially if the sheet exits the cold rolling mill at low temperatures.

Mechanical Properties and Earing

Table 3 shows the range of mechanical properties measured in the final gauge (0.279 mm) samples with and without stabilization treatments, compared to typical ingot processed AA3104 can body stock. The mechanical properties fall within a typical range for ingot processed AA3104. The final gauge sheet samples subjected to stabilization treatment showed an increase in tensile yield and ultimate tensile strength by as much as 37 MPa, and elongations were in the range of 5-7 percent. The strength increase was attributed to precipitation hardening from Al-Cu-Mg phase, as reported by Inaba and Usui [15].

Table 3. Mechanical Properties and Earing of the Final Gauge Samples
Compared to Typical Ingot Processed AA3104 Alloy

Source	Ultimate Tensile Strength (Mpa)	Yield Strength (MPa)	Elongation (%)	Earing (%)
Strip Cast	278-303	268-280	1 - 4	2-4
Strip Cast + Stabilized	292-338	275-294	5 - 7	2-4
Ingot Cast AA3104	276-324	255-300	3 (minimum)	>4 (not acceptable)

Low elongation in the as-rolled sheet was due to rapid strain hardening from the higher level of copper and magnesium in the alloy. Earing was 45 degree type and lower than typical ingot processed sheet earing.

CAN MAKING PERFORMANCE

Strip cast coils were evaluated on commercial can lines along with coils processed by the ingot metallurgy method. Quality of the production cups from the experimental coils was excellent. Earing on the production cup was noticeably lower than that from the ingot processed coils. Although a limited number of cans (approximately 60,000) were produced to get a valid tear-off rate, the number of tear-offs were no higher than those from standard ingot processed coils. Surface defects, such as banding of the constituents, did not cause tear-offs, although occasional blemishes on painted can surfaces were visible.

Overall formability of the strip cast coils during cupping, drawing, ironing, necking, and flanging was excellent. The finished cans had acceptable column strength, and the dome reversal pressure, as well as cans, met dimensional specifications.

CONCLUSIONS

- An alloy with lower manganese and higher copper than standard AA3104 was developed for strip cast D&I can body stock.
- Using the alloy, a thermomechanical processing method for producing a low earing and good formability can body stock was developed.
- Hot band annealing practice is critical, as it significantly impacts final gauge earing.
- Surface quality of the belt cast slab needs to be improved and produced consistently for the demanding application of can making.
- The can making performance of strip cast coils was good and comparable to coils produced by the ingot metallurgy method.
- Further alloy and process development of continuous cast sheet offers additional advantages, such as heat treatable potential for optimum strength-formability improvements and lower earing, vis-à-vis ingot processed sheet. This, in turn, can provide further down-gauging potential and productivity improvements in sheet processing and can making.

ACKNOWLEDGMENTS

Technical support and encouragement from Mr. J. H. Kuhns of Reynolds Global Can Division and Dr. W. A. Cassada of Reynolds Corporate Research and Development are acknowledged. Many thanks to Barbara Dunbar for her help in preparing the manuscript.

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