Development of Low-Earing Can Body Stock Using the 4-stand Hot Finishing Mill at the Fukui Works

by Katsumi Koyama, Sachio Urayoshi*, Toyonobu Tanaka*,
Ryo Shoji*, Yoshikazu Tsuzuki*2 and Hiroshi Matsuda*3*

ABSTRACT In the effort to reduce the weight of aluminum beverage cans, progress is being made in reducing lid diameter and there is a need for materials with lower anisotropy (earing). To obtain such low-earing materials, it is necessary to arrange for the texture to be dominated by crystals of the cube orientation prior to cold rolling. Accordingly a study was made of the effect of hot rolling conditions on the formation and growth of cube oriented grains during recrystallization.

To obtain a structure with cube orientation (*a strong cube texture*) during recrystallization, it was found necessary that, during hot rolling, a strong rolling texture first be formed. To this end the number of finishing stands in the tandem hot-rolling mill at Furukawa Electric's Fukui Works was increased to four. This made it possible to improve manufacturing productivity and increase the size of coils manufactured, as well as to manufacture low-earing can body material to facilitate the ongoing program of diameter reduction.

1. INTRODUCTION

Aluminum cans account for a large percentage of packaging containers, and it is estimated that in 1997 over 15.7 billion cans were consumed in Japan alone[1)].

Aluminum's light weight and good thermal conductivity make it particularly attractive for use in beer cans, and it has attracted further attention in recent years from the standpoint of recycling. Despite these excellent properties, this material is in fierce competition with steel cans and PET (polyethylene tetraphthalate) bottles, necessitating cost reductions. One way to do this is to reduce weight, and this approach has long been actively pursued[2)].

A particularly effective way to decrease weight is to reduce lid diameter, and Figure 1 shows the progress made over the years in the United States[3)]. The percentage of reduction in lid weight effected by diameter reduction alone, even as roughly estimated by the surface ratio, has reached 37% and should go even further. More than the forming of the lid per se, the main technological problems in reducing lid diameter involve the necking of the can body in response to smaller lid diameter and the development of materials that can accommodate these smaller neck diameters[4)]. This paper discusses technological problems involving the materials for can bodies resulting from the

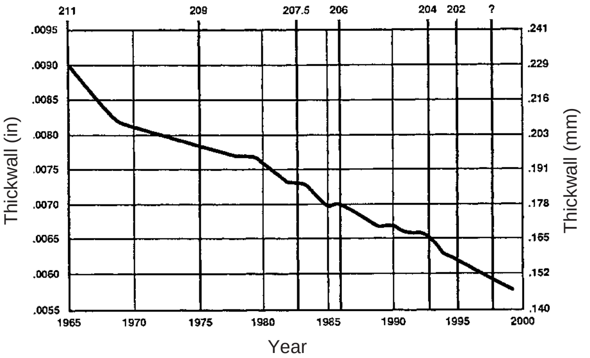

Figure 1 Historical perspective in the reduction in average neck diameter for 12-oz aluminum can bodies in the U.S.A. (outer diameter notation: 206, equals 2-6/16 in)

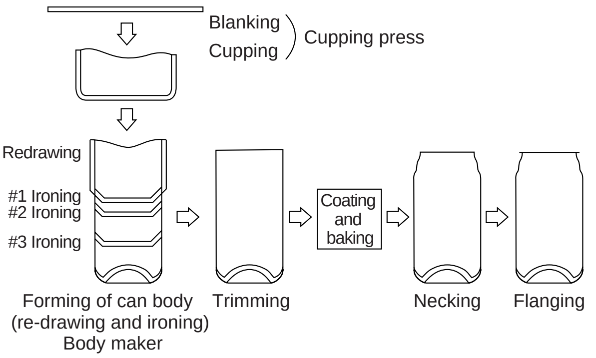

Figure 2 Manufacturing process for aluminum D&I can bodies

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* Material Research Sec., Fukui Lab., R&D Div.
*2 Materials Research Center, Yokohama Lab., R&D Div.
*3 Products Engineering Sec. (Currently with Production Engineering Sec.), Fukui Works

recent movement to reduce lid diameter, as well as the measures taken by Furukawa Electric to solve them.

2. PROBLEMS ARISING FROM DIAMETER REDUCTION

Figure 2 is a schematic showing the manufacturing process for aluminum D&I can bodies. Cans are stamped from coiled sheet, and after being deep drawn into the shape of a cup on the cupping press, are drawn and ironed (D&I) on a bodymaker to obtain the desired can height. They are then trimmed to a uniform height and washed, and the inner and outer surfaces are coated with lacquer and baked. This is followed by the necking of the can body to the outer diameter of the lid. Finally, the can end is attached to the body with the formation of a flange.

As a result of the texture of the material, earing--unevenness in can height--may occur during the drawing process. In the past the problem of earing that occurs during deep drawing and redrawing has received attention due because heavy earing of the cans after the cupping and D&I processes both interferes with their smooth transport and can result in pinholes or cracking during ironing of the can body. Further, a high level of earing creates the problem of wastage because a larger amount of aluminum must be trimmed to avoid valleys in the edge of the trimmed can.

Figure 3 shows the relationship between reduction by necking and earing. Earing is also produced in the sidewall of the can by the necking process that follows D&I[4]. Further the trend in earing during the necking process is the same as that occurring during deep drawing and redrawing described above so both are considered to be phenomena caused by the texture of the material. Earing during the necking process is manifested as variation in flange width and results in a poor fit to the lid. With the further progress in lid diameter reduction now taking place, the appearance of earing during the necking process has come to constitute a major problem.

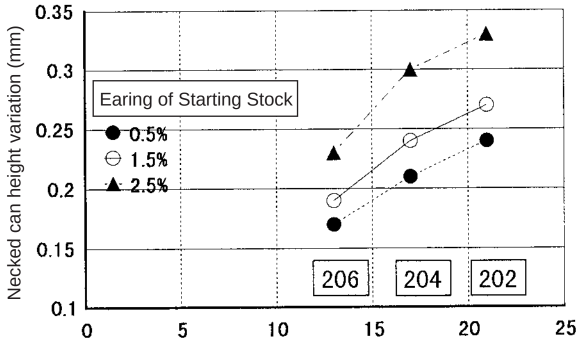


Figure 3 Can height variation in the necked can vs. reduction by necking

Table 1 Chemical composition of A3004 alloy for can body stock

mass %

JIS designation	Si	Fe	Cu	Mn	Mg	Zn	Al
A3004	0.3 max.	0.7 max.	0.25 max.	1.0~1.5	0.8~1.3	0.25 max.	remainder

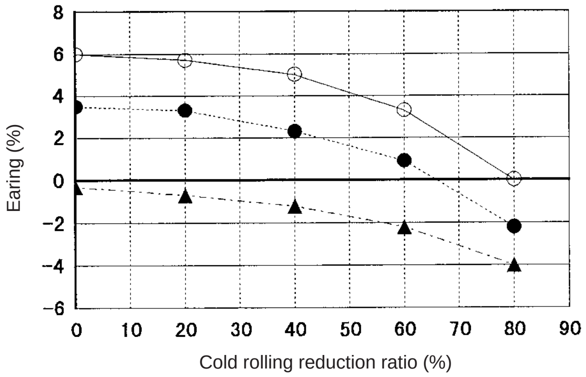


Figure 4 Earing vs. reduction ratio of cold rolled sheets

3. EARING AND TEXTURE

The material most commonly used for aluminum can bodies is fully work-hardened (H19) sheets of JIS-A3004 (see Table 1), which has high strength and high drawability. Figure 4 shows the relationship between the cold rolling reduction ratio and earing ratio. Rolling imparts deformation to the material in only one direction, resulting in a rolling texture with grains aligned in a specific direction. It is known that the alloy used here has a rolled texture composed primarily of S orientation {123} <634>, Bs orientation {110} <112> and Cu orientation {112} <111>[5]. Together with the development of this rolled texture, earing occurs at 45° with respect to the direction of rolling.

Recrystallization textures known to be obtained by annealing, on the other hand, are of the cube orientation {100} <101> and the Goss orientation {110} <001>[5]. In

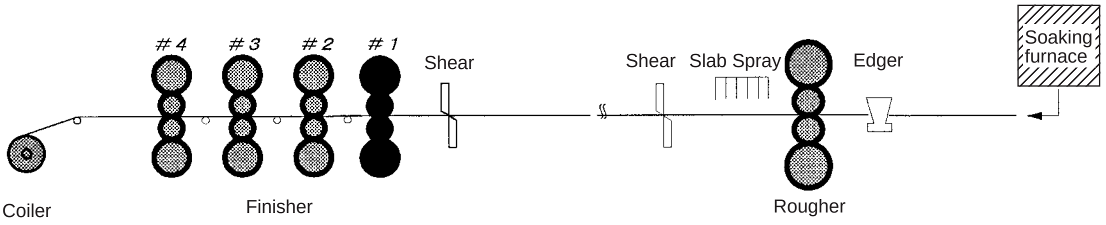


Figure 5 Layout of the hot rolling line at Furukawa Electric's Fukui Works

the cube orientation, high earing occurs in the 0/90° direction, while in Goss orientation it occurs in the 0/180° direction. It is possible to obtain a material having a low earing ratio by a suitable combination of crystals with an orientation that results in 45° earing and those that produce 0/90° earing[6]. Thus it is apparent that to obtain material of the requisite strength by cold rolling, it is necessary that a recrystallization texture be formed prior to cold rolling -- that is after hot rolling or during the subsequent annealing process -- in which crystals with a cube-orientation such that 0/90° earing occurs have a clear dominance[6].

4. FORMING CUBE-ORIENTATION DURING HOT ROLLING

Figure 5 shows the layout of the hot rolling line at Furukawa Electric's Fukui Works. Most industrial-scale hot rolling lines combine a reversing mill, called a rougher with a multi-stand tandem mill, called a finisher. In the rougher, the ingot is repeatedly rolled back and forth to achieve a thickness that can be accepted by the finisher. The tandem finisher consists of 4 stands arranged in series that roll the sheet successively. The sheet is then wound into coils by the coiler.Then, after the hot-rolled coil has completely recrystallized using the residual heat from hot rolling, the product is brought to its final thickness by cold rolling.

Photo 1 shows the crystal grain structure of the material immediately after hot finishing. When the final temperature is low, the result is a partially recrystallized microstructure in which granular crystals that are completely recrystallized are intermixed with worked material with a fibrous appearance in which recrystallization has not occurred. When the final rolling temperature is high, on the other hand, a recrystallized structure with equiaxed grains is obtained.

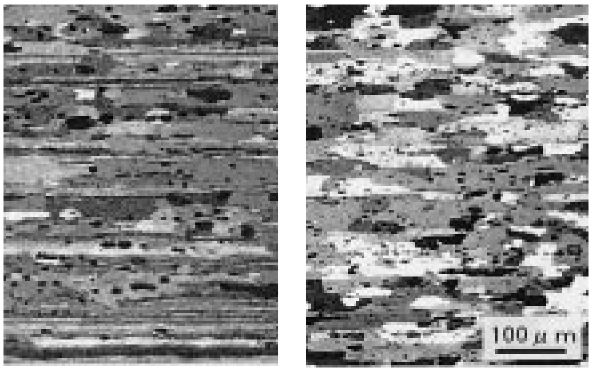
Both hot-rolled bands take on a completely crystallized structure after annealing (at, for example, 360°C for 2 hours). As already noted, obtaining a material with low earing requires an increase in the volume fraction of cube texture at the point at which complete recrystallization occurs. It is known that the recrystallized texture is strongly influenced by the amount of solute in solid solution in the material, the distribution of the dispersoids, and the hot-rolling conditions[7]. It is thought that these factors are related to the nucleation of the cube orientation, grain growth and the formation of other recrystallization textures (R orientation or random orientation), and determines the volume fraction of cube orientation[7].

Figure 6 shows the relationship between the total rolling reduction and cube orientation density in a hot tandem finishing mill. As the total rolling reduction in the hot finisher increases, a recrystallization texture with dominant cube orientation is obtained. This demonstrates that the nucleation and growth of the cube texture is related to the degree of development of the rolling texture.

However, no relationship was found between the cube orientation density after annealing and the total reduction during reversible hot rolling, which is the step that precedes hot finishing. This is thought to be due to the waiting time (several seconds to several minutes) between each pass during reversible hot rough rolling, during which partial recrystallization occurs[8]. The formation of the rolling texture is thus interrupted between every pass. Up until now the dominant theory holds that the cube orientation has its origin in cube oriented bands seen in the hot-rolled sheet[6]. Cube oriented bands are residual of the grains recrystallized during hot rough rolling that have been elongated during the hot finish rolling step. It has been confirmed that subgrains within the cube oriented bands act as the nuclei of discontinuously recrystallized grains, and these grow faster than recrystallized grains of other orientations[6]. The above results, however, demonstrate that when the rolled texture becomes extremely well developed the formation and growth of recrystallized grains of cube orientation from elsewhere than the cube orientation band is dominant.

Figure 7 plots the effect of total rolling reduction during hot finishing on the ODF of two materials having different volume fractions of the cube orientation.

The cube orientation fraction in these completely recrystallized specimens differed, but there was no difference in the other specified orientation densities. That is to say, the crystal grains having other than cube orientation had an unaligned, random orientation. In rolled material (Photo 2)



300˚C 335˚C

Photo 1 Grain structure of AA3004 hot band rolled at two different temperature

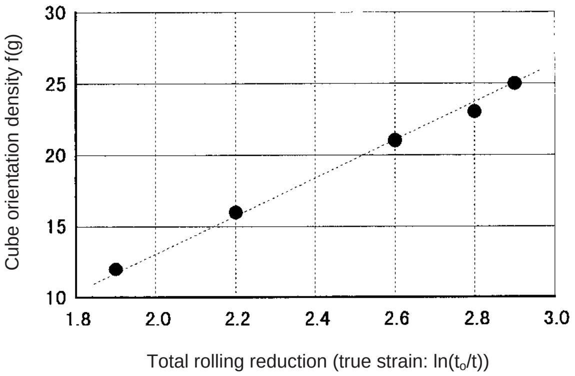


Figure 6 Relationship between total rolling reduction ratio and cube orientation density in tandem hot finishing mill

the lines indicating old grain boundaries can be seen to curve around Al-Mn-Fe particles.

This is due to the fact that strain concentrations occurred around the dispersoid, and the deformation was disordered. Crystals having random orientation --that is to say no orientation with respect to the direction of rolling-- are thought to originate from the regions surrounding eutectic constituent particles in which the amount of deformation was very large and the direction of deformation was disordered. This corresponds to the description that by decreasing the amount of Fe in the material thereby decreasing the eutectic constituent, the volume fraction of cube texture is comparatively increased[9].

On the other hand, it is difficult to conceive that an increase in reduction during hot rolling would be accompanied by the suppressed formation of recrystallization nuclei near the dispersoids. It is therefore concluded that the development of a rolling texture promoted the formation and growth of cube orientation from the matrix.

Other hot rolling conditions such as hot rolling temperature, and rolling speed can be combined using a parameter such as the Zener-Hollomon parameter. These other hot rolling conditions are also known to affect the formation of cube orientation[10]. The Zener-Hollomon parameter is related to the amount of mechanical energy that accumulate in the metal --energy which is required for recrystallization to proceed-- and is known to affect the formation of cube texture.

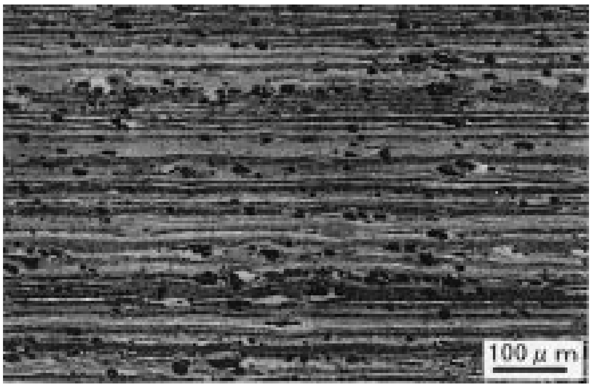
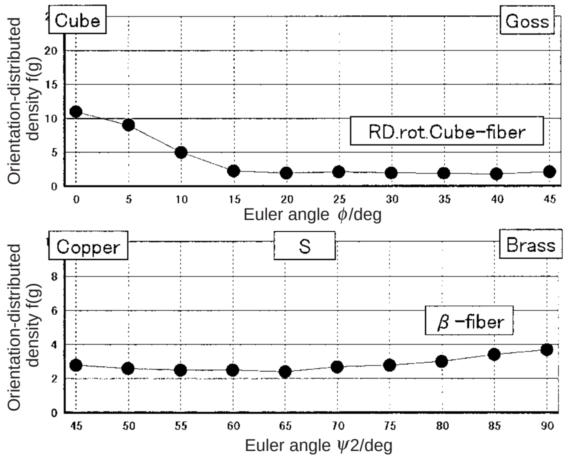
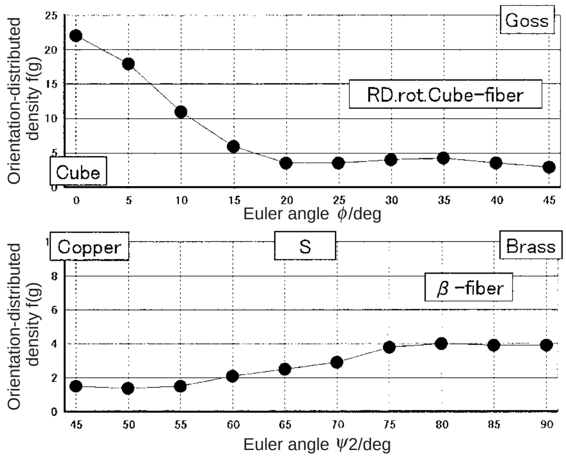


Photo 2 Grain structure of material hot rolled at a low deformation temperature

In addition, the Zener-Hollomon parameter is thought to influence the competition for growth between those recrystallization grains originating from the regions surrounding the eutectic constituents and those originating from the matrix.



Total true strain: 1.9



Total true strain: 2.6

Figure 7 Effect of total rolling reduction ratio in tandem hot finishing mill on the fiber texture of completely recrystallized hot band

5. RESPONSES TO LID DIAMETER REDUCTION

In order to develop a low-earing material that can cope with the reductions in lid diameter that will continue as productivity rises, Furukawa Electric has augmented the stands of its tandem hot finishing mill in accordance with the information described above. This has led to a dramatic reduction in earing in D&I can bodies; it has been confirmed that the range of deformation of can height (flange width) following necking has been reduced to about half that of conventional materials. This level of earing is compatible not only with current lid diameters but with the reduced lid diameters expected in the future.

6. CONCLUSION

The manufacture of can body materials with low earing to accommodate reduced lid diameters requires a recrystallization texture after hot rolling in which the cube orientation predominates. Accordingly this study investigated the hot rolling conditions that are considered important to recrystallization behavior, and it was found that the formation and growth of cube oriented recrystallized grains is promoted by the development of a rolling texture during hot rolling. Based on this information, Furukawa Electric has augmented the number of hot finishing stands, thereby raising productivity and increasing coil diameter, and making possible the manufacture of a can body stock with low earing suited to smaller lid diameters, which has found favor with can manufacturers around the world.

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