AN ALUMINIUM ALLOY SUITABLE FOR CANBODY AND END MANUFACTURE

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Abstract

Conventional two-piece aluminium beverage containers are fabricated from two separate alloys; 3004 alloy is used to form the body by deep drawing and wall ironing forming methods and 5182 alloy has the strength and formability properties desirable for the complex can end fabrication.

In the present work 7XXX series based Al alloys have been used to manufacture can bodies and ends, from the one composition. These alloys offer the advantages of being non-galling and of very low earing characteristics (<2%), are highly formable and have strength and ductility in reserve to allow significant downgauging in future can and end developments.

The paper describes the alloying, processing, and the microstructural features of the final product. Two alloys are processed so as to attain appropriate strength for applications as body and end. Anisotropy is controlled through alloying and processing to ensure earing is kept to a minimum.

Introduction

Conventional two-piece aluminium beverage containers are generally fabricated from two distinct work hardenable alloys such as the Aluminium Association Specification 3004 and 5182. The body utilises an Al-Mn-Mg alloy (AA 3004) which is suited to the D & I forming process (deep drawing and wall ironing) but lacks the necessary rigidity and strength properties to be useful for end stock (See Table 1). An Al-Mg alloy (AA 5182) alloy is used to meet the high strength and formability property requirements for end manufacture. However, this alloy is unsuitable for body stock.

The commercial success of the aluminium can has been due mainly to lightweighting and recyclability within the industry (1). Increased demand for Al beverage containers and the drive towards cans of thinner gauge material has spurred development of alternative canstock alloys of higher strength. Inaba et al (2) have developed a can body stock from an $A\ell$-Mg-Mn alloy with Cu additions that hardens during lacquer baking. The can body stock shows desirable formability for D&I forming before baking, and gives high buckle strength after baking.

Doherty (3), and Althoff (4) have shown that can bodies and ends can be formulated from Aℓ-Mg-Mn-Cu and Aℓ-Si-Mn based alloys respectively. Doherty's alloy is solutionised at two different temperatures to produce materials of varying strength at final gauge. A rapid annealing heating rate to temperatures >400C is required to attain these properties. Althoff's alloy is silicon rich and aims to cut costs in the recycling chain through substitution of Si for Mg and the use of the lower cost alloy for both body and end.

These alloys (3,4) have been developed in response to the recycling and productivity issues. Due to the differing requirements of body and end, two different alloys and two process lines have traditionally been required as well as special care in the separation of waste. The practice also complicates the recycling process for UBC as remelt compositions contain Mg in excess of 1% (up to 4.5%) and commercial purity Aℓ must be added to balance composition for re-fabrication into body and end alloy blocks.

The finished properties of body and end stock are centred around current customer property requirements in the aluminium D & I container industry. The minimum yield for bodystock is some 30 MPa lower than that of endstock and is 3% lower in ductility (Table I). For an alloy to be suitable for both applications it must possess high strength to satisfy the endstock requirements and high formability to meet the criteria for D & I canstock.

For the alloy to be attractive in the future it must also have potential for the properties to be tailored and improved for new applications. Downgauging of conventional strain-hardened alloys to reduce cost of body manufacture requires the use of increased alloying element concentrations or cold rolling reductions to increase strength. As element concentrations are increased, for a given rolling strain, the formability of the resultant alloy decreases. Other aluminium alloy systems currently used for other applications are potentially capable of acheiving much higher strength and ductility levels than 3004.

Table I. Property specifications of 3004 bodystock and 5182 endstock alloys

Alloy	Spec	YS (MPa)	TS (MPa)	Elong (%)	*Post Bake YS
3004-H19	Min	280	300	1	255
	Typical	290	310	3.5	
	Max	305	325		
5182-H19	Min	310	355	6	295
	Typical	325	370	8	
	Max	340	385	-	

* Simulated lacquer bake cycle: 205°C for 20 mins.

The object of this paper is to describe a 7000 series aluminium alloy suitable for can stock which has non-galling, low earing and high strength characteristics with excellent formability when compared to existing AA3004 type alloys. These properties will, ultimately, allow can bodies to be made at low body-maker failure rates from thinner sheet feed stock. It is intended to demonstrate how to provide material which is also suitable for the manufacture of can ends thus allowing manufacturing of a complete two-piece beverage can from one alloy composition. The original concept work was conducted at Commonwealth Aluminum, KY. by C. Mohr (5). The work presented in this paper was conducted at Comalco Research Centre by the authors.

Materials Processing

Two alloys, A and B of compositions shown in Table II were direct chill cast into ingots 100 x 300mm in cross-section and 1.2m in length and ingots were scalped into a number of blocks 190mm wide, 100mm thick and of 200mm in length. Each of the blocks were then homogenised at temperatures between 550°C and 585°C. A higher homogenisation temperature was used for the alloys of highest solute content to allow for more complete homogenisation.

Table II. High Strength Can Stock Alloy Composition

	CHEMICAL COMPOSITION (wt%)							
	Aℓ	Zn	Mg	Mn	Si	Fe	Cu	Cr
Alloy A	Bal	4.6	1.3	0.42	0.2	0.4	0.10	<.008
Alloy B	Bal	6.0	1.8	0.56	0.2	0.35	0.10	<.009

To hot roll the alloys the scalped blocks were cooled to a rolling temperature of 485°C in the furnace and then individually rolled in a laboratory mill from 100mm to a gauge of 2-3mm in steps of up to 12mm/pass. Radiant heaters were used on entry tables, exit tables and the rolls and ingots were returned to the holding furnace between some passes. Hot rolling lubricant was applied to the rolls between each hot rolling pass. The hot rolling finishing temperature was always above 280°C which was sufficient to allow some recrystallisation and recovery of the rolled structure before cold rolling to the solution heat-treatment gauge. With alloy B, the material was given an anneal at a temperature of 345°C for 3 hours to allow the material to recover and recrystallise fully. In this softened condition, the alloys were cold rolled to a number of different gauges. This was to allow for a number of different schedules of rolling at final gauge.

The sheet was solution heated at a temperature of 500°C to dissolve the alloying elements, cold water quenched and then given a number of ageing heat treatments to characterise the response of the alloys. Tensile testing was performed on the final gauge sheet. Lengths of finished sheet were fed into a pilot can line and cups and bodies made from each of the sheets. The earing level of each cup was measured prior to the bodymaking operation. The buckle resistance of selected cans was measured on a conventional buckle resistance testing machine.

Results and Discussion

Microstructure

Figure I shows the microstructure of alloy A after hot rolling to 3mm gauge on the pilot rolling mill. Extensive recrystallisation had occurred during the hot rolling process and some residual deformation is present from the final hot rolling passes. The material was then cold rolled to ≈1mm and solutionised. The solutionising treatment annealed and fully recrystallised the structure to an average grain size of 19μm (ASTM 8.5) (Figure II). Some of the plates were hot rolled to thin gauges at high temperatures; the material thereby anneals automatically after rolling. In the higher solute alloy B, the auto-annealing allowed the material to be cold rolled further to the solutionising gauge without edge cracking. Auto-annealing is also facilitated by restricting the levels of zirconium and chromium in the melt to obtain a fully equi-axed recrystallised structure upon hot finishing or furnace annealing.

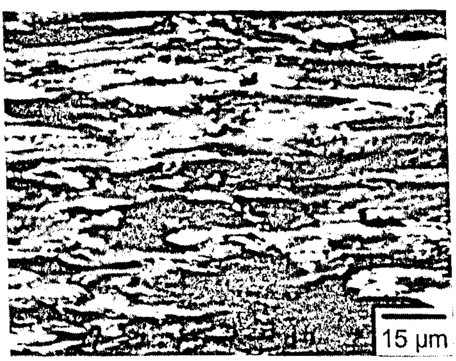

Figure I : Hot Rolled Microstructure

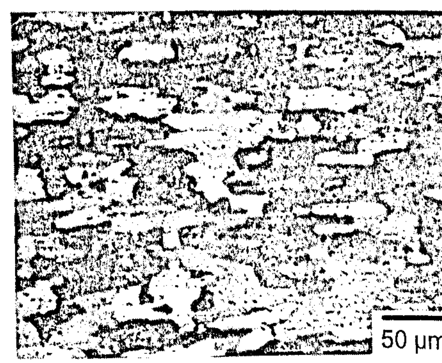

Figure II : Anneal 345°C for 1 Hour

The composition of the alloy is balanced to give very high percentages of the alpha (Type α-$A\ell_{17}$ $(Fe, Mn)_3$ Si_2) intermetallic upon DC casting. Figure III shows the dispersion of alpha particles through a section of the rolled sheet. The dispersion is typical of that in DC cast alloy sheet and no significant centre-line segregation is apparent The silicon, manganese and iron elemental levels are required in the alloys to form alpha primary particle distribution critical for the production of a wall ironed can of excellent non-galling properties and surface finish.

Properties

After solution heat treatment, the majority of the magnesium and zinc are retained in a supersaturated solid solution and precipitate during the ageing heat treatment adding strength to the alloy prior to the cold rolling operation. In the final stages of manufacture the required sheet properties may be produced by a combination of cold rolling reduction and heat treatment. Consequently, the fabrication steps vary with the application requirements and a number of treatments have been used. During the heat treatment processes, it was found that the alloy was especially adaptable to high temperature solution heat treatment of very short duration. More lengthy heat treatments of up to 1 hour were used to simultaneously anneal and recrystallise the sheet

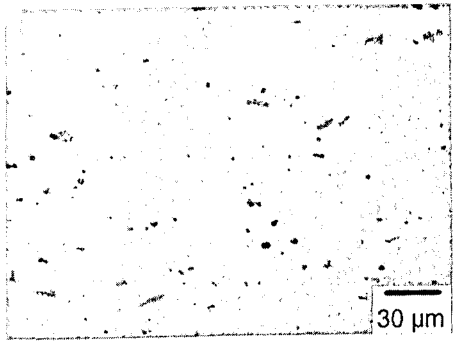

Figure 3 : Finished Cansheet Showing Alpha Phase Dispersion.

Figure IV demonstrates some of the effects of an ageing practice on the hardness of alloy A and B. The alloys have undergone a solution heat treatment of 500°C for 1 hour, cold water quenching and 24 hours natural ageing before cold working 60% and artificially ageing at 121°C for 3 hours. A second artificial ageing treatment of 155°C was used in order to enhance the properties and obtain a flatter ageing curve across the heat treatment time range. Some examples of the mechanical properties of the duplex ageing of alloy B are shown in Table III.

The strength and elongation of alloy A after 75% reduction and ageing at 121°C is described in Figure V. The alloys are of very high tensile strength with ductilities in excess of 4% across the range reaching 6% in the T87 temper. Some of the tensile and earing test results of alloys rolled to 30% and 60% reductions are described in Table III.

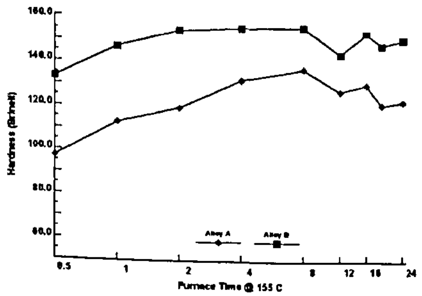

Figure IV: Ageing response of alloys @ 155°C after preageing at 121°C for 3 hours

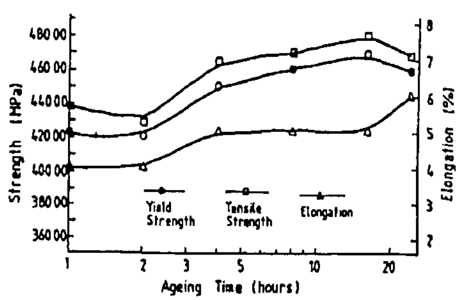

Figure V: Tensile properties of alloy A after 75% reduction (ageing at 121°C)

Figure VI shows a comparison between the range of tensile properties obtainable from alloys A and B and those of 3004.. The 3004 alloy has yield and tensile strengths of around 290 and 310 MPa. The earing levels of can bodies made from alloy A have earing levels between 0 and 2.4%.

These levels are, on average, 1% lower for a given condition than that of can bodies made from 3004 alloys.This property may allow the canmaker to take advantage of trim height (initial blank size) and a reduction in tear-off rates caused by pinched ears and tracking jams in the canmaking process.

Table III. Tensile and Earing Properties

Alloy	Final Reduction %	Ageing Temperature (°C/ # of hrs)	YS/UTS/El^{n} (Mpa / %)	Earing %	Buckle strength (psi)
A	30	121/6	353/390/7.3	1.7	104
	60	121/6	372/391/4.9	1.8	>108
	60	121/24	383/403/6.3	1.3	-
	60	121/24	369/392/3.5	1.5	>108
	60	121/24	375/395/4.6	1.9	>110
B	60	121/1 + 155/4	448/475/5.0	-	-
	10	121/3+ +155/3	386/473/10	0.6	
	30	121/3 + 155/3	417/451/5.6	0.9	
	60	121/3 + 155/3	441/454/2.0	1.9	

The chemistry of the alloy influences the earing properties of the alloy. If the zirconium and chromium levels in the alloy are increased the material strength increases and earing levels rise. A more elongated grain structure is created after hot and cold rolling which is retained during the solution heat treatment or anneal and the properties of the final gauge sheet are more anisotropic.

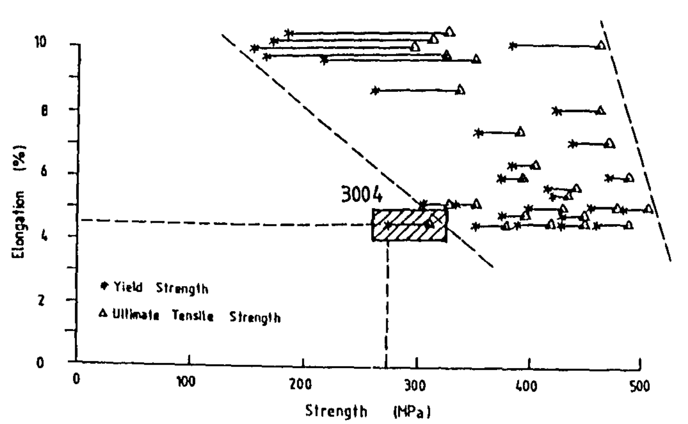

Figure VI

When the 7000 series alloy sheet is drawn and wall-ironed into a body for a two-piece beverage container it possesses can buckle strengths in excess of 100 p.s.i.(Table III) with wall thickness of

0.12mm (3004 alloy is ≈90 psi) The combination of high strength and ductility in this alloy compared to that of coventional can bodystock allows the canmaker to have the benefits of high formability while drawing and ironing the can without sacrificing column strength. This, in combination with the can geometry for added buckle resistance, can allow the gauge of sheet used for the initial forming operation (can line feed) to be reduced by at least 10% while still retaining column strength, dome reversal strength, formability and surface quality in the finished body.

Generally, endstock is manufactured in coil form and is sent to the end makers who then coat the material and bake the coated sheet at modest temperatures of between 155°C and 210°C for 10-30 minutes. Usually a specified test for the aluminum metal supplier is to test tensile strength after a furnace bake at 205°C for 20 minutes.Minimum post-bake yield strengths for 5182-H19 are approximately 295MPa.

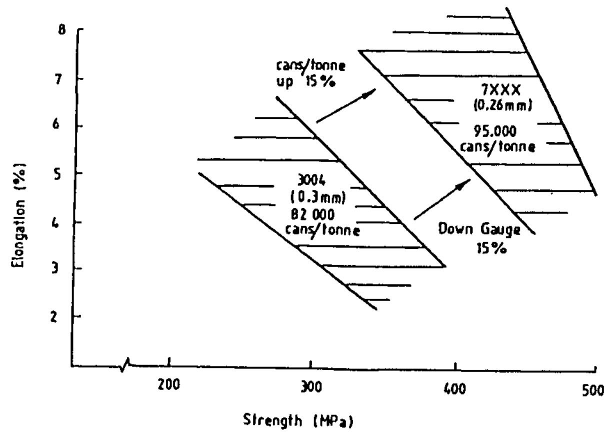

Figure VII.

The effects of the post-bake heat-treatment on the experimental alloy B are detailed in Table IV for the respective processing treatments. Results are shown for sheet which have been cold rolled 10% and 30%, naturally aged for 24 hours and artificially aged at 121°C for 3 and 6 hours. Half of each sample was baked at 205°C for 20 minutes and tensile tests were performed on each sample. The treatments for Alloy B in Table IV produced post-bake properties in excess of the minimum yield strength (295mpa for 5182) and elongations of 6 to 7%. The gauge of the material was, however, 0.315mm which is slightly heavier than current 5182 endstock. However, if the final rolling reduction for Alloy B was increased to bring the gauge down to 280µm, then the yield strength would increase above its present value of ≈435 MPa. Annealing the material back to a level above 310 MPa would still produce sheet tensile elongations of 6.0% minimum.

Table IV: Alloy B Final Gauge and Post-Bake Property Comparison

Heat Treat	Reduction	YS Pre Bake	YS Post Bake	YS % Drop	UTS Pre Bake	UTS Post Bake	UTS % Drop	Elongation Pre Bake %	Elongation Post Bake %
121/3	10	403	334	16.7	447	377	15.6	9.0	7.0
121/6	10	440	326	13.2	474	367	22.6	8.0	7.0
121/3	30	433	342	21.0	464	376	18.9	7.0	6.0
121/6	30	464	335	27.8	487	371	23.8	6.8	6.5

The 7000 series alloys have been shown to have the strength and formability suitable for two piece beverage containers.The alloys can be used to advantage in the areas of downgauging, productivity cost and recyclability by both sheet manufacturers and can makers.With this knowledge it is hoped that the phenomenal growth of aluminium in the packaging industry can be sustained

Conclusions

1. Canbody sheet produced from 7000 series alloys has superior strength, ductility and galling properties when compared with conventional body sheet alloys such as 3004. Further advantage is that the 7000 alloys show less anisotropy and reduced earing.

2. The same 7000 series alloys may be used to produce end stock. These alloys therefore offer the opportunity of using a single alloy for all component parts which should reduce production costs and improve scrap recycling efficiency.

3. Because of the high strength of the 7000 alloys, these materials also offer the prospect of achieving cost reductions by using thinner gauge sheet.

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