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ALUMINUM CAN TECHNOLOGY TO MAINTAIN COMPETITIVENESS BY REDUCING COST

presented by

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of the requirements for

Master degree in Science

Harold Hughes
Major professor

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ALUMINUM CAN TECHNOLOGY TO MAINTAIN COMPETITIVENESS BY REDUCING COST

By

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ABSTRACT

ALUMINUM CAN TECHNOLOGY TO MAINTAIN COMPETITIVENESS BY REDUCING COST

By

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Aluminum cans for beverages are one of the most popular forms of packaging. In 1994, aluminum cans made up 72 percent of the US beverage can market. The aluminum can has advantages, such as light weight, excellent shelf life, good recyclability and inexpensive price. This research focused on the cost reduction of aluminum cans by reduction of weight. The highest fraction of a can production cost is the aluminum metal cost, about 58 percent for a can body and 78 percent for a can end. Reducing the weight of aluminum metal has been a primary approach to reducing the cost of the aluminum can since its introduction. The weight of the can body has been reduced to 54 percent of the weight in the early 1960's.

The can body is divided into three parts in terms of weight reduction: thick wall area, thin wall area and bottom area. The weight of each area can be reduced by different technologies. By using a combination of technologies, it will be possible to reduce the weight by about 11 percent in the near future.

The weight of the can end has been reduced to 45 percent of the weight in the early 1960's. There are two ways to reduce the can end weight, reduce the diameter and the thickness of the can end. Reducing end diameter is more

effective because the reduction of the diameter enables a simultaneous reduction in thickness. Over time, the diameter of the can end has decreased in steps from 211(2-11/16 inches) to 209, 207.5, 206, 204, 202. Further switch to a 200(2 inches) diameter end is expected and will be required to further reduction of the cost.

The total expected weight reduction of aluminum can is around 11 ~ 12 percent. However, the fluctuation of the aluminum metal price may be large enough to counteract the can weight reduction. Therefore, not only weight reduction, but also recycling or increasing the attractiveness of aluminum cans will be important to maintain the competitiveness of aluminum cans in the future.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

Introduction

History of aluminum cans for beverages

The aluminum can is one of the most popular and dominant forms of packaging for beer and soft drinks. The history of the aluminum beverage can began in the mid 1900's, less than 40 years ago. However, steel cans were used earlier for beverages.

In 1909, a Montana brewer made the first inquiry about the use of metal cans for beverages. He wrote to the American Can Company, one of the largest commercial can manufacturers in the USA at that time, asking if cans were available for packaging beer. Of course, beer cans were not commercially available at that time. But researchers at American Can had made experimental cans for beer. The results had been unsuccessful and a negative reply was returned to the brewer(1-1). Twenty years later, Anheuser-Bush and Pabst also tried and failed to develop a metal beer can.(1-2).

One of the primary difficulties was the inability of the cans to withstand the pressure during pasteurization process. Beer cans must withstand an internal pressure as high as 5.6 kg/cm^2 (80 psi), much higher than the pressure used for ordinary food cans (around 2.8 kg/cm^2).

The taste or flavor of beer is very sensitive and changes when exposed to steel. To protect against the effect, manufacturers tried using tin plated steel, but it wasn't satisfactory. There were enough flaws in the coating to negatively affect the taste.

In 1933, the Gotfried Krueger Brewing Company of Newark, NJ, test filled 12-oz[(1)] (355 ml) three-piece steel cans, made by the American Can Company, and delivered them to beer drinkers, along with questionnaires asking their opinions about beer in cans. Two years later, in 1935, the same Gotfried Krueger Brewing Company test-marketed the first commercial beer in cans in Richmond, VA. They had made two significant improvements to the cans. They developed a stronger seam for the three-piece steel can and applied a two-layer coating on the internal surface of tin plated steel with "Vinylite", a vinyl copolymer (synthetic plastic) which was developed by Carbide and Carbon Company to prevent off-flavor(1-3). Later, still in 1935, following the lead of G. Kerueger Brewing and the American Can Company, other breweries and can manufacturers engaged in the canned beer business. In 1935, more than 200 million cans were sold to 23 brewers. They were all of the tin plated steel three-piece type.

The first canned soft drink was test-marketed by Clicquout Club in 1936. Coca-Cola test-marketed 474 ml (16 oz) and 947 ml (32 oz) cans in 1941, but postponed the launch of canned soft drinks because of the metal shortage during the war (1-4).

The history of the D&I aluminum can (drawing and ironing can) was started by Jakob Keller in Switzerland during World War II. At that time, Switzerland was almost totally cut off from imports and ran short of tin plated steel

(1) Since the term 12-oz occurs many times as a descriptive term, the metric equivalent will not be expressed.

to make cans. However, Switzerland had aluminum available. Jakob Keller, a consulting engineer in Zurich, Switzerland, proposed using aluminum to make cans instead of tin plated steel, but few people believed it would be possible because aluminum didn't seem to have enough strength and was very expensive when compared to steel (1-5). Keller was issued the first D&I patents in 1944 and 1947. He used a horizontal press to make cans. The process formed a circle of aluminum sheet into a shallow cup and then stretched the cup by using 2 or 3 ironing dies. He discovered that the ironing die required a sharp edge profile to effectively thin down the walls of the aluminum cups. At that time, Keller was using soft tempered pure aluminum instead of a work hardened aluminum alloy (1-5). Switzerland used the drawn-redrawn cans for packaging condensed milk during World War II. The D&I process was suited to making pressurized cans, but beer in cans was not imaginable in Europe at that time. After the end of World War II, the attraction of the aluminum can faded when tin plated steel again became available.

At that time, Alcan had an office in Zurich and supported Keller's work. Sometime later, Alcan established a can laboratory in a research center in England where they installed a Keller D&I press and an impact extrusion press. They promoted the potential benefits of aluminum cans to companies in the US, and several of the companies started to research aluminum cans as a result. Among them were Coors, Kaiser and Reynolds. Kaiser and Coors worked in parallel. Kaiser pursued the D&I process and Coors worked with the impact extrusion process(1-5).

In the 1950s, Coors was still a regional brewery, distributing lager to eleven western states and attempting to expand into other markets. Coors was less devoted to bottles and more committed to cans than other brewers. In spite of all the advances in can making over the years, the beer can was still an imperfect container. Beer was sometimes exposed to steel which caused the beer to cloud and gave it a metallic taste. In addition, the three-piece steel cans available at that time were of indifferent quality with a tendency to leak through the body seam and the top and bottom lid seams. Coors initiated research to develop better beer cans to solve these problems because cans were the brewery's single largest expense (1-6). Coors established a company called Aluminum International in conjunction with Beatrice Foods and Bronsten. They bought impact extrusion equipment from Germany and supplementary equipment from Italy and set up an impact extrusion can line (1-7). Coors and Aluminum International made aluminum cans for Primo, small Hawaiian brewery. They test-marketed in 1958. This was the first use of commercial aluminum cans for beverages. The Coors aluminum can, which debuted in January 1959, was a 7-ounce impact extruded beer can. It went on the market nearly 24 years after the first steel cans for beer had been introduced to the world(1-8). The impact extrusion method was never suitable to be scaled up to full-size cans. The process was too slow and it required the use of pure aluminum, which was soft and had difficulty holding its shape and withstanding the internal pressure after being filled with beer. To compensate for these defects, impacte extruded cans had to have a relatively thick wall. In fact, that original 7-ounce can weighed more than a modern 474 ml (16-ounce) can (1-8). The impact extrusion process produced a side wall of uniform thickness from the bottom of the wall to the top flange. The thickness of the can wall was determined by the thickness of the can flange to which a lid (a can end) was seamed after the can was filled. The can's side wall didn't need to be as thick to withstand the internal pressure, so there was unnecessary metal on the can wall and it was less economical. After recognizing the shortcomings of their process, Coors began looking for an alternate can manufacturing process.

Kaiser Aluminum set up a can development center in Chicago in 1956 and concentrated on the D&I process. The big advantage of the D&I process was that it allowed control of the distribution of metal along the side wall of a can. The neck and bottom side wall areas could be thicker than the middle portion of the side wall. Kaiser used an aluminum-magnesium alloy, 3004-O, with soft temper instead of pure aluminum(1-9). The 3004 alloy is still one of the standard materials for aluminum can manufacturing. The alloy was stronger than pure aluminum, so cans could be lighter in weight without losing their shape or strength to withstand the internal pressure and the axial load during seaming. A pilot scale can line was set up at the Kaiser Wanatah facility in Indiana. However, the major can makers, who were still committed to tin plated steel cans, opposed Kaiser's aluminum can development. They threatened Kaiser Steel with cancellation of all tin plate orders. Kaiser followed their "suggestion" and terminated development work on the aluminum can. Several members of the development team promptly moved to other companies which were still interested in aluminum can manufacturing. Some of the former Kaiser employees took their expertise to the Reynolds Metals

Company, which became the first commercial producer of 12-ounce aluminum D&I cans in 1964 (1-10).

Reynolds also started their development effort with the extrusion process. After the former Kaiser researchers joined the company, Reynolds changed the direction of their efforts. They built D&I presses and set up a pilot line at their equipment center. They made 12-ounce beer cans from 3004 half hardened sheet in 1964 (1-11). The cans were not necked down at that time. This was the first 12-ounce aluminum two piece can with 211 diameter (2 11/16 inches diameter, about 68 mm) and it became an industry standard size for beverages.

Meanwhile, Coors replaced the impact extruders on their 207 ml (7-ounce) aluminum can line with Kaiser D&I presses. In 1966, they set up an 11-ounce line in a new can plant (1-12). At that time, Reynolds had already introduced the 12-ounce aluminum can for beer and it had become the industry standard size. Therefore, Coors also had to again convert their equipment to adopt the 12-ounce size. These circumstances still left Coors with a non-standard can which had a different height and diameter than the industry standard which was a 12-oz can with a 211 diameter. Since Coors used the aluminum cans to package their own beer, there was no problem with this difference and they continued to use the non-standard 12-ounce cans.

Soon after the major can manufacturers entered the aluminum two piece can business, the industry initiated an ongoing program of developments to reduce costs because aluminum is a relatively expensive packaging material. The efforts focused on weight reduction and improvement of can production efficiencies.

There were few changes which increased costs until recently. One was the introduction of “Stay-on-tab” which was introduced to reduce the littering of tabs. The “Stay-on-tab” was developed by the Reynolds Metals Company in response to complaints from the public about tab littering, but it also increased the can weight and cost. Other than that example, most of the developments were aimed at cost reduction. Manufacturers reduced the can side wall thickness, bottom thickness and end thickness. They changed the bottom shapes to get higher inner pressure resistance and reduced end diameter to save material. Initially, the end diameter, denoted the 211 end, was same diameter as the can body. End diameters were reduced in steps from 211 to 209, 207.5, 206, 204 then 202. Currently, 204 ends are used for beer and 202 ends are used for soft drinks in the US.

In 1994, 106 billion aluminum cans were used in the US. Canned beers held 60.8% of the total beer market and canned soft drinks held 53.7 % of the total soft drink market(1-13). Aluminum cans are clearly the dominant form of packaging for beverages.

The largest portion of the cost of an aluminum can has continued to be the aluminum metal. Fluctuation of aluminum prices directly affects the cost of cans. The price of aluminum metal started to increase in 1994, causing the price of cans to increase. As a result of the price increases, the competitive position of aluminum cans has been declining in comparison to other containers such as glass and PET bottles. As a result, can manufacturers are again emphasizing further efforts at cost reduction.

Aluminum beverage can market in the USA

Metal cans, the second largest sector of the packaging industry following corrugated paper packaging, represent over 18 percent of the package market in terms of sales dollars, as shown in Figure 1-1. Aluminum cans are used primarily as containers for food, especially beverages. The overall rigid food and beverage container industry, including metal cans, glass bottles, jars, plastic containers and paperboard cartons, had an average growth rate of 3.3 % annually between 1988 and 1993. Each segment of the rigid food and beverage container industry has competed to win a larger share of the market. Table 1-1 shows the size of each market segment and the rate of increase for the last 13 years. The table shows that metal cans have historically held the largest share of the food and beverage container market, but have been losing market share since the middle 1980's. The rate of increase in the sales of metal container market is relatively low compared to the rate of increase in plastic packaging.

Figure 1-2 shows a breakdown of the can market. Aluminum cans have had a dominant share of the beverage can market and consumption has been growing steadily since the late 1970's. Steel cans have lost market share in the beverage market but still are dominant in the food can market.

Table 1-2 shows US can shipments by sector for the last four years. In 1994, beverage cans made up 74 percent of the US can market and food cans represented 26 percent. The can market grew steadily during these four years. The increase in aluminum can shipments during these years was mainly the result of the increase in use for beverages, especially soft drinks. Shipments of cans for beer have been declining.

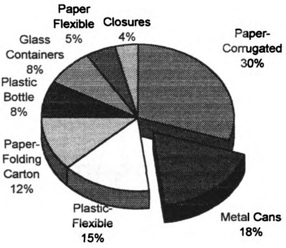


Figure 1-1 US Packaging Market in 1993
source: Industry, Goldman Sachs estimates (1-14).

Table 1-1 The US food and beverage container market

Year	Metal			Glass			Plastic			Paperboard		
	Sales $ millions	Change %	Share %	Sales $ millions	Change %	Share %	Sales $ millions	Change %	Share %	Sales $ millions	Change %	Share %
1982	9483	-	55.2	586	-	25.4	1507	-	8.3	2502	-	13.8
1983	9322	-1.7	52.8	4073	-11.2	23.1	1692	12.3	9.6	2582	3.2	14.6
1984	9890	6.1	53.1	4104	0.8	22.0	1928	13.9	10.3	2717	5.2	14.6
1985	9989	1.0	52.2	4224	2.9	22.1	2165	12.3	11.3	2770	2.0	14.5
1986	10103	1.1	50.5	4545	7.6	22.7	2592	19.7	12.9	2781	0.4	13.9
1987	10179	0.8	50.2	4321	-4.9	21.3	2947	13.7	14.5	2815	1.2	13.9
1988	10189	0.1	49.1	4396	1.7	21.2	3217	9.2	15.5	2955	5.0	14.2
1989	10352	1.6	47.9	4564	3.8	21.1	3507	9.0	16.2	3191	8.0	14.8
1990	11218	8.4	49.1	4657	2.0	20.4	3764	7.3	16.5	3219	0.9	14.1
1991	11544	2.9	48.8	4671	0.3	19.8	4103	9.0	17.4	3323	3.2	14.1
1992	10897	-5.6	46.3	4690	0.4	19.9	4527	10.3	19.2	3407	2.5	14.5
1993	10873	-0.2	44.6	4903	4.5	20.1	5037	11.3	20.7	3556	4.4	14.6
1994	11041	1.5	44.0	4995	1.9	19.9	5452	8.2	21.7	3628	2.0	14.4

Source: Can Manufactures Institute
US Department of Commerce
International Trade Administration
Business Trend Analysts (1-16)

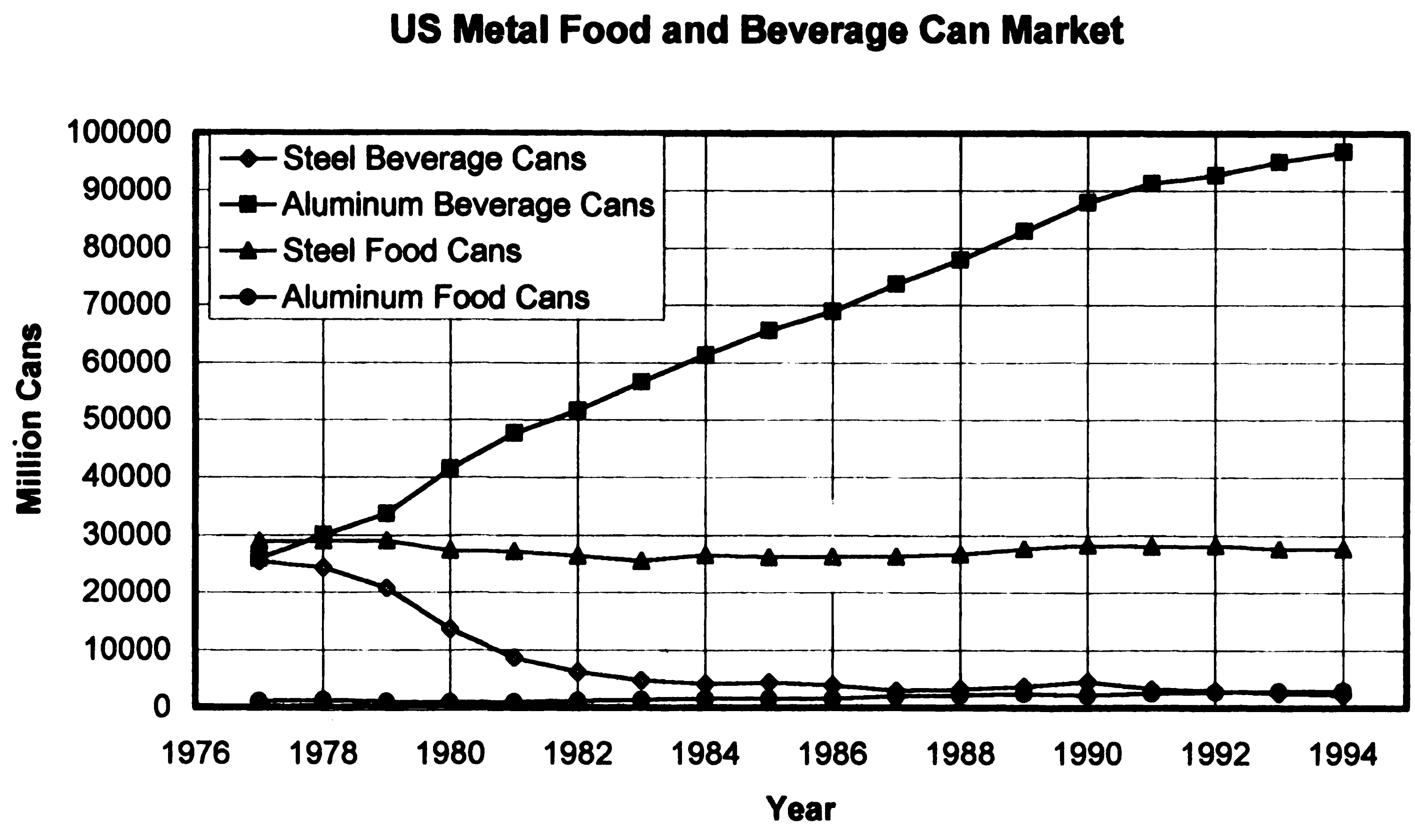


Figure 1-2 US Metal Food and Beverage Can Market
source: Can Manufacturers Institute; Business Trend Analysts (1-16)

Table 1-2 US can shipments by sector (Millions)

Year	1991	1992	1993	1994
Total Shipments	**129248**	**130685**	**132148**	**139254**
Beverage (total)	**94651**	**95678**	**97605**	**103119**
	(73.2%)	(73.2%)	(73.9%)	(74.1%)
Soft drinks	55821	57449	60074	66325
Beer	38830	38229	37531	36794
Others (total)	**34597**	**35007**	**34543**	**36153**
	(26.8%)	(26.8%)	(26.1%)	(26.0%)
Vegetables/juices	9982	9466	8739	9738
Pet foods	6061	6703	7000	7389
Other foods	5618	5568	5603	6063
Fruit/fruit juices	3192	3000	3009	2463
Aerosols	2653	2843	2785	2914
Seafood	1788	1907	1880	1906
Meat and poultry	1296	1435	1452	1782
Baby foods	1101	1116	1134	1040
Dairy products	1051	1008	1015	1010
Material used				
Steel	35276	35211	34156	33240
	(27.3%)	(26.9%)	(25.8%)	(23.9%)
Aluminum	93972	95469	97992	106014
	(72.7%)	(73.1%)	(74.2%)	(76.1%)

Source: Can Manufacturers Institute

Cans for soft drinks and beer

As shown in Table 1-2, about three-quarters of all cans are used for beverages, soft drinks and beer. Both beverages contain carbon dioxide which produces pressure in the cans. Carbonated products are suitable for aluminum cans. The aluminum can wall is too thin to provide enough strength to support normal stacking loads. The pressure is needed to support loads. Therefore, if aluminum cans are used for beverages without carbon dioxide, liquid nitrogen is usually used to create the needed internal pressure.

The shipments of cans for soft drinks increased steadily until recently, but the market for beer in cans has been declining for several years. Figure 1-3 shows the trends in beverage can shipments for the last six years. Can shipments increased during each of these six years, except for 1995. In 1995, total can shipments decreased in comparison to the previous year. However, the simple statistics do not reveal the entire story. In early 1994, the price of aluminum increased sharply. Alert can users bought extra supplies of cans before the increase in the price of aluminum affected can prices and stockpiled them for later use. This pre-buy in 1994 was estimated to be as high as 3.2 billion cans (1-15). If the data are adjusted to compensate for this pre-buying, aluminum can usage for beverages increased in each of the last six years.

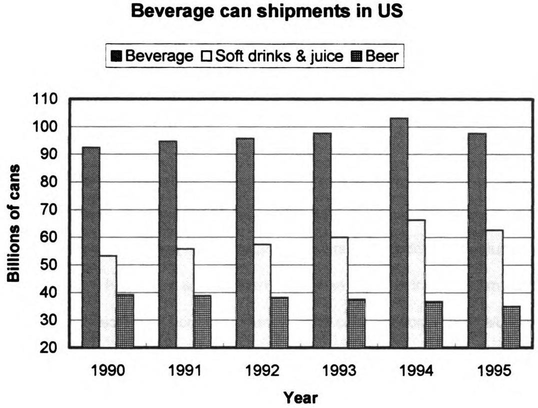


Figure 1-3 Beverage can shipments in US
Source: MPC Chronicle, March 1996 (1-15)

Table 1-3 shows the share of the beer market held by each type of container. Aluminum cans were used for 60.4 percent of US beer production (including draft). The second position was held by glass bottles. Table 1-4 shows the relative amounts of each type of container used for soft drinks. The aluminum can share was 53.7 percent of the US soft drink container market in 1994. The PET (Polyethylene terephthalate) share of the soft drink market has been increasing rapidly for the last four years. The increase in the PET bottle shipments for soft drinks is a direct threat to the aluminum can industry. Figure 1-4 shows the metal can market and the non-returnable glass bottle market for beer. As shown in Table 1-3, about 99 percent of the metal cans for used for beer are aluminum. Therefore, the graph if Figure 1-4 can be regarded as that of "aluminum cans vs. glass bottles for beer containers". The aluminum can has been gradually losing its market and the glass bottle has been gradually gaining. Figure 1-5 shows the metal can market and PET bottle market for soft drinks. As shown in Table 1-3, about 95 percent of the metal containers for soft drinks are aluminum cans. Therefore, Figure 1-5 shows nearly the same trend as that of "aluminum cans vs. PET in soft drink container market". The consumption of both aluminum cans and PET bottles have been increasing for several years, but the rate of increase in PET bottle shipments is higher than the rate for aluminum cans.

Table 1-3 US Beer container market share
(12-Ounce Equivalent, %)

Year	1987	1988	1989	1990	1991	1992	1993	1994
Can (100%)	62.7	63.0	62.9	63.6	64.2	62.4	61.2	60.8
Aluminum (%)		100.0	99.7	99.0	99.0	99.0	98.9	
Steel (%)		0.0	0.3	1.0	1.0	1.0	1.1	
Glass (100%)	25.5	25.6	26.0	25.3	24.5	26.0	27.5	27.8
NR Glass (%)	97.2	97.2	97.1	97.8	97.3	97.3	96.8	97.2
R Glass (%)	2.8	2.8	2.9	2.2	2.7	2.7	3.2	2.8
Draft	11.8	11.4	11.1	11.1	11.3	11.6	11.3	11.4

Source: Beverage Industry; Business Trend Analysts
Can Manufacturers Institute; Business Trend Analysts (1-16)

Table 1-4 US soft drinks container market share
(12-Ounce Equivalent, %)

Year	1989	1990	1991	1992	1993	1994
Can (100%)	47.9	50.4	51.3	52.5	53.2	53.7
Aluminum (%)	92.5	92.3	95.0	95.5	96.5	
Steel (%)	7.5	7.7	5.0	4.5	3.5	
PET	30.6	30.2	31.9	35.0	37.9	39.3
Glass (100%)	21.5	19.3	16.8	12.5	9.0	7.0
NR Glass (%)	59.5	67.4	69.0	74.4	80.0	84.3
R Glass (%)	40.5	32.6	31.0	25.6	20.0	15.7

Source: Beverage Industry; Business Trend Analysts
Can Manufacturers Institute; Business Trend Analysts (1-16)

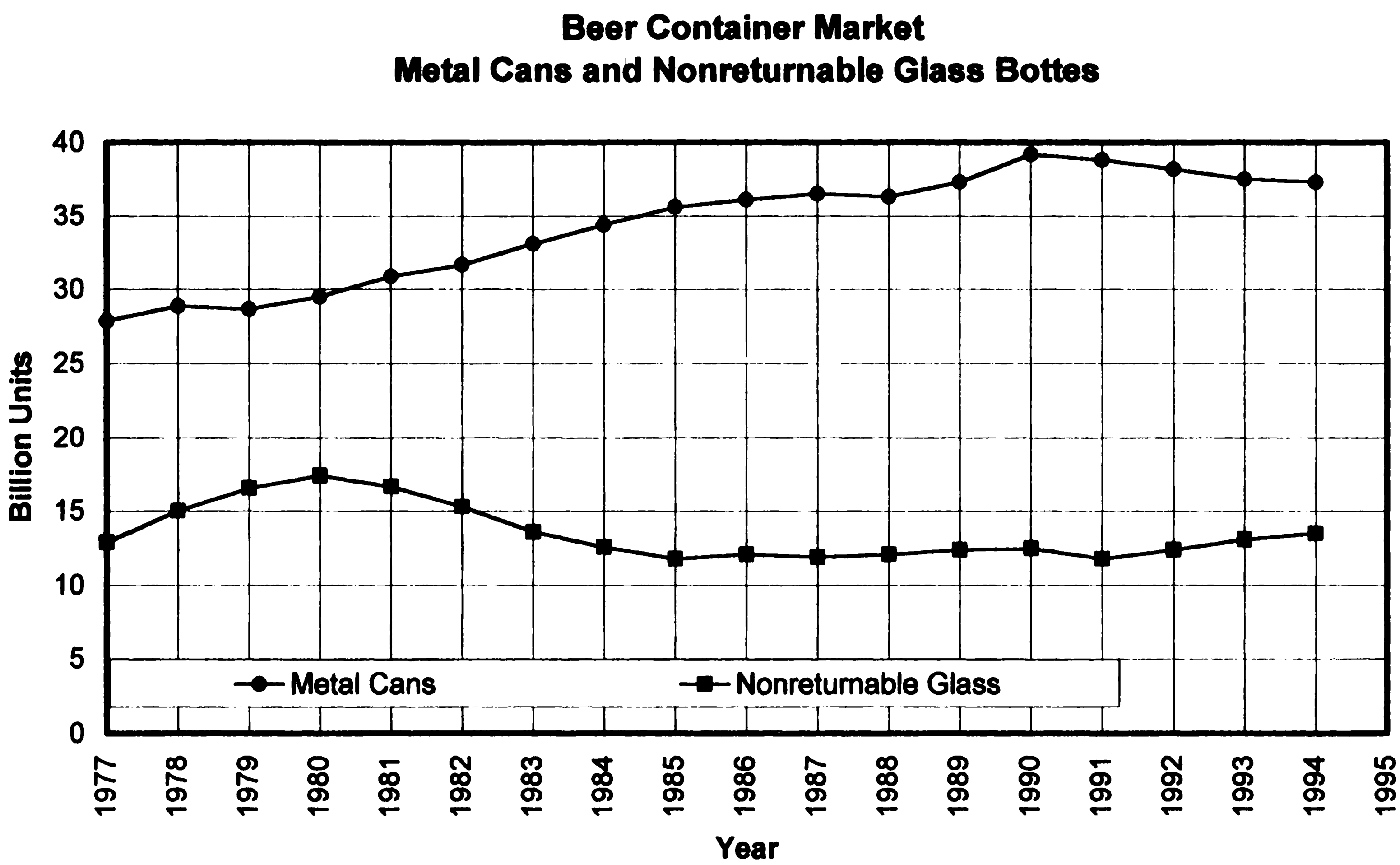


Figure 1-4 Metal cans and non-returnable glass market trend for beers in US
Source: Business Trend Analysts, Inc. (1-16)

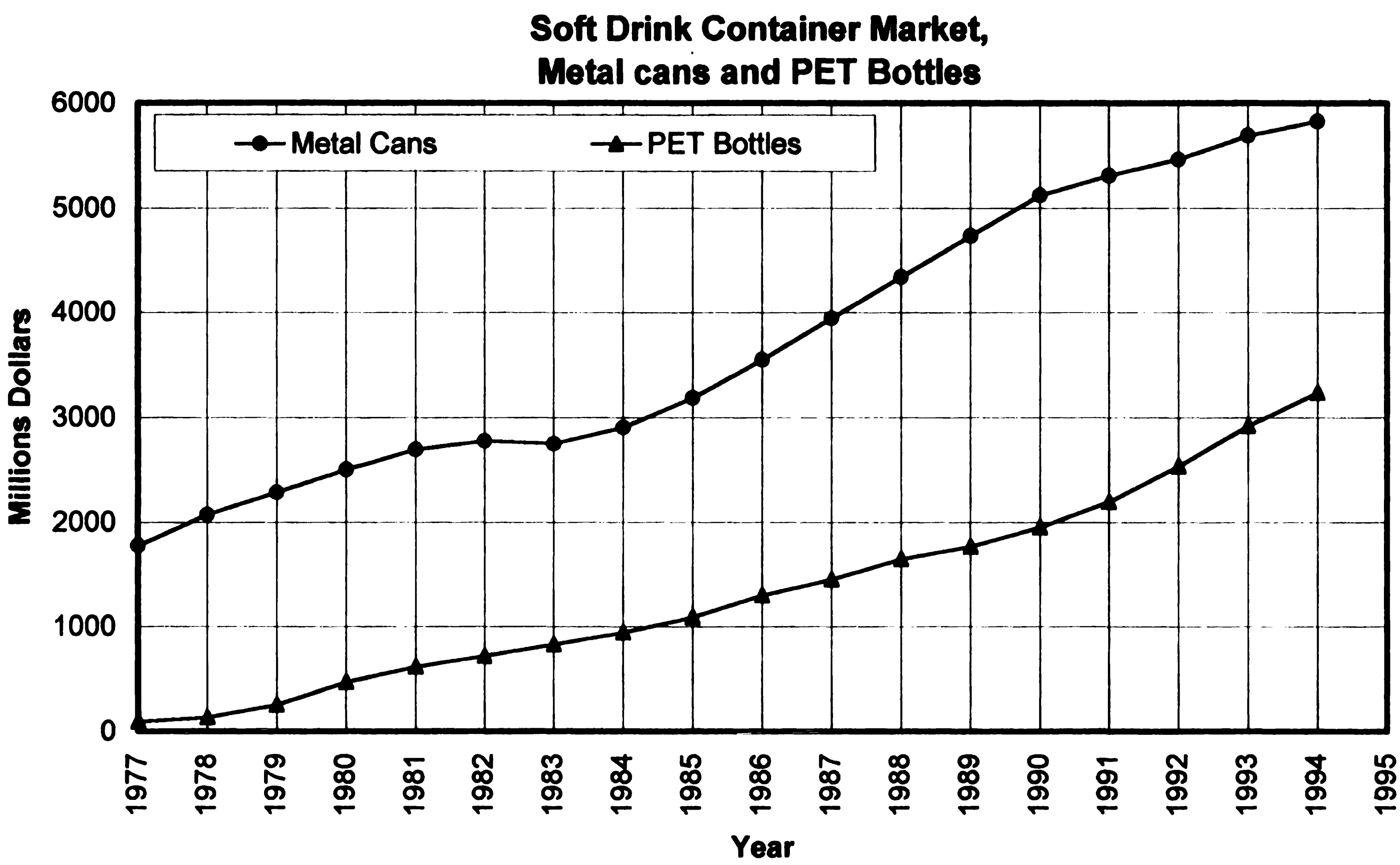


Figure 1-5 Metal cans and PET bottles market trend for soft drinks in US
Source: Business Trend Analysts, Inc. (1-16)

Objective

The goal of the research reported in this thesis was to evaluate and discuss the factors that have affected the ability of aluminum cans to gain and maintain competitiveness, especially the cost competitiveness gained by lightweighting. The specific objectives are:

1. To survey trends in the aluminum beverage can market.
2. To identify and evaluate methods which have been used to reduce the costs of aluminum beverage cans.
3. To identify and evaluate techniques used to reduce the weight of aluminum cans.
4. To determine the effect of the price of aluminum metal on the price of aluminum beverage cans.
5. To predict the potential for future weight reduction and cost saving for aluminum cans.

In this paper, the discussion of can manufacturing production costs other than the cost of the aluminum metal have been excluded. Those costs are specific to each manufacturer. The discussion is focused on the general trends affecting the can itself, especially can weights in the past and the future.

Chapter 2

Literature review

The technical literature about aluminum beverage cans is limited. Most of the available papers have been written by researchers or engineers in the aluminum can industry or the aluminum metal industry. Some of them have been written to emphasize the advantage of certain products, machines or technologies over those of other companies. The aluminum can companies occasionally publish papers about forming processes using their machines to emphasize their advantages. Recently, there has been a trend toward reducing can end diameters, so papers about can body neck reducing processes have been published.

The following section describes and discusses recent papers about aluminum cans.

Aluminum can body

Smith (1995) discussed and summarized some of the major formability barriers that limit lightweighting aluminum cans(2-1). He presented a summary of the history of aluminum can body lightweighting and classified aluminum can body lightweighting into three categories, thick wall thickness, thin wall thickness and dome gauge (can body bottom thickness). He discussed smooth die-necking technology which enables neck reduction from 211 diameter to 204 or 202 diameter. Suggested number of steps of die-necking, diameter reduction for each step, and thick wall thickness were shown in the paper. Required steps for neck reduction with 0.167 mm of thick wall from 211 to 204 was nine steps and that for 202 is twelve steps. He further showed that if a thinner thick wall is used for necking, more necking process steps will be needed.

Smith pointed out that the end diameter for soft drink cans has been reduced to 202 and that a new can bottom design with a smaller base diameter is required as a result to facilitate stackability. However, cans with smaller base diameters tend to have wrinkles on the bottom. To solve this problem, he recommended the introduction of a process using a pre-formed cup.

Aluminum can end

Biondich(1989) discussed the shell forming process for can ends (2-2). He introduced a newly designed reformed shell, and discussed advantages of reforming the shell, the process used for reforming, and computer simulation of the reformed shell. The advantage of the reformed end is that reforming process can make a deep countersink without thinning the panel wall. The conventional shell process uses one-step forming. If the countersink is deepened to increase pressure resistance, thinning occurs at the panel wall due to restrained metal flow and it is difficult to get satisfactory pressure resistance. The reforming process uses two steps to make the countersink without creating tensile stress at the panel wall. Therefore, no thinning will occur. Biondich emphasized cost saving of reformed shells due to lightweighting.

Aluminum can forming process

Lee and Payne (1993) introduced and discussed the spin-flow-necking process which is used to reduce the neck diameter of cans (2-3). The process was first introduced on a production line in 1992. Advantages of the spin-flow process were discussed. Spin-flow necking is a tension process which is tolerant of thick wall variation and defects in the can body. Thick wall variations of ± 0.013 mm were acceptable, whereas normal acceptances were ± 0.008 mm. The tension process allows the manufacturer to use a shorter can height. The can height for a 204/211 12-ounce spin-flow-necked can is around 123.19 mm, about 0.38 mm shorter than a spin-necked can and 0.64 mm shorter than a smooth die-necked can. Those characteristics enable further lightweighting and saving cost. The paper showed the detailed function of each die and included an explanation of the spin-flow process.

Jowitt (1993) discussed can bottom reforming (2-4). In the continuing efforts to reduce the weight of the aluminum two-piece can, the ability to create an improved bottom profile is becoming an important factor. He described a process that allowed further lightweighting of can bodies by reforming can bottoms. The process of reforming bottoms involves reshaping the stand area of the can bottoms. A smaller stand area radius increases inner pressure resistance of the bottom. However, conventional bottom forming processes have limitations in their ability to shape the stand area and the radius. The bottom reforming process adds another opportunity to form the bottom and gives further freedom in shaping the bottoms. In the paper, the effect of the reforming was 16.5 percent increase in buckling pressure of the bottom. The target of the reforming was reducing aluminum sheet thickness for can bodies from 0.300 mm (0.0118 inches) to 0.280 mm (0.0110 inches) with same bottom shape and material. This reduction in thickness lead to a seven percent material saving.

Jowitt (1995) discussed forming processes, including spin-necking, for metal can manufacturing (2-5). The spin-necking process for necking a 211 can body into a 202 neck was described as follows.

Die-necking ➡ Spin pre-necking ➡ Spin-necking and Flanging

Two or three steps of die-necking were required for first stage, depending on material and wall thickness. It was emphasized that a significant number of can manufacturing lines in Europe and in the US were running the spin-necking machine.

Other information sources

Most of the papers on can manufacturing, including those discussed in the preceding section, were written for specialists in the aluminum can industry. Therefore, the contents are about specialized technological topics.

Most of the research and technological development has been done by aluminum metal or aluminum can companies instead of public organizations or institutes. Competition has been an issue. This situation has decreased the number of the papers about aluminum cans.

Other information sources include industrial or trade magazines. There are three magazines which emphasize information about the can industry: "The Canmaker", "The Canner" and "Cantech International".

The Canner (1995) (2-6) discussed price trends of beverage cans. In 1994, aluminum cans were the lowest cost choice with a price of $56.56 per 1000 cans, compared to $60.77 for steel cans, $71.01 for PET containers and $95.99 for glass bottles. However, since the beginning of 1994, the price of aluminum metal has been increasing. By 1995, aluminum cans had lost price competitiveness with a price $70.58 per 1000 cans, compared to steel cans at $65.58, PET bottles at $70.6, and glass bottles at $95.22. The Canmaker (1995) (2-7), discussed prices for aluminum metal aluminum cans. They predicted that the price of aluminum can sheet would rise by 60 percent during 1995.

Cantech International (1995) (2-8), discussed the availablility of alternate containers, since aluminum cans had lost price competitiveness, such as glass bottles for beer or PET bottles for soft drinks.

The articles in magazines usually discussed economic situations or trends and showed little specific explanation of factors related to can manufacturing technologies with data. Magazines tend to pick up the topics currently popular. Therefore, the contents tend to focus on the temporary topics and narrow areas and sometime they are too vague to understand the whole trend because of lack of technological explanation and specific data.

So far, no comprehensive papers are known about aluminum can cost reduction which include the trends of the recent technologies for lightweighting, aluminum metal cost and aluminum prices.

This paper focuses on a comprehensive study of aluminum beverage can technological trends, including lightweighting for cost saving.

Chapter 3

Aluminum can manufacturing

The Aluminum can manufacturing process

An aluminum two piece can literally consists of two parts, a can end (lid) and a can body. The process of can end manufacturing is similar to the process used for other types of cans, such as food cans. Aluminum can ends are often used on steel two-piece or three-piece cans. Aluminum can bodies are made by a unique process not used for other cans, such as steel three-piece cans or two-piece draw-and-redraw steel cans. The ironing process is used for making the aluminum can body. The process and equipment for can body and can end manufacturing are shown in Figure 3-1 and 3-2.

Aluminum can Body Line

The aluminum can body manufacturing line is relatively large and long compared to lines for other containers or can ends. The capital investment for a new can body line may be as high as 30~40 million dollars today. To reduce the cost of the cans, line speeds have been increased. In the early 1980's, a common speed was around 800 cans per minute. Manufacturing rates in excess of 1600 cans per minute are common today. The function of each step in the process of making a can is explained in the following section.

1. Lubricator

   Add lubricant to aluminum sheet for drawing.

2. Cupper (Cupping Press)

   Blank the aluminum sheet into circles and draw them into shallow cups.

3. Bodymaker (Redraw and Ironing Press)

   Redraw the cups and iron into cans. The can body wall and bottom is formed in this process.

4. Trimmer

   Trim the top of the cans to the specified height.

5. Washer

   Wash the cans to remove lubricant and contamination and apply surface treatment to improve corrosion resistance and adhesion of coating, then dry the cans.

6. Base Coater

   Apply white coating to improve the quality of color.

   This process is for special design products.

7. Base Coater Oven

   Dry and cure the base coating.

8. Decorator

   Print and apply varnish on the cans.

9. Decorator Oven

   Dry and cure the ink and varnish.

10. Inside Spray

    Spray coating on the inside of the cans.

11. Inside Spray Oven

    Dry and cure the inside coating.

12. Necker & Flanger

    Form neck and flange.

13. Tester

    Check the cans for pin holes or cracks.

14. Palletizer

    Stack the cans on pallets.

The process step which differentiates the manufacturing of aluminum two-piece cans from other two-piece cans, is the ironing process in the bodymakers, the redraw and ironing presses. The aluminum sheet is first drawn into shallow cups in the cupper. The cups are then redrawn and ironed into cans by the bodymakers. The drawing process is illustrated in Figures 3-3 and 3-7.

Drawing and ironing forming is limited in the amount of forming reduction that can be done. The limit is called the limiting draw ratio or limiting ironing ratio. Drawing the aluminum circle into a cup with the same diameter as the can and ironing the deep cup into a can exceed the limits of the limiting draw ratio and the limiting ironing ratio, respectively. Therefore, each forming operation needs to be done in multiple steps. The drawing process is usually done twice to reduce the aluminum circle into a can and the ironing process is usually done three times in one pass of a punch to achieve the desired can wall thickness. Figure 3-8 shows the die set for the redrawing and ironing process. Figures 3-9 and 3-10 show the ironing forming of the can body. The bottom of the can body is also formed by the bodymaker at the end stroke of the punch as shown in Figure 3-11.

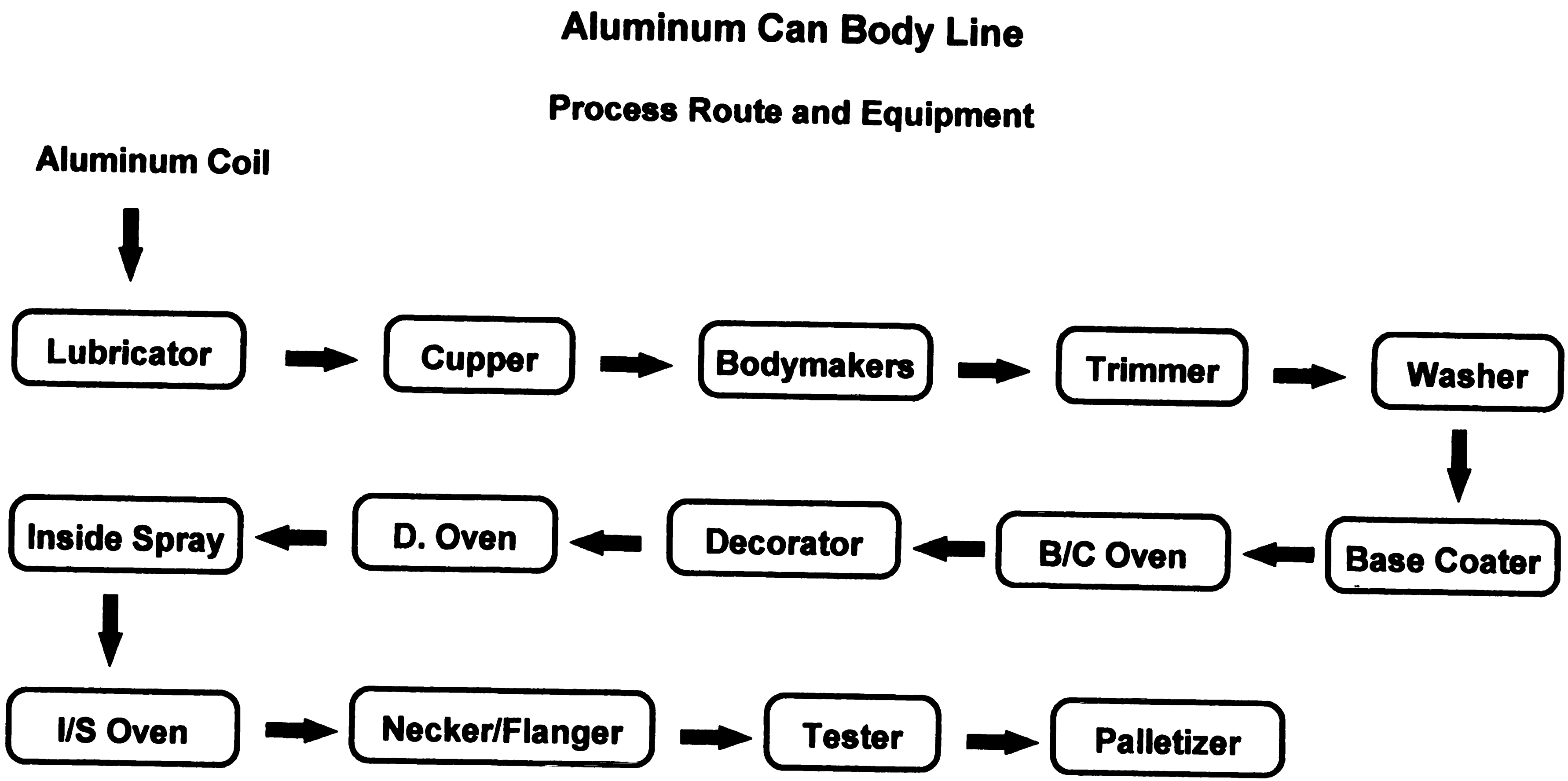


Figure 3-1 Typical aluminum can body line

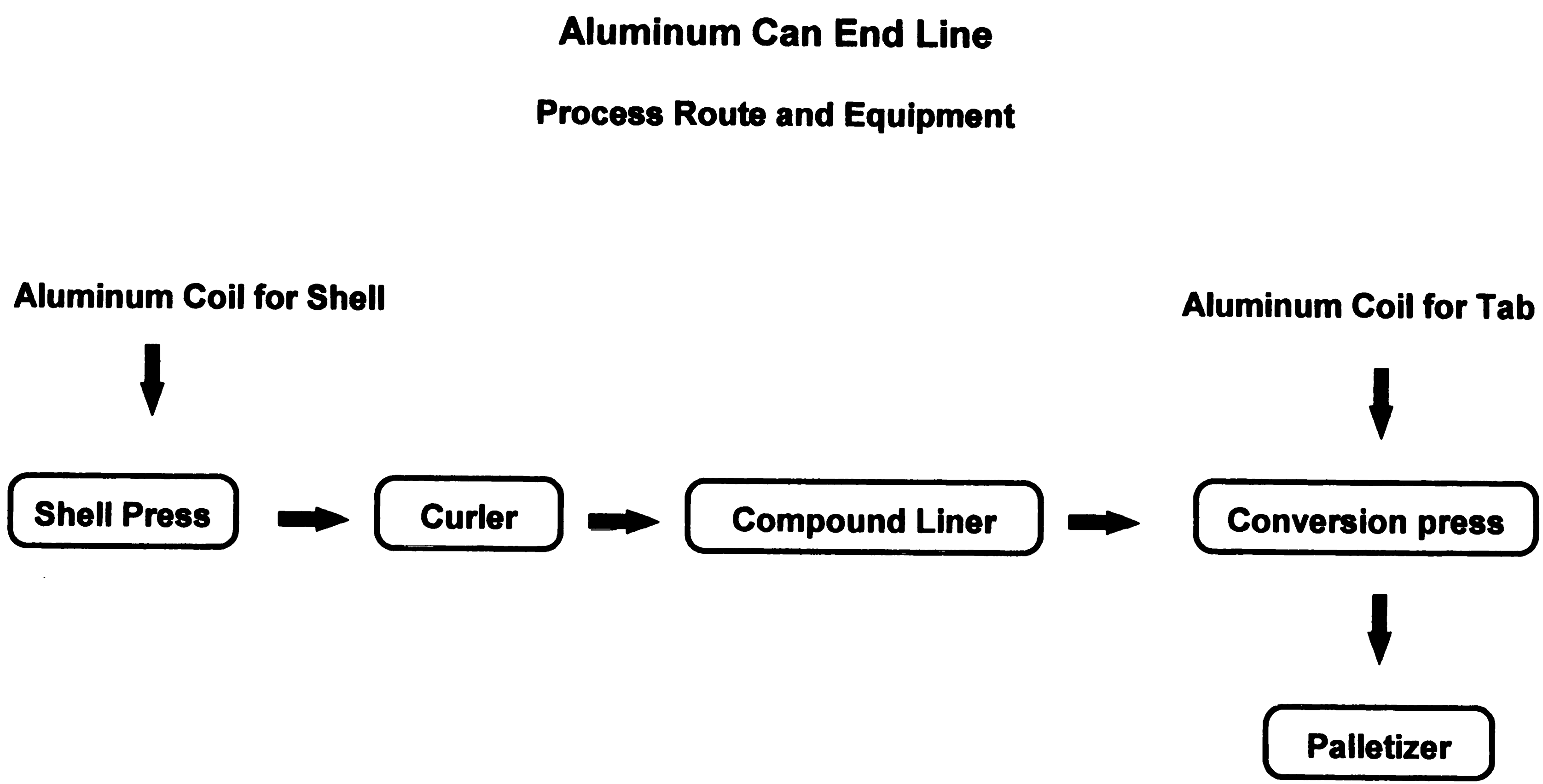


Figure 3-2 Typical aluminum can end line

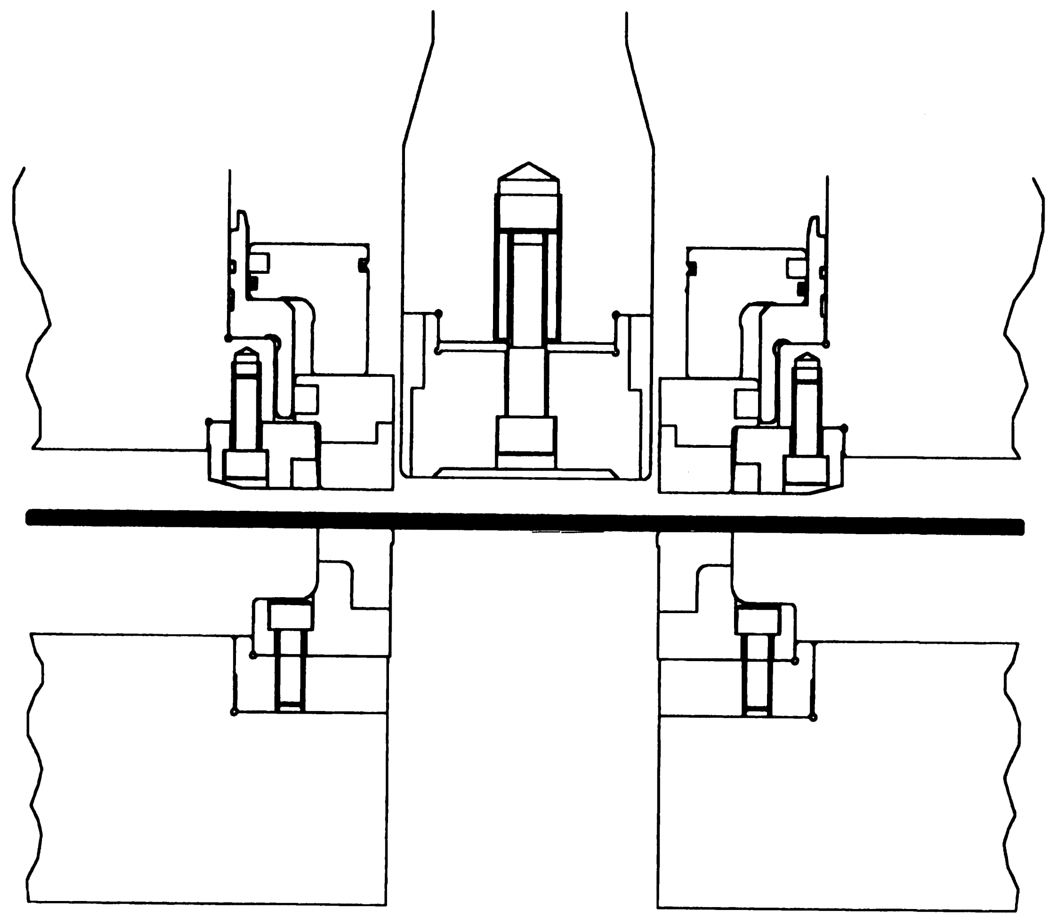


Figure 3-3 Drawing process (1)

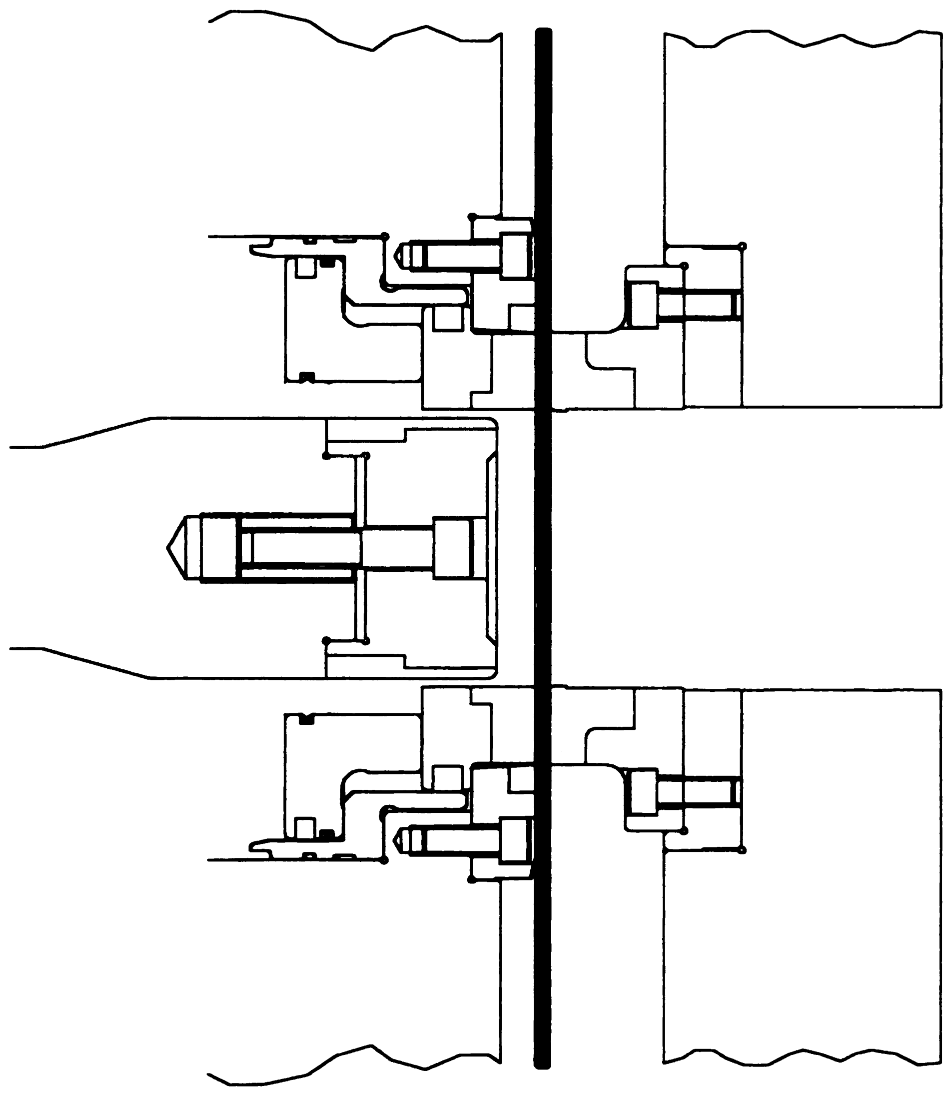


Figure 3-4 Drawing process (2)

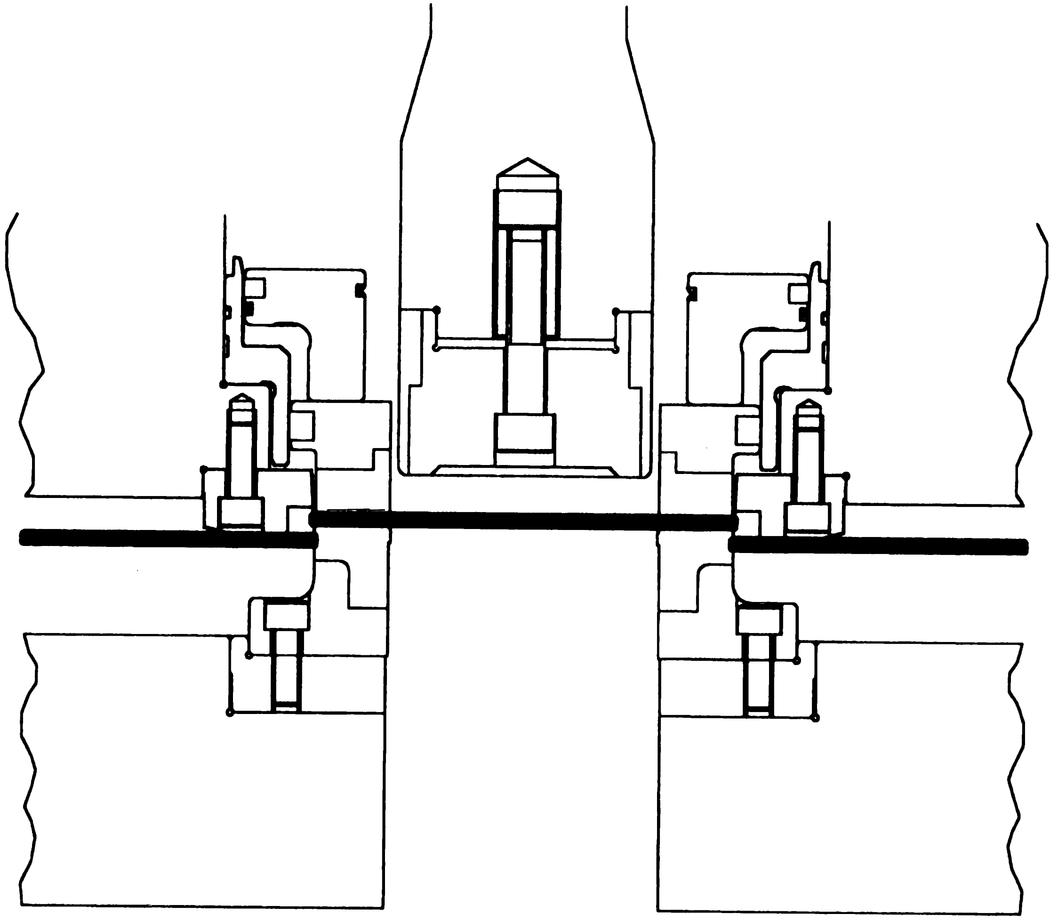


Figure 3-5 Drawing process (3)

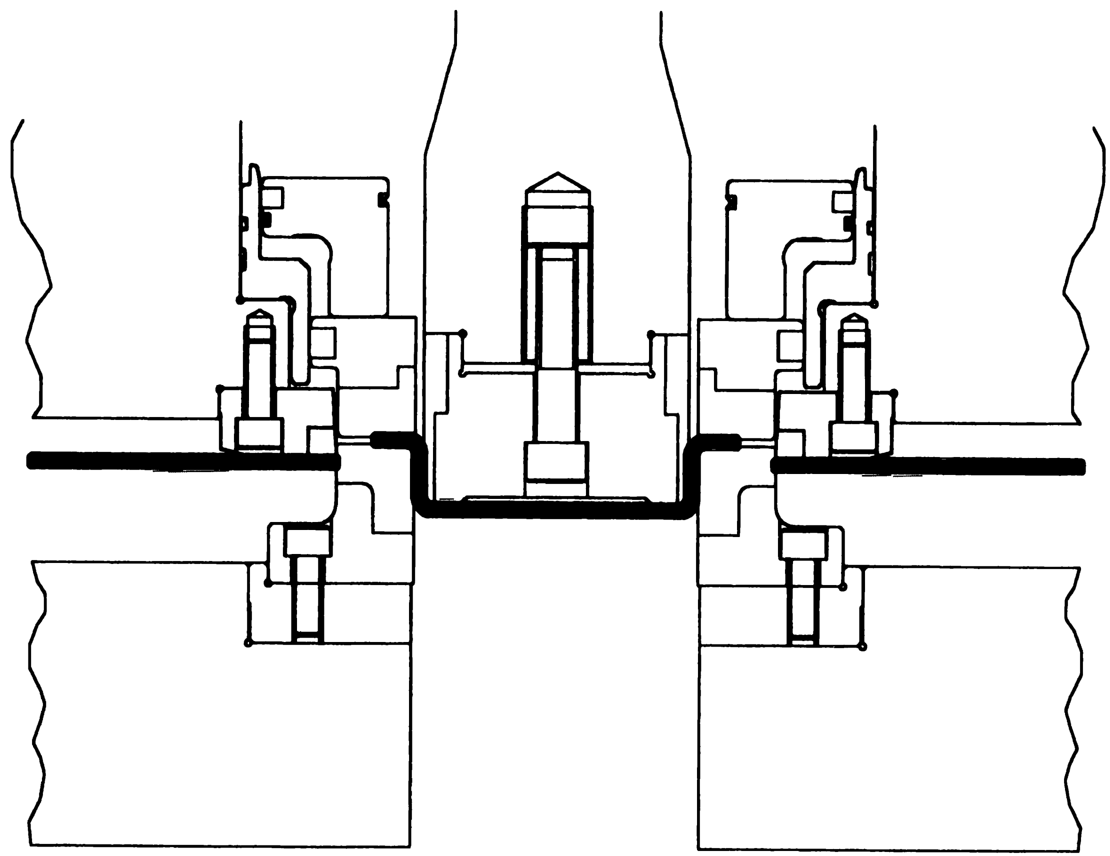


Figure 3-6 Drawing process (4)

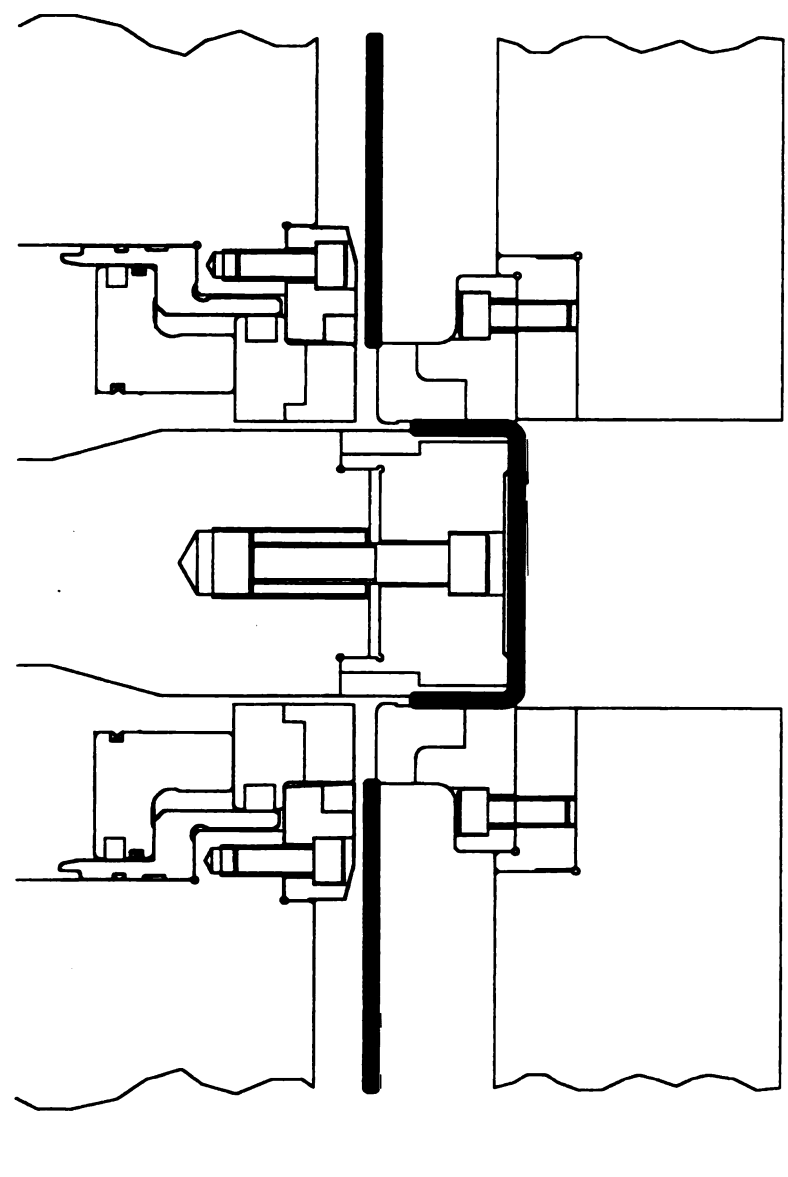


Figure 3-7 Drawing process (5)

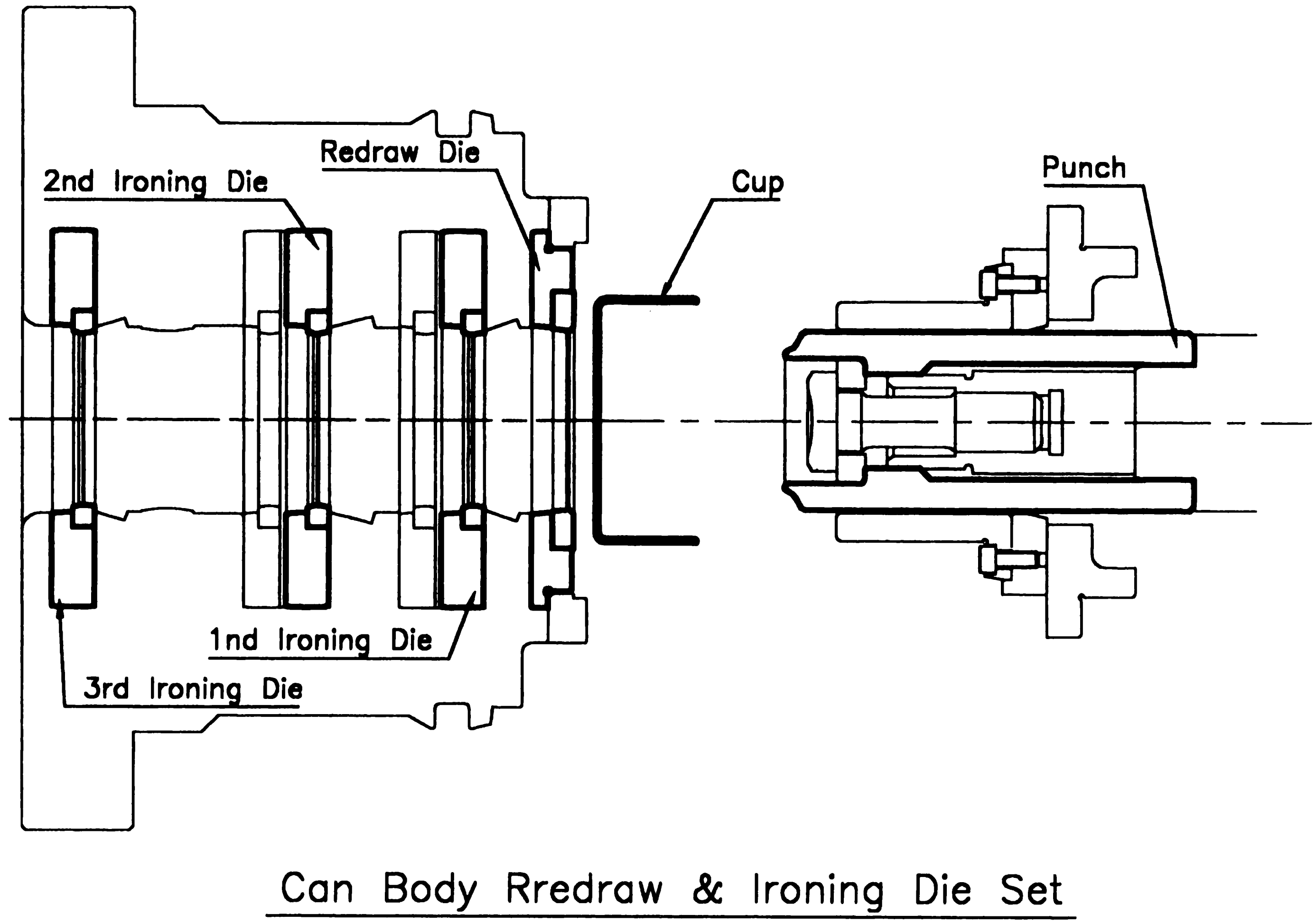


Figure 3-8 Redrawing and Ironing Die Set

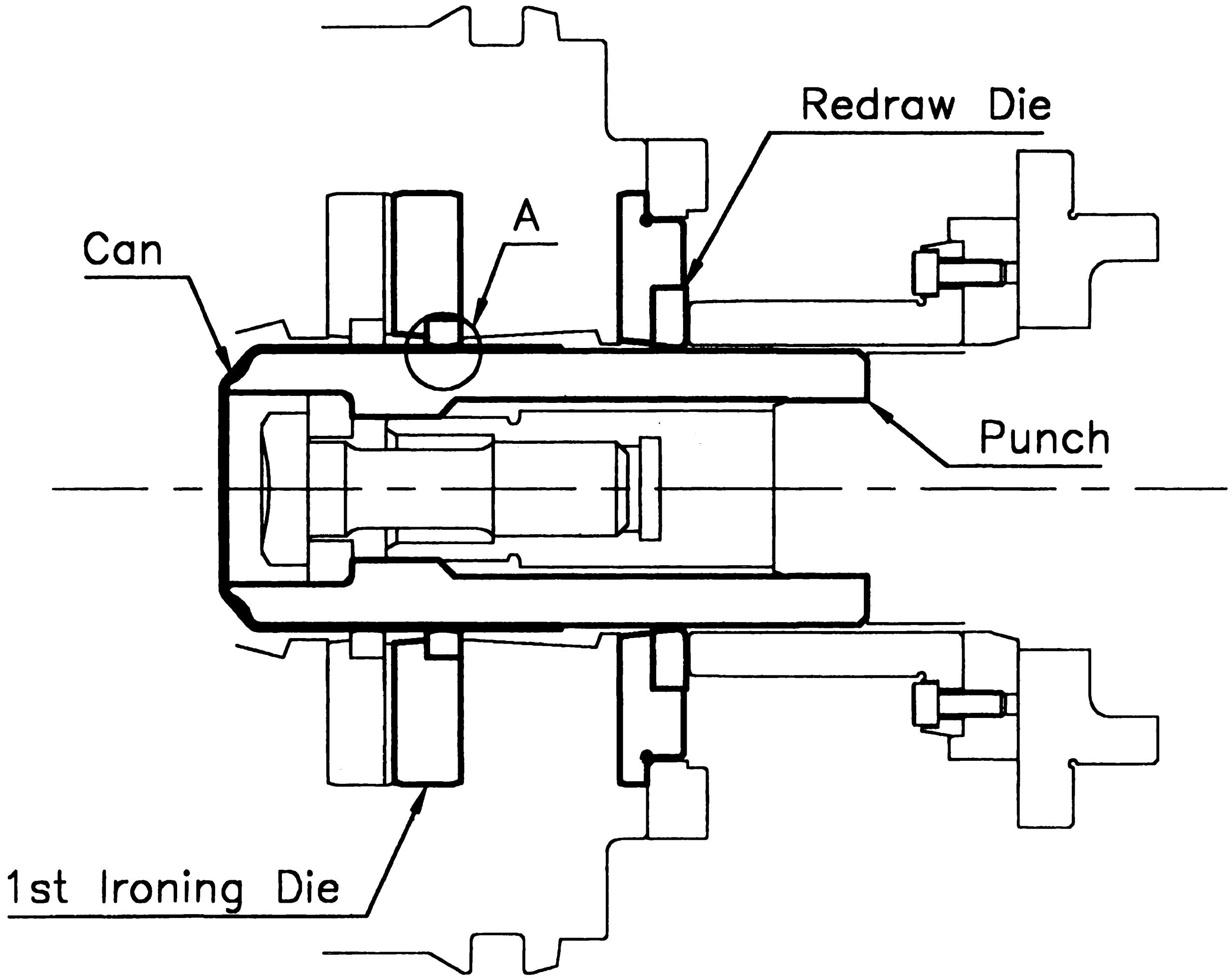


Figure 3-9 Ironing Process

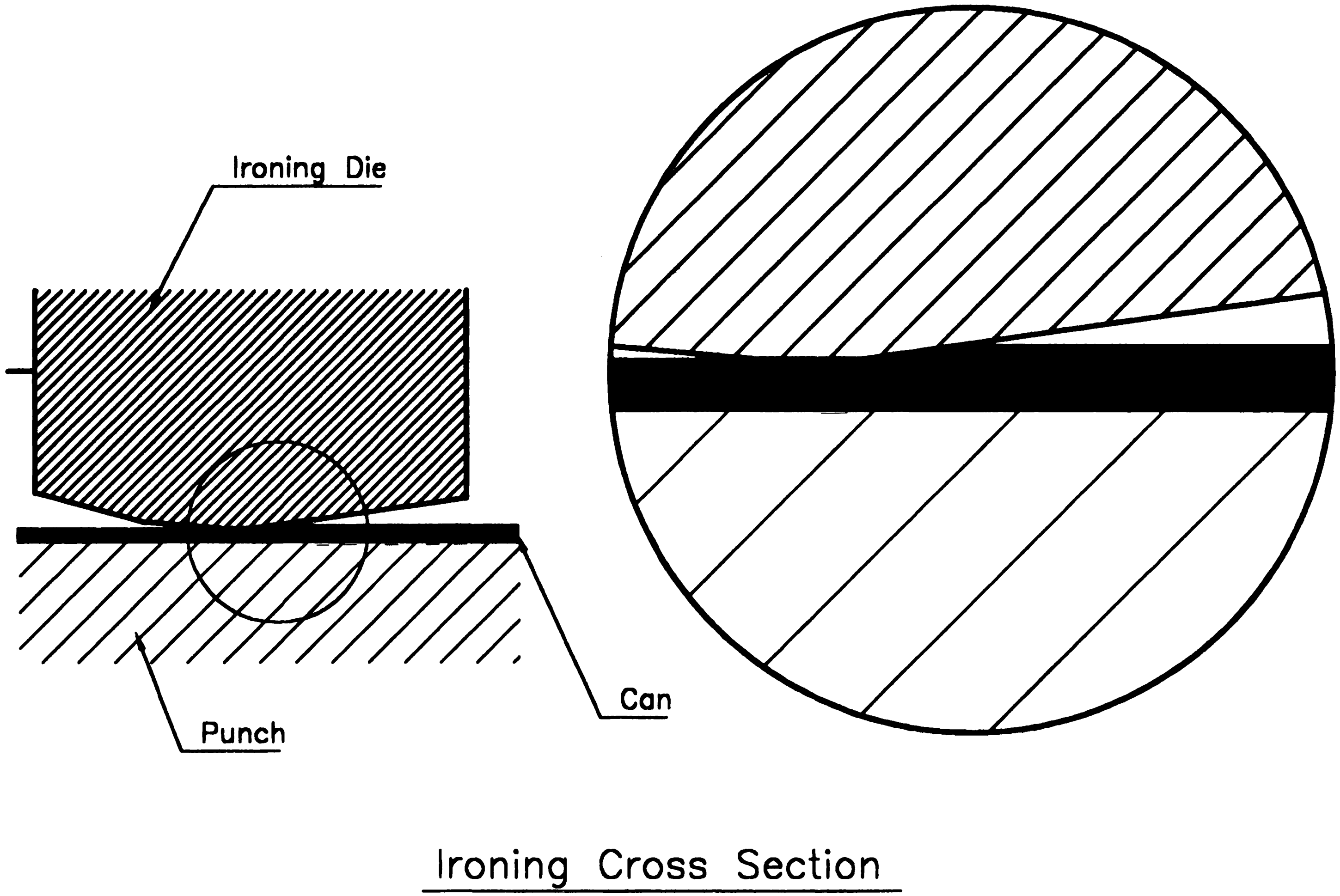


Figure 3-10 Ironing Process, Magnified picture

Aluminum Can End Line

Figure 3-2 shows the process of a typical can end manufacturing line. Each process is explained below.

1. Shell press

   Blank out circles from aluminum sheet and make shells for ends.

2. Curler

   Roll the edge of the shell with a curl shape which is important for seaming the end to a can body.

3. Compound Liner

   Spray rubber based material onto the curl of the shells to improve sealability.

4. Conversion Press

   Make tabs and convert the shells into ends by combining with the tabs.

5. Palletizer

   Stack the ends into paper bags and load them onto pallets.

Can end lines are relatively small and short when compared to can body lines. There are no painting or coating processes and no bulky washing machines and drying ovens. The speed of can end lines has increased dramatically in recent years. A new type of shell press can produce 4,500 ends per minute and a new type of conversion press can produce 1800 ends per minute for a three-lane system and 2400 ends per minute for a four-lane system. Two conversion presses are usually required for one shell press. Since there is no washer, decorator or coating process, other equipment, such as a water treatment and distribution system, a central coating storage system, a fuel storage system for dryers, an exhaust treatment system, etc., is not required.

Can ends are packaged in a cylindrical paper bags which are stacked on pallets. Ends are not bulky like can bodies and are relatively flat. Therefore, the transportation cost is relatively lower than for the can body. Because of these differences, the can end lines are not necessarily located in the same plant as the can body lines.

Aluminum metal for beverage cans

When aluminum cans were first manufactured, by the impact extrusion process, they were made of pure aluminum metal. However, the use of stronger aluminum alloys in the drawing and ironing process has enabled manufacturers to make cans lighter and less expensive. The aluminum alloys used for can bodies are different than those used for the can ends. The alloy for tabs is also often different from the can ends.

Aluminum alloys for can bodies

The aluminum metals currently used for can bodies are aluminum-manganese alloys 3004 or 3104. The most common is 3004. The nominal composition of these alloys is shown in Table 3-1.

Table 3-1 Nominal Composition of Aluminum Alloy for can body Weight (%)

Element	Si	Fe	Cu	Mn	Mg	Al
3004	0.18	0.45	0.13	1.10	1.10	Remaining
3104	0.18	0.45	0.15	0.9	1.25	Remaining

Source: Reynolds Metals Company

Mg, Mn and Cu, the major strengthening elements, are controlled carefully to achieve desired strength. However, the rate of strain caused by cold milling and the heat treatments after cold milling or during cold milling are also important factors determining strength.

The first aluminum alloy used for beverage can bodies was 3004-O. It had relatively low strength, so the industry switched to 3004-H32 which predominated until the late 1960's. In 1970's, there was another switch to a stronger alloy, 3004-H19, which is still the most common aluminum alloy for beverage cans (3-1). The symbols have the following meanings.

O : Annealed

> The alloy loses the strength produced by strain hardening, so it is weaker than a strain hardened alloy, such as a cold rolled alloy, but is also easier to form.

H1 : Strain hardened

> The alloy is made stronger by strain hardening than when originally cast. The strain hardening is usually caused by cold rolling.

H3 : Strain hardened and stabilized

> After strain hardening, a heat treatment is applied to stabilize the alloy. This process increases the elongation and decreases strength slightly.

The number after the H1 or H3, as in H32 and H19, shows strength.

The can body manufacturing line includes several process, such as the base coater oven, decorator oven and inside spray oven, which take place at temperatures about 200° C. The aluminum alloy receives a certain amount of heat treatment in those processes which changes its mechanical properties. Table 3-2 shows the mechanical properties of aluminum alloy both before and after the heat treatments.

Table 3-2 Mechanical properties of aluminum alloys for can bodies

	As rolled Properties			After baking, 20 min at 204°C		
Alloy	Tensile Strength (kg/mm^2)	Proof Stress (kg/mm^2)	Elongation (%)	Tensile Strength (kg/mm^2)	Proof Stress (kg/mm^2)	Elongation (%)
3004	30.8	28.0	5.0	27.8	25.9	5.0
3104	31.5	28.1	5.0	29.4	26.6	5.0

Source: Aluminum Company of America (3-2)

Aluminum alloys for can ends

Aluminum alloys for can ends are strengthened by adding magnesium. Other elements such as manganese and chromium are also added in minor amounts to fine tune strength and formability. The Table 3-3 shows the guaranteed chemical composition of ALCOA (Aluminum Company of America) aluminum end sheets.

Table 3-3 Guaranteed chemical composition of aluminum alloys for can ends

Alloy	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Other	Al
5182	0.20	0.35	0.15	0.20~ 0.50	4.0~ 5.0	0.10	0.25	0.10	0.15	remaining
5082	0.20	0.35	0.15	0.15	6.0~ 5.0	0.15	0.25	0.10	0.15	remaining
5052	0.25	0.40	0.10	0.10	2.2~ 2.8	0.15~ 0.35	0.10	-	0.15	remaining

Composition in percent maximum unless shown as a range

Source: "Aluminum Easy Open End Manual", ALCOA (3-3)

Alloy 5182-H19 is the most common selection for beverage can ends, but some can manufactures use 5182-H42. Alloy 5082, developed for rivet-easy-open beer can ends, is composed of aluminum plus 5.5 percent magnesium. It used to be common for beverage can ends, but the improved alloy 5182, which has higher strength, has mostly replaced it. Another alloy, 5052, has lower strength than 5082 or 5182 but has good formability. It is used to make ends for unpressurized cans for oil and dry food products. Table 3-4 shows the mechanical properties of these alloys.

Table 3-4 Mechanical Properties of aluminum alloys for can ends

	Tensile Strength (kg/mm^2)	Proof Stress (kg/mm^2)	Elongation (%)
5182-H19	48.2	40.1	4
5082-H19	40.8	39.0	4
5052-H19	33.0	31.6	3

Source: "Aluminum Easy Open End Manual", ALCOA (3-3)

The aluminum alloys used for tabs have properties similar to those used for ends. The most popular aluminum alloy for tabs is 5082-H19, but 5042-H19 is also used. The 5042-H19 has similar mechanical properties to those of 5082-H19.

Chapter 4

Lightweighting

To the ordinary consumer, two piece aluminum cans always look the same. It is true that the basic dimensions, the body diameter and the shape, of aluminum cans have not changed significantly. However, can manufacturers have been making efforts to change dimensions to reduce weights and costs ever since the introduction of the aluminum can, over 30 years ago. Table 4-1 shows cost of can bodies of some European can manufacturers.

The cost of the aluminum metal for the usual 12-ounce aluminum can body is the highest fraction of the total production cost, 57.6 percent. The standard can size in Europe is 330ml, a size close to the 12-ounce in the US. Therefore, it is reasonable to assume that the cost of aluminum metal for usual a 12-ounce US can is around 58 percent. The aluminum metal cost of the can end for 12-ounce beverage can is between 73 and 78 percent (4-2). Therefore, it is obvious that reducing the weight of aluminum metal in a can in order to simultaneously reduce costs has been a consistent goal for can manufacturers.

Table 4-1. Aluminum can body cost (206/211 330ml can)

Metal cost		57.6 %
Production cost		42.4 %
	Coating (inks, lacquers)	7.4 %
	Other supplies (lubricant, washer chemicals, etc.)	5.7 %
	Utilities (gas, water, electricity, etc.)	6.2 %
	Labor	9.8 %
	Others (taxes, equipment, building, maintenance, etc.)	13.3 %
Total		100 %

Source: "The Canner" July 1995 (4-1)

Table 4-2. Aluminum end cost (Diameter 206)

Metal cost		78.2 %
Production cost		21.8 %
	Compound	0.6 %
	Labor	5.6 %
	Overhead	15.6 %
Total		100 %

Example data from US companies (4-2)

To reduce costs, can manufacturers have developed technologies to lighten cans. Programs to reduce costs have focused on reducing the weight of metal for more than 30 years. It is not an exaggeration that the history of aluminum can manufacturing is the history of the can light weighting.

Figure 4-1 shows the historical pattern of lightweighting aluminum cans. Weights of both ends and bodies have been reduced. The weight of the end has declined to 45 percent of the weight of the first aluminum can end, and a can body weighs 54 percent as much as it did in the early 1960's (4-3).

Can manufacturers have reduced the metal thickness for can bodies from 0.495mm (0.0195 inches) to 0.292mm (0.0115 inches). Net weight of the can body fell from 17.7g (39 lbs/1000cans) to 11.3g (25 lbs/1000cans) (4- 4).

Research on lightweighting of can bodies and can ends has been pursued separately and will be discussed separately in this paper.

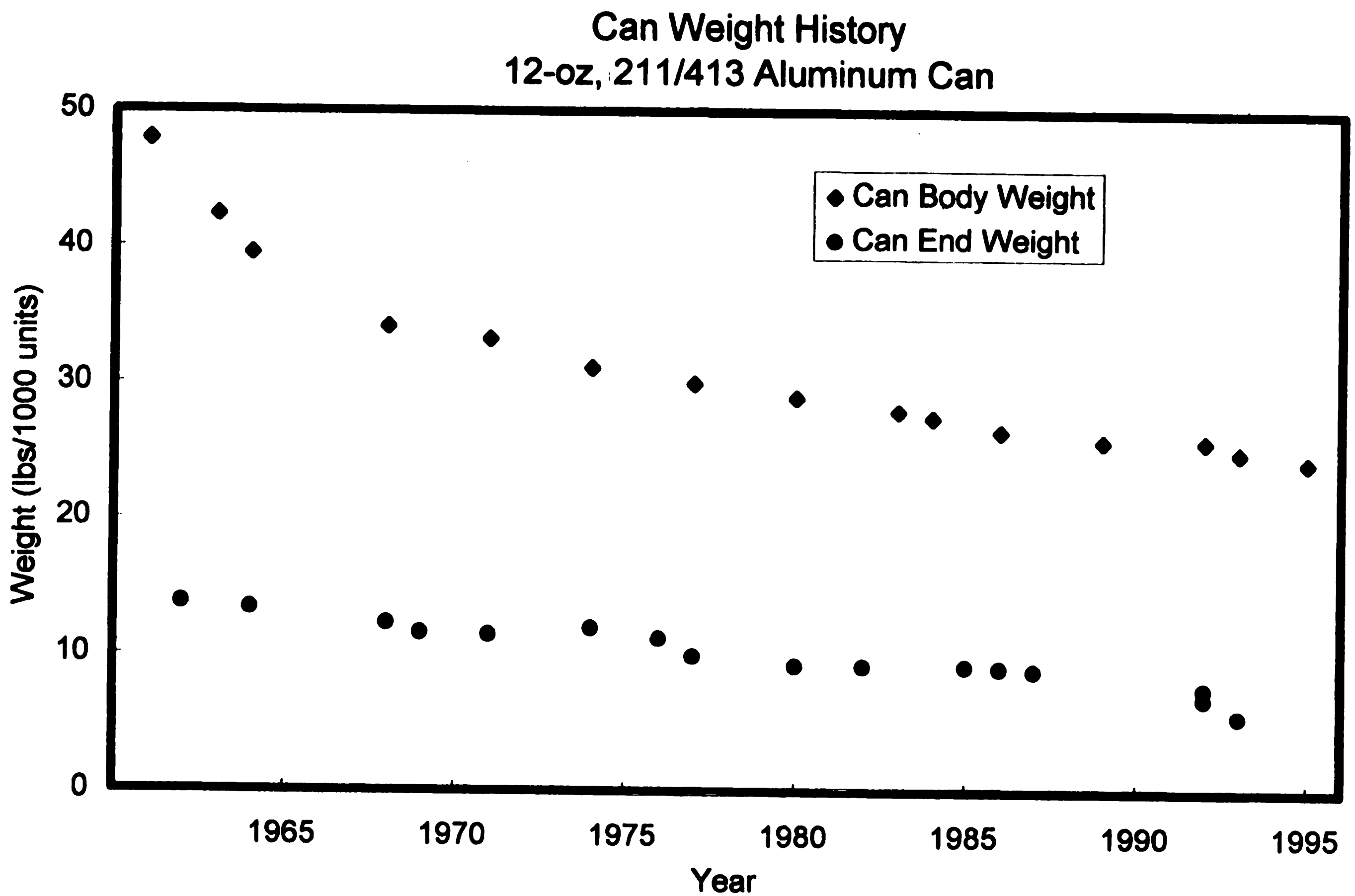


Figure 4-1 Aluminum can weight history (12-ounce can)
Example of aluminum can weight history in the US
Source: Mitsubishi Materials Corp.

Can body lightweighting

Figure 4-2 shows the history of the can body weights over more than 30 years. Lightweighting progress in the first several years, from 1962 to 1968, was relatively rapid. This was the initial improvement of the can technologies in use when aluminum beverage cans were first manufactured. After the initial period, the weight of the can body has been decreased gradually over time, reaching 25pounds/1000 cans in 1995. Recently, however, the weight has been decreased further with a new technology, bottom reforming. By adding an extra forming process in a can line after necking, the thickness of the bottom of the can has been decreased further.

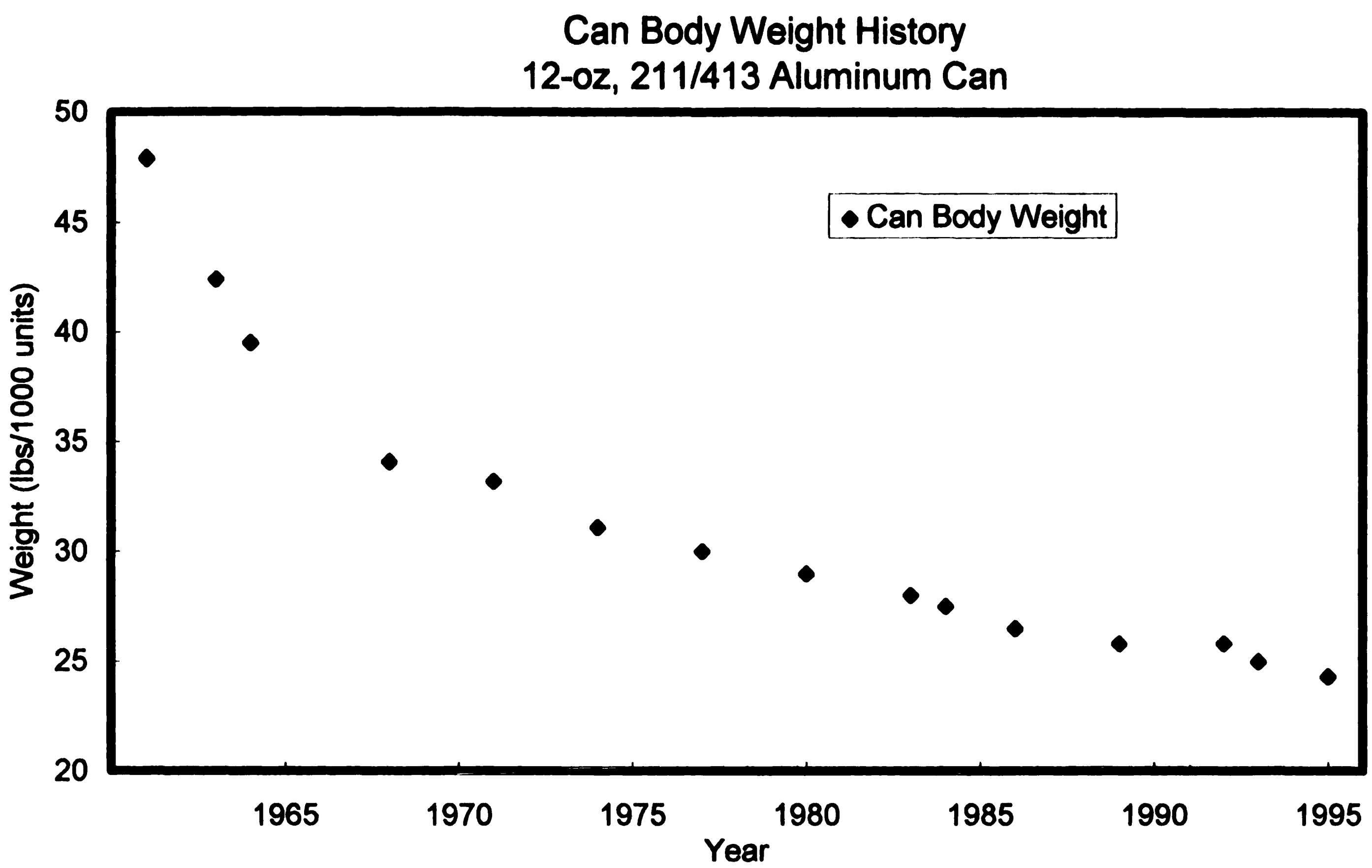


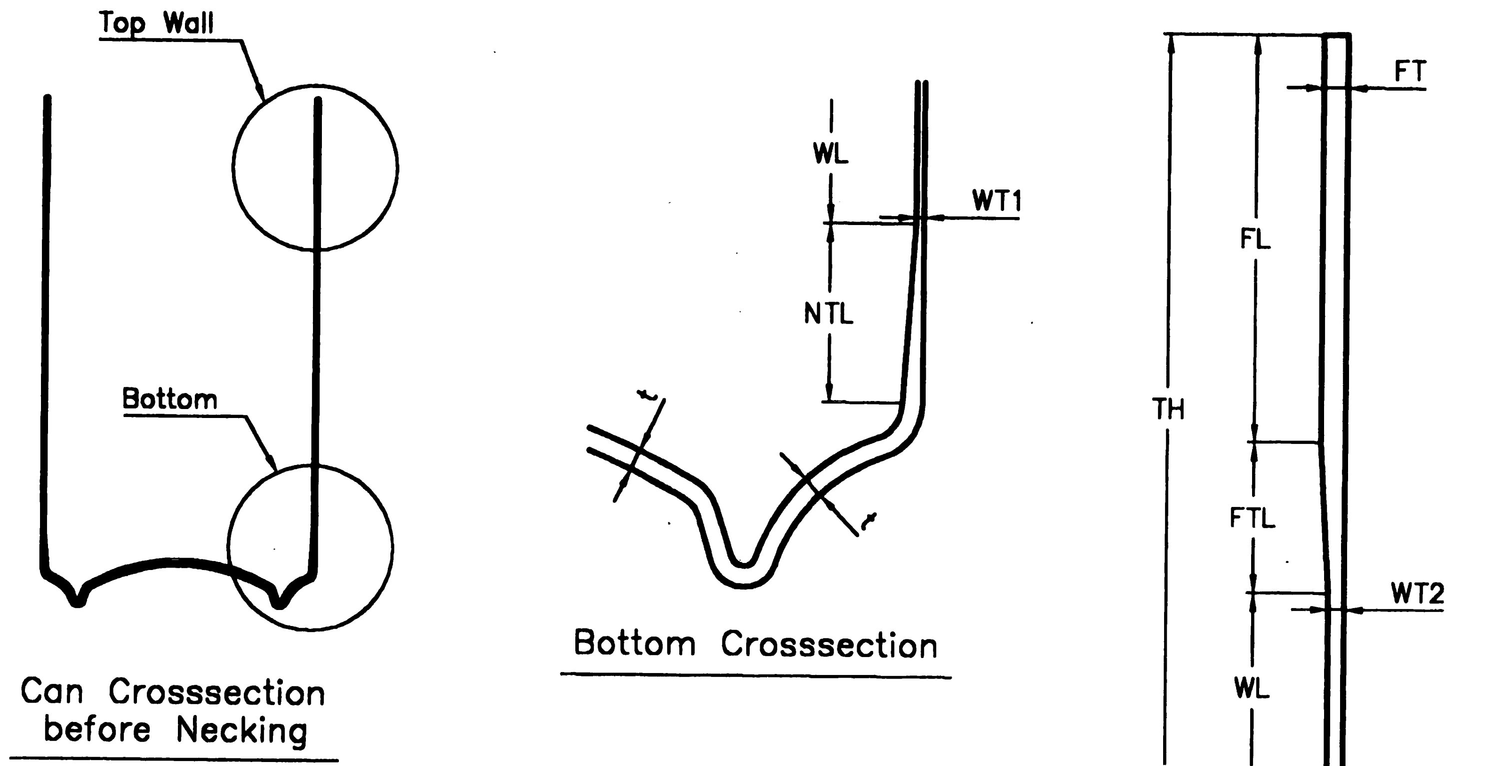
Figure 4-2 Aluminum can body lightweighting history
Example of aluminum can body weight history in the US
Source: Mitsubishi Materials Corp.

Figure 4-3 shows the cross section of a typical aluminum two piece can body. Can manufacturers have developed technologies to reduce the thickness of the can wall including the neck thickness and the thickness of the can bottom. Weight reduction in each of these areas uses significantly different technologies.

Can wall thickness reduction

The aluminum sheet is first drawn to shallow cups with a diameter larger than the cans. The cups are drawn again to the same diameter as the cans. Then, the relatively deep cups with the same diameters as the cans, are stretched. The thickness of the wall of the cups is reduced to the clearance between two dies, the punch and ring-die. This can wall forming process is called the "ironing" and the ring-die is called "ironing die". Usually, to get the wall thin enough, the ironing reduction is done three times on each stroke of the punch, using three ring-dies in one tool pack as shown in Figure 3-4.

The can wall is further classified into two regions, the thin-wall, the middle portion of the can side wall, and the thick-wall, the neck area.



FT: Thick-wall (Neck) thickness
WT1≅WT2 : Thin-wall thickness
t : Bottom thickness

Figure 4-3 Can Cross-sectional Profile

Thin-wall

The thickness of the thin wall, the middle portion of the side wall, is important if the can is to have adequate strength to withstand the hoop stress developed by the internal pressure from carbonated drinks. The hoop stress can be calculated as shown in the following example,

$$\text{Hoop Stress} = \frac{(\text{Internal Pressure}) \times (\text{Can Diameter})}{2 \times (\text{Wall Thickness})}$$

Maximum Internal Pressure : 6.3 kg/cm^2

Can Diameter : 6.64 cm (2.61 inches)

Wall Thickness: 0.0102 cm (0.0040 inches)

The maximum internal pressure was assumed to be 6.3 kg/cm^2, the standard inner pressure resistance required for the beverage can in the US. Thin wall thickness in the US is approximately 0.102 mm.

In the preceding example, the hoop stress was estimated to be 20.5kg/mm^2. This stress is well below the tensile strength of the can wall, about 30 kg/mm^2 (43 kpsi). However, the strength needed to support the axial load when the can body is seamed together with the can end is usually greater than the strength required to support the hoop stress. Therefore, the axial load is used first to determine the required thin-wall thickness.

The thin-wall of the standard 12-ounce aluminum can body has been reduced from 0.165mm (0.0065 inches) in 1965 to 0.107mm (0.0042 inches) in 1990 and is expected to reduced to less than 0.100mm in a few years (4-5). There are several concerns about the thinner thin-wall, such as dent and puncture resistance during distribution and axial load resistance while being seamed with a can end. The processability of the thin wall during the ironing process may also be a problem when the thin wall is reduced even further. Tear-off, the breakage of the side-wall of the can during the ironing process, will occur if the forming force surpasses the strength of the wall.

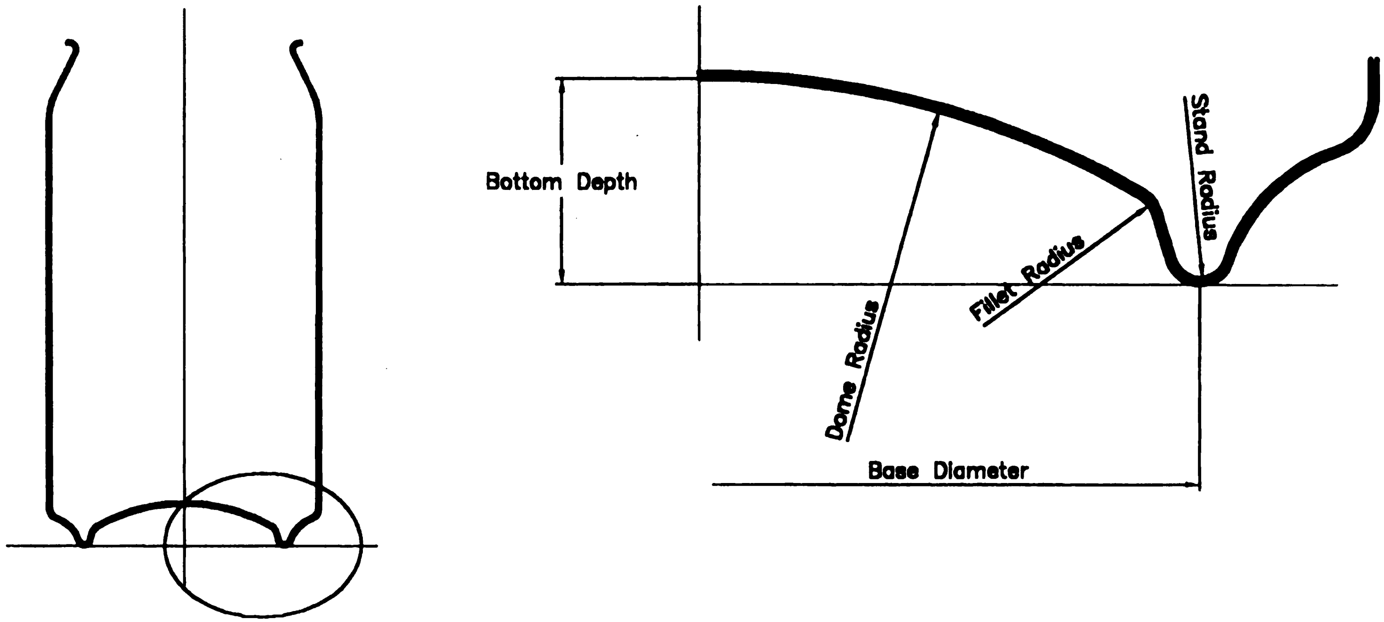
Thick-wall (Neck Wall)

The thick-wall section, sometimes it called the neck wall, is made thicker than the thin-wall section to allow for neck forming. The typical thick wall has been reduced from 0.229mm (0.0090 inches) in 1965 to 0.157mm (0.0062 inches) in 1990 (4-3). In the same time period, neck diameters have been reduced from 211 (two and 11/16 inches, 68 mm) to 206 (two and 6/16 inches, 60mm). Generally it is more difficult to form the neck as the neck diameter reduction increases and the neck thickness gets thinner. However, thinning the neck has proceeded steadily despite the difficulty of neck forming to smaller diameters. Wrinkles are a primary problem when forming the reduced necks with thin thick walls. Wrinkles, sometime called pleats or creases, vary in size and shape. Some are just cosmetic defects with no significant effect on the performance of a can as a beverage container.

However, when there are wrinkles, the danger of imperfect seaming or splitting the flange of necks during the filling operation is a concern for can users.

Bottom thickness

Bottom thickness is important since the bottom of the can body must have enough strength to withstand the inner pressure produced by carbon dioxide or nitrogen, up to 6.3 kg/cm^2 (90 psi) in the US. The bottom should be designed with a shape and thickness which provide enough strength to resist the inner pressure. Stability of the can while being conveyed in a can making line or in a filling line and stackability are also important factors to be considered in the design. Bottom thickness of a typical can has decreased from 0.495mm (0.0195 inches) in 1965 to 0.292mm (0.0115 inches) in 1994. Further reduction of the bottom thickness will require an extra forming process, called bottom-reforming. As shown in Figure 4-4 and 4-5, this forming process reduces the stand radius of the can body and the base diameter. Some lightweighting of the can body is currently done by this process.



Can Crosssection

Bottom Crosssection

Figure 4-4 Bottom cross section

Can End Lightweighting

Figure 4-6 shows an example of end lightweighting. The end weight has fallen from 6.3g (13.8lbs/1000 ends) to 2.5g (5.6lbs/1000 ends) during the last twenty years. The lightweighting rate has not been steady. There are two ways to reduce the can end weight. One way is to reduce the thickness of the aluminum sheet used for end making. The other is to reduce end diameter. As can been seen in Figure 4-6, the reduction of end weight has been done gradually by the reduction of stock gauge, the thickness of aluminum sheet, and drastically by diameter changes in 1977, 1992 and 1993. The increase in the weight in 1974 was due to the introduction of the "stay on tab" which replaced the "ring pull tab" to solve the tab littering problem.

Usually the minimum internal pressure which can buckle the can end is required to be more than 6.3kg/cm^2 (90 psi). Development of a new type or shape of end shell may lead to a reduction of the metal thickness and weight. But, the reduction of end diameters produces greater pressure resistance at the same metal thickness. When the end diameter is reduced, the metal thickness can also be reduced even with a similar shape.

One of the reasons that aluminum cans dominate the large US beverage packaging market is their relatively low cost. The decrease in aluminum metal ingot prices contributed to the success of the aluminum can industry until 1993. As can been seen in Table 4-2, metal cost is as much as 78.2 percent of the total end cost for 206 diameter ends. Of course, the percentage will fluctuate in response to the prices of aluminum metal and other raw materials. The metal cost ratio against the total cost of a 204 or 202 end, both of which were developed to reduce can costs, will become relatively lower than for the 206 end because the cost of metal decreases but the capital investment including end making machinery will be required and other costs may remain the same.

Can End Weight History
12-oz, 211/413 Aluminum Can

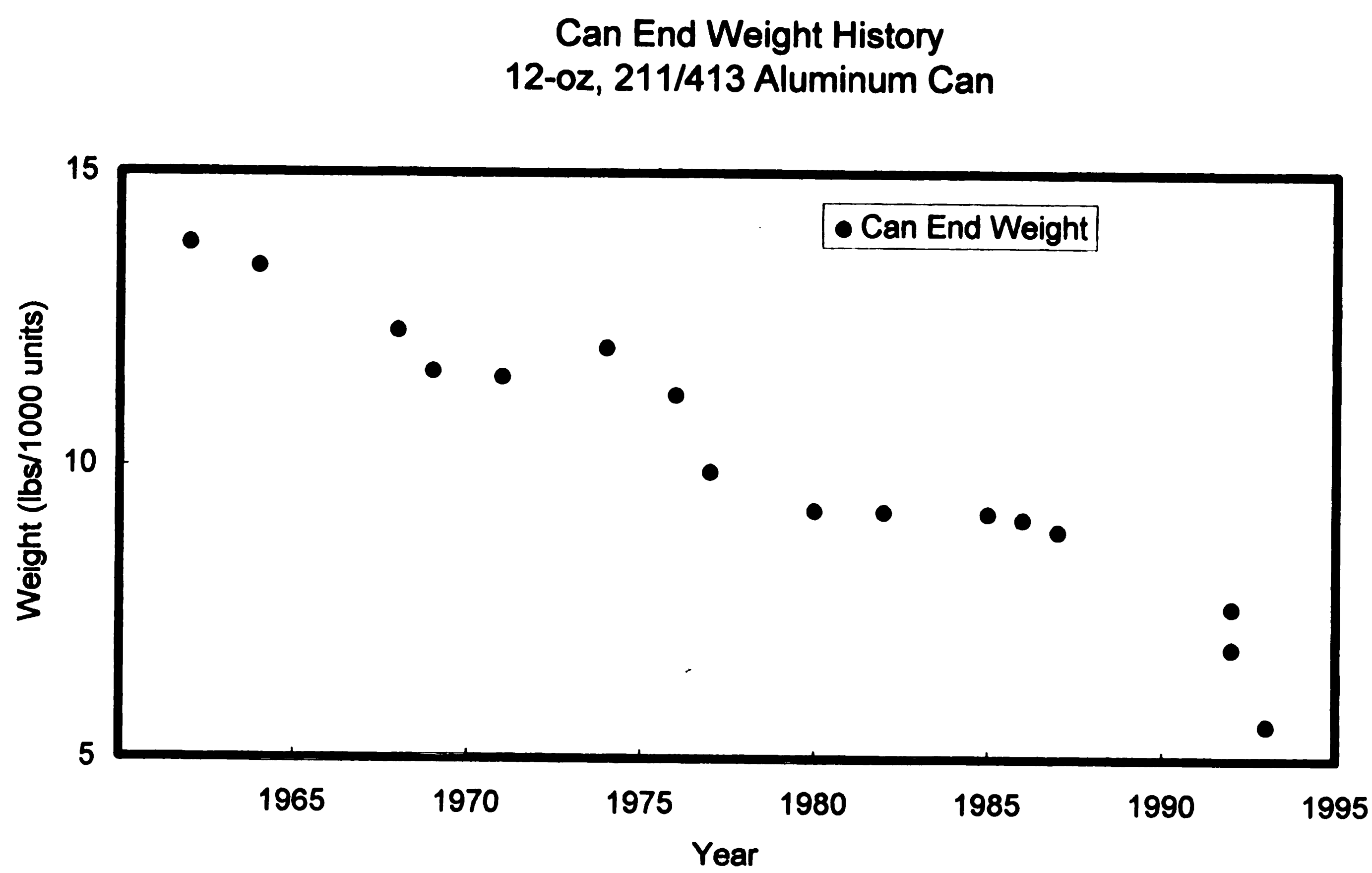


Figure 4-6 Aluminum can end weight history
Example of can end weight history in the US
Source: Mitsubishi Materials Corp.

Chapter 5

Recycling

The aluminum can market for beverages in the US has grown steadily since the cans were introduced in the 1960's. Light weight and stackability helped the aluminum can quickly displace glass bottles and other containers in both the soft drink and beer markets. But, one of the most significant characteristics of the aluminum can is its recyclability compared to other packaging materials. In the US, aluminum beverage cans are considered to be environmentally friendly. This is one reason that aluminum cans for beverages were accepted so quickly. According to the Aluminum Association, 106,014 million aluminum cans were shipped in the US In 1994, and the recycling rate reached 65.4 percent(5-1).

Aluminum cans must be reasonably cheap to be accepted as beverage containers, even though the raw aluminum is not inexpensive. As shown in the cost breakdown for aluminum cans, Tables 4-1 and 4-2 in Chapter 4, 57.6 percent of the total production cost of the aluminum can body and 78.6 percent of that of aluminum can end is the direct cost of the aluminum metal (5-2).

Since 1994, the price of aluminum has been increasing because of the decreased shipments of aluminum ingots by Russia. As a consequence, aluminum can recycling is attracting attention, not only from the environmental viewpoint, but also from the business viewpoint, because recycling aluminum used beverage cans (UBCs) is profitable. In 1994, the industry paid $1.15 billion for the 64.7 billion aluminum UBC's which were recovered for remelt (5-3).

Packaging materials in the municipal solid waste

Since the late 1980's, information and environmental events have raised public awareness of the municipal solid waste crisis. In 1989, the Environmental Protection Agency (EPA) formed a group to analyze the solid waste problem and propose solutions. The experts developed an "Agenda for Action" to solve the garbage problem(5-4). One program was designed to minimize the volume of solid waste generated from packaging because approximately one-third of all landfilled Municipal Solid Waste originates from packaging (5-4). EPA statistics on major categories of MSW are shown in Figure 5-1. In 1993, 207 million tons of municipal solid waste were generated in the United State and the recovery of materials for recycling and composting reached an estimated 22 percent (5-5). The recovery rates in 1993 for each component of municipal solid waste are shown in Figure 5-2. The recovery rates of metal packaging, both aluminum and steel, are significantly higher than for other package materials. In 1993, the aluminum packaging recovery rate was 53.0 percent overall and 59.5 percent for aluminum cans (5-5). The recycling of aluminum cans has been good example of the benefits of recycling in general and has given the public a positive impression about aluminum cans for beverages.

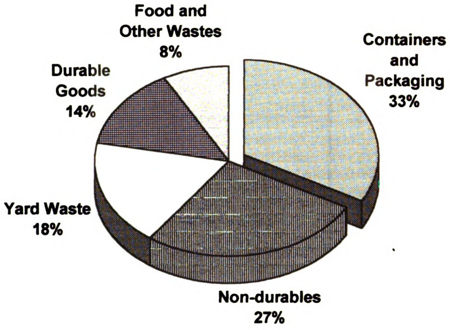


Figure 5-1 Sources of Landfilled Waste

Source: Characterization of the Municipal Solid Waste Stream, 1992 Update, US, EPA, October 1992 (5-13)

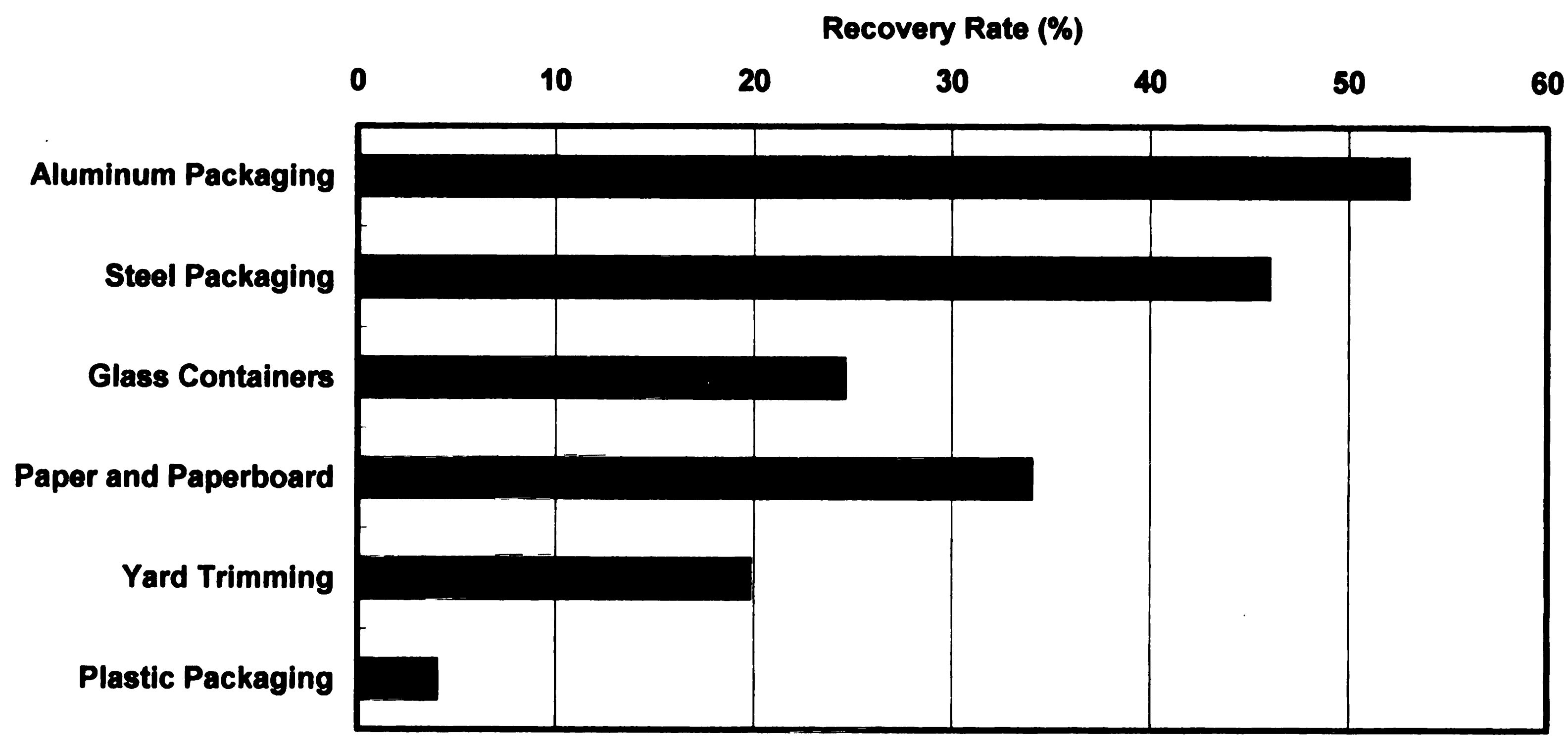


Figure 5-2 **1993 recovery rates for selected components of municipal solid waste (percentage of total generation)**

Source: US Environmental Protection Agency, Characterization of Municipal Solid Waste in the United States: 1994 Update, Washington, 1994 (5-14)

Recovery of aluminum metal from municipal solid waste

Aluminum metal recovered from municipal solid waste (MSW) is mainly from packaging, beverage cans for soft drinks or beer. The breakdown of aluminum metal from MSW is shown in Table 5-1.

Table 5-1 Aluminum Products in MSW, 1993

	Durable Goods	Nondurable Goods	Containers and Packaging		
			Beverage Cans	Food and Other Cans	Foil and Closures
Generation (1000tons)	810	180	**1610**	40	330
Recovery (1000tons)	Neg	Neg	**1020**	Neg	30
Recovery (%)	Neg	Neg	**63.4**	Neg	9.1

Neg. = negligible

Source: Franklin Associates, Ltd.

As shown in Table 5-1, the biggest aluminum product in MSW is aluminum cans for beverages. Most of the recovered aluminum comes from UBC's. The recovery rate was 63.4 % in 1993 and 65.4 % in 1994, the highest recovery rate for common packaging materials (5-5). The primary reason for the high recovery rate is the value of the UBC. However, the size of the market for aluminum UBC's also has a positive influence on the recycling rate.

Aluminum used beverage can recycling business

The market for aluminum beverage cans is substantial and the value of UBC's is relatively high, so some companies are collecting UBC's as a business. Most of these companies are subsidiaries of major aluminum, aluminum can, or beverage companies. They have understood the importance of recycling since the start of the aluminum beverage can business.

The following five companies controlled about 80 percent of UBCs collections in US in 1994 (5-4).

- Anheuser-Bush Recycling Corp.

  Subsidiary of Anheuser-Bush Inc., largest beer company in the world

- Alcoa Recycling Co.

  Subsidiary of Alcoa, largest aluminum company in the world

- Reynolds Aluminum Recycling Co.

  Subsidiary of Reynolds Metals Co., third largest aluminum company in the world and world's third largest aluminum can company,

- American National Can Company

  Second largest aluminum can company in the world

- Golden Aluminum Company

  Subsidiary of Coors beer company

In 1994, the industry paid approximately $1.15 billion to recyclers to get back aluminum UBCs (5-10). The money was injected back into local economies to benefit individuals, municipalities, schools, churches, scout troops and non-profit organizations (5-6). Most of the used aluminum cans are returned through the industry's market-driven collection infrastructure, which includes thousands of buy-back centers nationwide. About 60 percent of the total UBCs collected come from buy-back centers (5-7).

Energy saving is a main benefit of recycling aluminum. Recycling aluminum saves about 95 percent of the energy needed to make the primary metal from bauxite. It takes more than 15,000 kWh to produce one metric ton of primary aluminum metal compared with less than 1,800 kWh for recycled aluminum (5-8). Aluminum recycling also requires much less capital investment than production of the metal from primary sources. The processing cost of UBCs is about $143 per ton (6.5 cents/pound) (5-9), whereas the price virgin aluminum metal was $1100 ~ 1980 per ton (50 - 90 cents/pound) last year as shown in Figure 5-3. Processing costs vs. prices of recycled materials are shown in Table 5-2.

Table 5-2 Processing costs vs. prices of recycled materials

	Processing Cost (Dollars per Tons)	Selling Price (Dollars per Tons)	Ratio of Price and Cost
Newspaper	34	0~25	0~0.74
Corrugated Board	43	8~30	0.19~0.70
Steel Cans	68	65~90	0.96~1.32
Clear Glass	73	40~45	0.55~0.62
Amber Glass	112	20~35	0.18~0.31
GreenGlass	87	4~12	0.05~0.14
PET	184	35~195	0.19~1.06
HDPE	188	35~240	0.19~1.28
Aluminum Cans	**143**	**500~800**	**3.50~5.60**

Source: Average process cost: National Solid Wastes Management Assn. Recycled materials prices, East Central region, May 18, 1993: Recycling Times, Packaging Digest, June 1993 (5-15)

For these reasons the industry demand for UBCs as a source of raw material for making new cans has been stable and strong, especially since 1994, when the price of aluminum began to rise sharply.

Aluminum metal price and recycling

The aluminum metal price affects aluminum can prices directly. Figure 5-3 shows aluminum metal prices and aluminum UBC prices. As can be seen, the price of aluminum metal is unstable and the price of UBCs has been changing in relation to the LME (London Metal Exchange) prices for aluminum. This fluctuation in aluminum metal price is due to the relationship between demand and supply. Prices were relatively low until the end of 1993 because of the high rate of export of aluminum ingots to the world market from Russia. In January 1994, when aluminum industries of the West signed a "Memorandum of Understanding" with Russian aluminum suppliers(5-11), aluminum prices begins to rise. After the fall of the Soviet Union, Russia had steadily increased the amount of aluminum ingots that the nation sold on the world market. In the 1980's, Russia was exporting about 200,000 tons (441 million pounds) of aluminum ingots per year, but had raised its annual aluminum ingot export to 2,000,000 tons (4410 million pounds) in 1993. The "Memorandum of Understanding" requires export of 500,000 tons (1100 million pounds) per year (5-11). The world wide aluminum surplus quickly turned into an aluminum shortage and the price of aluminum rose almost 60 percent in less than 10 months. Negotiations about aluminum can prices began between suppliers and purchasers.

According to "Beverage World" (5-11), it is projected that as of year-end 1995, the cost of aluminum cans will stand at $70.58 per 1000 - versus $70.68 for PET bottles and $65.66 for steel cans due to the aluminum metal price of $1760 per ton (80 cents per pound) (5-11). This price for aluminum cans is an increase of 25 percent compared to $56.56 per 1000 in 1994(5-12), and is the first significant increase in beverage can costs in the last 10 years. The industry's strong demand for UBCs and the high recovery rate of UBCs in 1994 resulted from this economic situation.

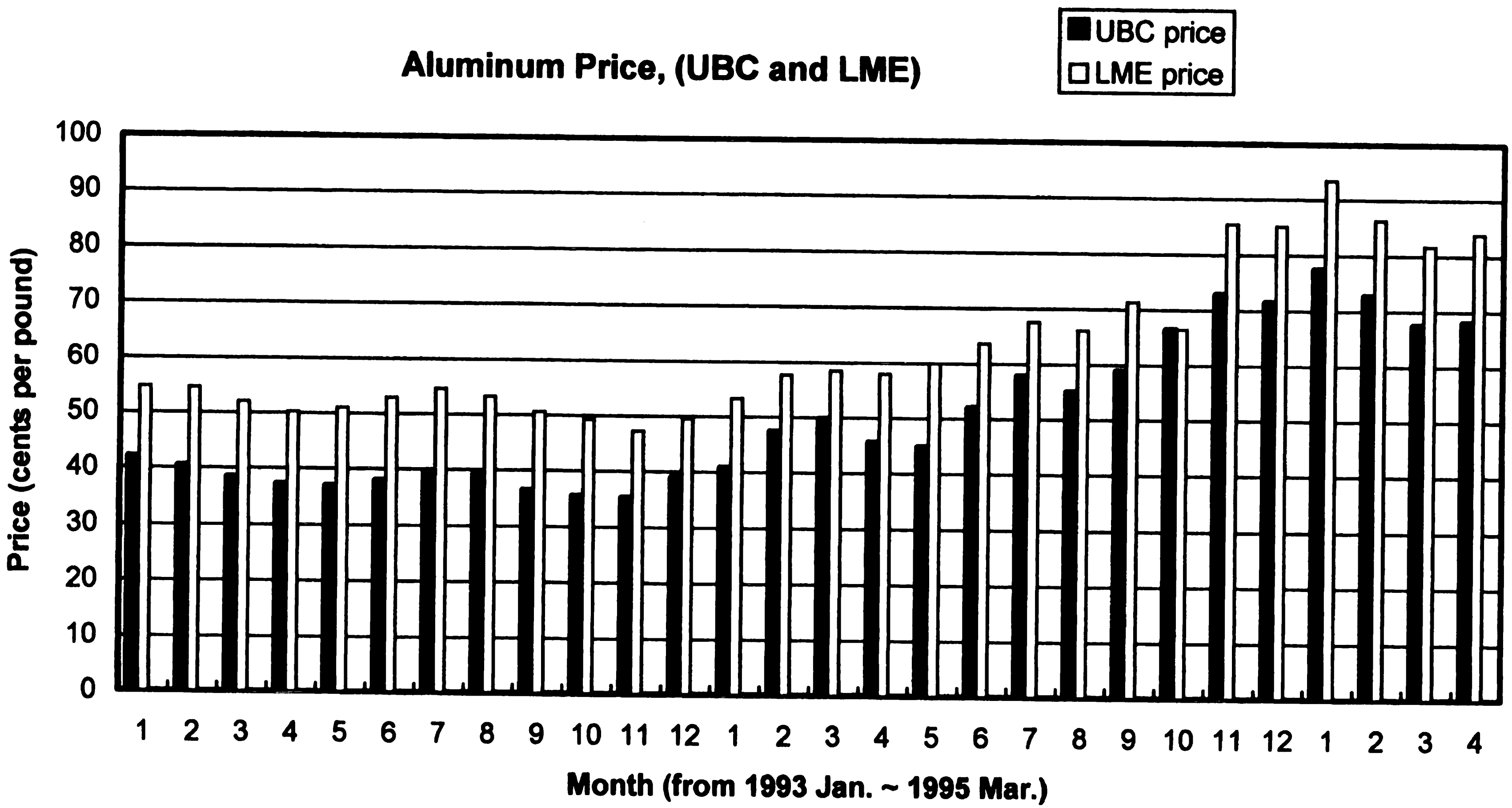


Figure 5-3 Aluminum metal prices, LME prices vs. UBC prices
source: Resource Recycling June 1995 (5-16)

Recycled content of UBC in new cans

According to the Aluminum Association and Can Manufacturers Institute, UBC recovery in 1994 was 807,000 tons (1.78 billion pounds) and 1492,000 tons (3.29 billion pounds) of cans were shipped (5-10). From these numbers the UBC content can be calculated to be 54.1 percent, and this number is used in some papers as an average UBC content in an aluminum can. However, recycled aluminum metal from UBCs is usually not used for can ends (lids) but only for can bodies. The reason is that different aluminum alloys are used for the can ends and the can bodies, as explained in Chapter 3. Components of an example of each type of alloy are shown in Table 5-3. There may be small differences in the amount of each element added to aluminum from company to company, but aluminum alloy 3004 is most commonly used for can bodies and 5182 for can ends.

Table 5-3 Aluminum alloy components list (weight %)

	Alloy No.	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Body	3004	0.28	0.48	0.23	1.00	1.1	0.02	0.05	0.03	rem.
End	5182	0.12	0.24	0.04	0.29	4.6	0.03	0.02	0.01	rem.

rem. = remaining

Source : Mitsubishi Aluminum Co.

The important components of 3004 (for can bodies) are manganese and magnesium. Manganese improves processability while ironing the can wall (the ironing process is to make the metal wall thin using a male die and female dies after the draw and redraw process, see Figure 3-10). The ironing process is not used for making can ends, so little manganese is needed in 5182. Magnesium increases the alloy strength which is important for resistance of the can against the internal pressure. More magnesium is added to the alloy for the can ends to increase strength.

Assuming that the average weight of the can end and the can body for 12 oz aluminum cans is 4.04 g (8.9lbs/1000) can ends and 11.7 g (25.8lbs/1000) can bodies, as shown in Chapter 4, the components of the recycled aluminum metal from UBCs can be calculated, as shown in Table 5-4.

Table 5-4 Calculated components of recycled aluminum from UBCs

Component	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Calculated %	0.24	0.42	0.18	0.82	2.00	0.02	0.04	0.02	rem.

rem. = remaining

By comparing the information in Tables 5-3 and 5-4, it can be seen that the alloy components must be adjusted before the recycled aluminum can be used to make new cans. For the can body alloy, virgin aluminum is added to reduce the fraction of magnesium. The average magnesium content for can bodies is about 1.00 - 1.10 %. If the Mg content is higher, the tear-off rate (tearing of the can body) during the ironing process may rise, causing production efficiency to decrease. The maximum allowable magnesium content is approximately 1.10 percent.

Therefore, the theoretical maximum content of UBCs for a can body alloy is 55 percent due to the content of magnesium. For a can end alloy, the maximum is 21 percent due to other component such as Cu.

However, the actual percentages of the various components are often different from the theoretical percentages because of oxidation or other reactions with contaminants. Magnesium, especially, tends to be oxidized easily and some of its oxides are eliminated when the UBC's are melted. The actual components of recycled aluminum from UBCs are shown in Table 5-5.

Table 5-5 Example of component of recycled aluminum metal from UBCs

component	Si	Fe	Cu	Mn	Mg	Cr	Zn	Ti	Al
Calculated %	0.27	0.47	0.22	0.97	1.35	0.02	0.05	0.03	rem.

rem. = remaining

Source: from Mitsubishi Aluminum Co.

The estimated maximum content of UBCs for can body alloy is 81 percent based on the preceding data. If the recycled aluminum is melted twice or if the melted time is longer than is usual for the process, the content of magnesium will be lower than 1.35 % because of increased oxidation. In this case, the maximum possible content of UBCs will increase due to reduction of magnesium. However, melting twice or using longer melting time will decrease production efficiency and increase the cost.

The maximum content of UBC for the can end alloy is still about 20 percent because the amount of Si, Cu, Fe and Zn in 5182 alloy should be low. Therefore, it is difficult economically to use UBCs for the can end alloy. If the content of certain components is higher than the specification, quality problems can result.

According to Reynolds Aluminum Recycling Company, "No companies are using UBCs for can end alloy, 5182". They are mainly using UBCs for can body alloys 3004 or 3104. Some companies are researching or testing new alloys for can ends which will allow greater use of UBCs.

Aluminum can recycling problems to be solved

Aluminum UBC recycling is business-oriented because the UBC has enough value to justify recyling and because the beverage can market is large. The recent rise of aluminum metal prices provides an incentive to attempt to increase the recovery rate of aluminum UBCs. An increase in the recovery rate improve the competitiveness of the aluminum cans vs. PET bottles or glass bottles. But, taking into account the strong demand for UBCs and the public understanding of the importance of recycling used packaging to avoid the future municipal solid waste crisis, the recovery rate of Aluminum UBCs, 65.4 %, should already be much higher. A more efficient or broader system including state and federal governments, communities, and industries will be needed to increase the recovery of UBCs.

The aluminum companies need to develop new alloys for can ends which can be made from UBCs to increase UBCs content in aluminum cans. If the UBC recovery rate increases, the companies need to be prepared to use UBCs for can ends. The ends should be less expensive as a result.

Chapter 6

Further can weight reduction

Price competitiveness

The price of aluminum is the most important factor in the competition between aluminum cans and glass bottles, plastic bottles (PET) and steel cans. Aluminum prices will have to be stabilized for aluminum cans to continue to be competitive. If the rate of increase in aluminum can prices is greater than the equivalent rate of increase for competing PET containers, aluminum will inevitably lose market share.

This chapter focuses on possible future cost reduction of aluminum cans. Three cost categories will be examined: 1) reduction of the amount of aluminum metal in cans, 2) aluminum metal price fluctuations, and 3) other costs including coating, production efficiency, and labor.

Can weight reduction

Since the introduction of aluminum cans, weight reduction has been the primary approach that has been used to reduce costs. Weight reduction will probably continue to be the primary method for the next several years. When evaluating the potential for additional reduction in the weight of aluminum cans, the can end and the can body must both be considered.

The can body and the weight of the can body can be segmented into three sections as defined in Figure 6-1: 1) neck, 2) thin wall, and 3) bottom. The can end weight can also classified into two parts: 1) shell weight and 2) tab weight. Figure 6-2 shows the parts of a can end. In this Chapter, each part is discussed separately.

To reduce the weight of a can, the dimensions of some part(s) of the can must be reduced. Each dimensional change also affects certain properties or characteristics of the can. Each change of dimension requires the consideration of one or more factors related to the properties or the processability of the can. Table 6-3 shows the outline of the relationships among these factors. Some factors are related to other factors and two or more may have to be considered in combination.

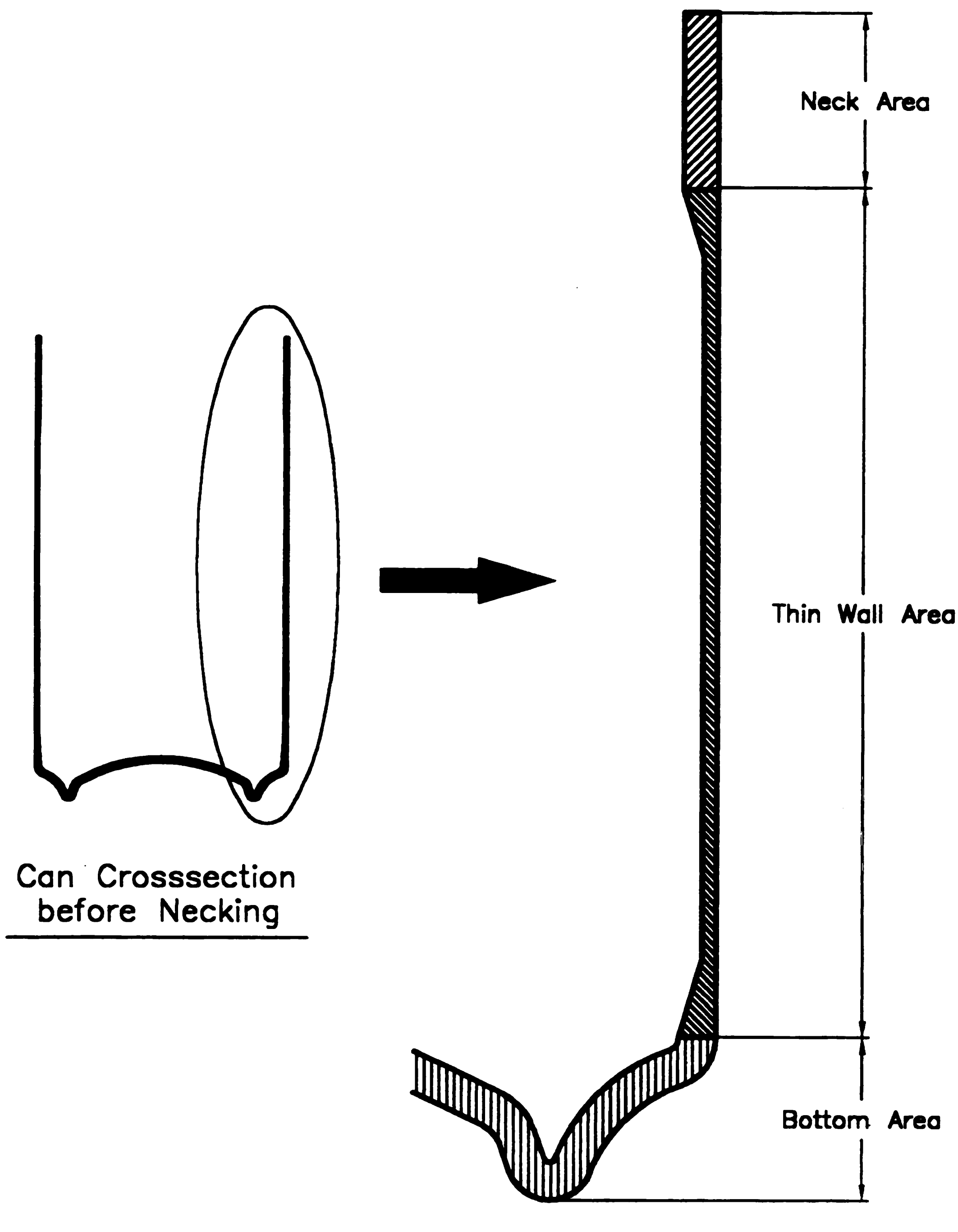


Figure 6-1 Can Body Classification

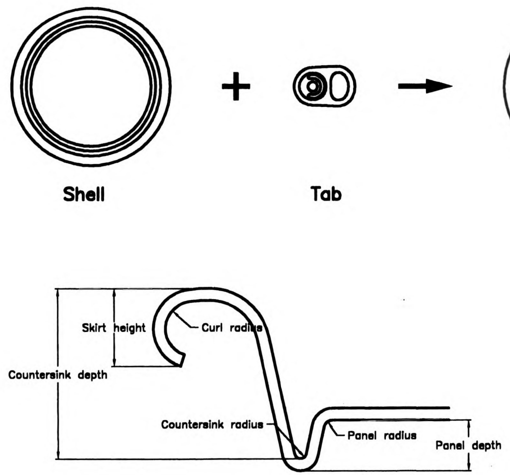


Figure 6-2 Can end classification and name of dimension

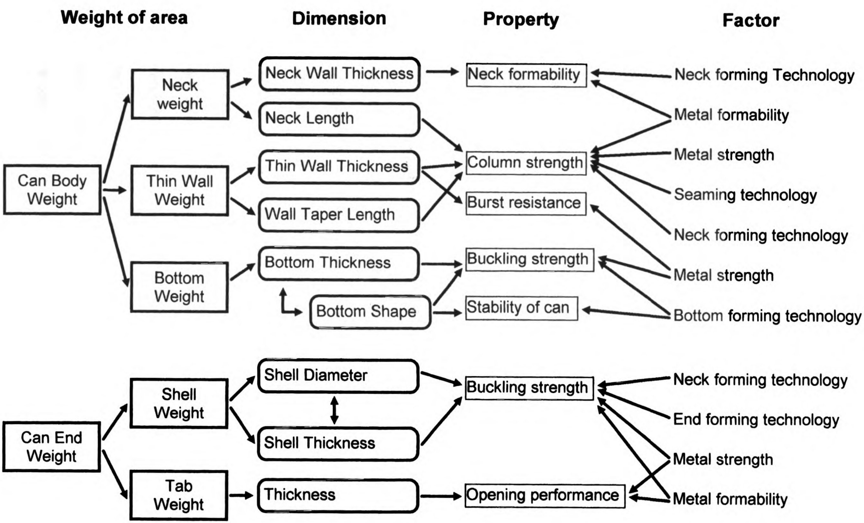


Figure 6-3 Can weight reduction : Relationship diagram of factors

Can body weight

The can body weight can be divided into three parts, neck weight, thin wall weight and bottom weight, as defined in Figure 6-1. The neck weight is defined as the weight of the upper part of the can wall where the thickness is usually constant before the neck forming process. After necking, the thickness will increase according to the amount of the reduction of the diameter. The thin wall weight is defined as the weight of the middle and thinnest part of the wall, including the thickness transition zones to the neck and the bottom. Bottom weight is defined as the weight of the bottom part of the can where no ironing forming takes place. Usually the weights of each of these three parts can be designed individually, independent of each other except for the lengths of the neck wall and the thin wall which are a function of the can volume.

The weight of each area of the can is not likely to be reduced at the same rate. Some part of the can may be reduced significantly, while the others are not changed as much. Figure 6-4 illustrates a can cross section based on the data in Table 6-2, Sample A, which is a recent typical US aluminum can for beverages. The length and thickness data were measured by a "Can Body Measuring Machine" at the Mitsubishi Materials Corp. The neck thickness and the neck length were obtained before neck forming. These data can be used approximately and as a reference. Each can manufacturer has different specifications, but the errors which result by using these typical specifications for current aluminum beverage cans in the US can be regarded as small. Therefore, in this chapter, these data are used to analyze can body lightweighting.

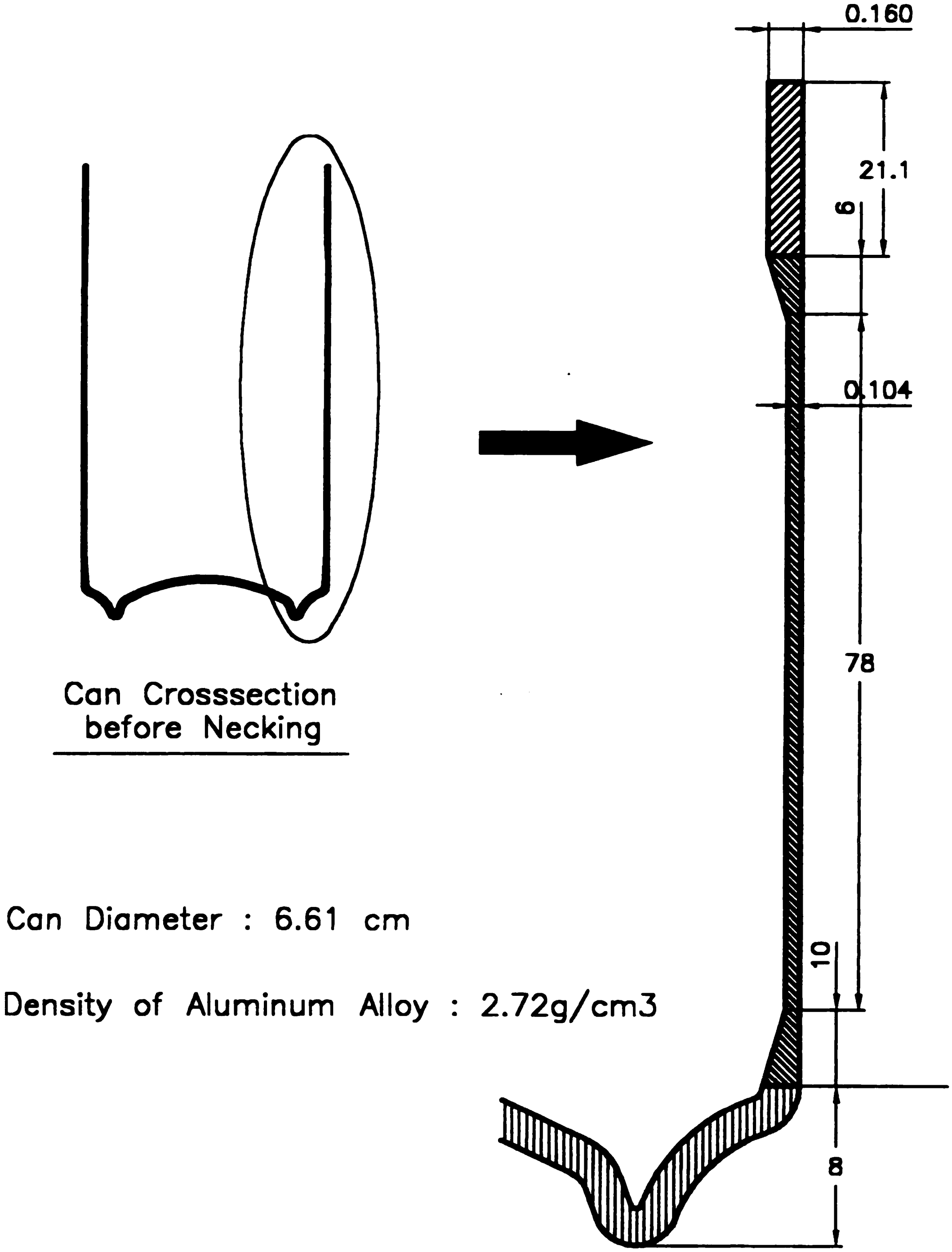


Figure 6-4 Typical can body dimension, 202/211 12-ounce can

Using the data in Figure 6-4, the weight of each part of the can body can be calculated as follows.

Neck Weight

$$2.11 \times 6.61\pi \times 0.0160 \times 2.72 = 1.95g\ (0.00430\ lbs)$$

Thin Wall Weight

$$0.6 \times (0.0160+0.0104)/2 \times 6.61\pi \times 2.72 = 0.45g\ (0.00099\ lbs)$$

$$7.8 \times 0.0104 \times 6.61\pi \times 2.72 = 4.58g\ (0.0101\ lbs)$$

$$1 \times (0.299+0.0104)/2 \times 6.61\pi \times 2.72 = 1.14g\ (0.00251\ lbs)$$

Total = 6.17g (0.0136 lbs)

Bottom weight can be approximated by using the inner diameter of the redraw die which is close to the diameter of the aluminum metal to be formed into the bottom. Strictly speaking, some plastic flow will occur from the outside into the bottom area. The actual thickness before forming is 0.002 - 0.003mm greater than the center of the bottom. Therefore, the actual weight will be slightly more than the estimate. Using the redraw inner diameter (can diameter + ironing reduction x 2), the approximate bottom weight can be calculated as follows.

Bottom weight

$$0.0299 \times \pi\{(6.61/2+(0.0299-0.0104)\}^2 \times 2.72 = 2.84g\ (0.00129\ lbs)$$

Therefore, the total can weight is estimated to 10.96g (0.0242 lbs) (1.95g + 6.17g + 2.84g), a little lighter than the actual weight, 11.45g (0.0252 lbs) (6-2). The difference of 0.49g (0.00108 lbs) is probably the result of under estimating the can bottom weight. If the weight estimates of the neck and thin wall are accepted as calculated, the bottom weight would be 3.33g (0.00734 lbs) (11.45g - 1.95g - 6.17g).

Figure 6-5 shows the weight break down for typical aluminum beverage cans in the US. The end shell weight and the tab weight in Figure 6-5 are from the same company (6-2).

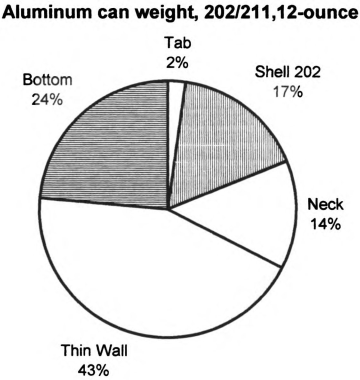


Figure 6-5 Aluminum can weight break down, 202/211 12-ounce

Because of the larger area of the side wall, the thin wall is the heaviest part of an aluminum can. The wall of an aluminum beverage can feels very thin, giving an impression that reduction of the wall would be nearly impossible. However, as seen in the preceding discussion, further reduction of the thin wall weight is essential to reduce cost.

The second heaviest section is the bottom. Reduction is also desirable in the weight of the bottom. A new bottom shape will be required. There is also another significant problem with the bottom shape of 202/211 cans: stability when cans are stacked on top of one another.

The example data is for a 202/211, 12-ounce can, indicating that the weight of the end has already reduced from that of 206 or 204 diameter ends. Further reduction of the end diameter is being researched by can manufacturers.

The possibilities of further lightweighting of each part are discussed in the next section.

Thin wall thickness and weight

The thin wall is formed by an ironing process which reduces the thickness of the can wall by squeezing it through the gap between a punch and ring-die. The ironing process has enabled manufacturers to make the can wall thin and less expensive by reducing its weight. The ironing process, shown in Figures 3-9 and 3-10, is used on beverage cans but not for making food cans. The thin wall is much thinner than the original aluminum sheet. The thinness of the wall is the reason that a positive inner pressure is always required when aluminum beverage cans are used. The cans simply do not have the axial strength required for stacking unless they are pressurized.

The percentage of reduction from ironing is illustrated below.

$$\text{Reduction (\%)} = \frac{\text{Thickness before Ironing} - \text{Finish Thickness}}{\text{Thickness before Ironing}} \times 100$$

A similar equation can be used to calculate other reductions. For example, the ironing reduction of a can which has 0.103mm (0.0041 inches) thin wall thickness made from 0.290mm (0.0114 inches) thickness aluminum sheet will be 64.5 percent. Immediately before ironing, the can wall is thicker than the original aluminum sheet due to drawing. Therefore, the real ironing reduction will be a little greater than 64.5 percent.

Generally, the maximum thickness reduction is about 40 percent in one ironing pass. Therefore, two or more passes are required to make a can body. Current practice is to use three ironing passes for good can quality and good operating efficiency of the can body press machine. To eliminate problems, three ironing dies are mounted in a tool pack, also called a die-set, to make the can wall.

A tool pack with three ironing dies is longer than one with two dies. There needs to be enough distance between dies to avoid two ironing dies working on the material at the same time. A shorter tool pack can be operated at a higher press speed, directly improving production efficiency. A longer ironing press stroke, which accommodates a longer tool pack, decreases the speed of the press. In the 1960's, presses which could operate at 100 strokes per minute were rather fast. Current ironing presses can be operated at more than 400 strokes per minute. Some manufacturers tried a shorter tool pack with only two ironing ring-dies to increase the press speed, but the tear-off rate increased and the life of the ring-dies decreased.

The following items are important factors to improve the ironing process.

a. Tool geometry and quality

b. Lubrication

c. Metal properties and quality

d. Ironing press quality (Tool Alignment)

Technologies to control these factors have been developed by can manufacturers. Metal properties, manipulated by aluminum companies, have affected both the production efficiency of the can line and can performance. Future changes could be made to increase the strength of the aluminum alloys and give higher strength to the cans but the changes might also decrease formability, which would lower production efficiency and could conceivably make the ironing process impossible.

Reduction of the thin wall

The thin wall has been reduced significantly since the introduction of aluminum can. The history the thin wall thickness is shown in the Table 6-1.

Table 6-1 Thin wall thickness history

Year	1965	1970	1975	1980	1985	1990	1995
Thickness (mm)	0.165	0.145	0.135	0.126	0.114	0.107	0.102

Source: Aluminum Company of America (G.L. Smith, "Barriers to Lightweighting of Aluminum D&I Beverage Can"), (6-1)

During these 30 years, the thin wall was reduced from 0.165mm (0.0065 inches) to 0.102mm (0.0040 inches), a 38 percent decrease. The critical factor limiting the reduction of the thin wall thickness is the axial strength of the cans, referred to as "column strength". Column strength is required when the can body is seamed together with a can end after being filled. Some axial loading is required to get proper double seam dimensions during the seaming operation.

Dimensions and other data about cans made by companies in the US and Europe are shown in Table 6-2 (6-2). Figure 6-6 shows the relationship of column strength and thin wall thickness. The data are from cans made by three US companies referred to as A, B, and C. It can be seen that the axial column strength of can bodies is approximately proportional to the thin wall thickness.

The column strength, axial strength of the can wall is theoretically a function of the thin wall thickness and the compression strength of the aluminum alloy.

Column Strength = F (t, σ, f)

t = thin wall thickness

σ = compression strength of aluminum

f = shape factor

The aluminum alloys used for the can bodies are all similar, usually 3004-H19 or 3104-H19, aluminum-manganese alloy and the hardness data of these can bodies in Table 6-2 doesn't show many differences. The shape factors are also assumed to be very similar to each other. Therefore, the column strength of the can bodies can be assumed as a function of the thin wall thickness.

Column Strength = F (t)

According to the data of the Figure 6-6, the relationship will be as following,

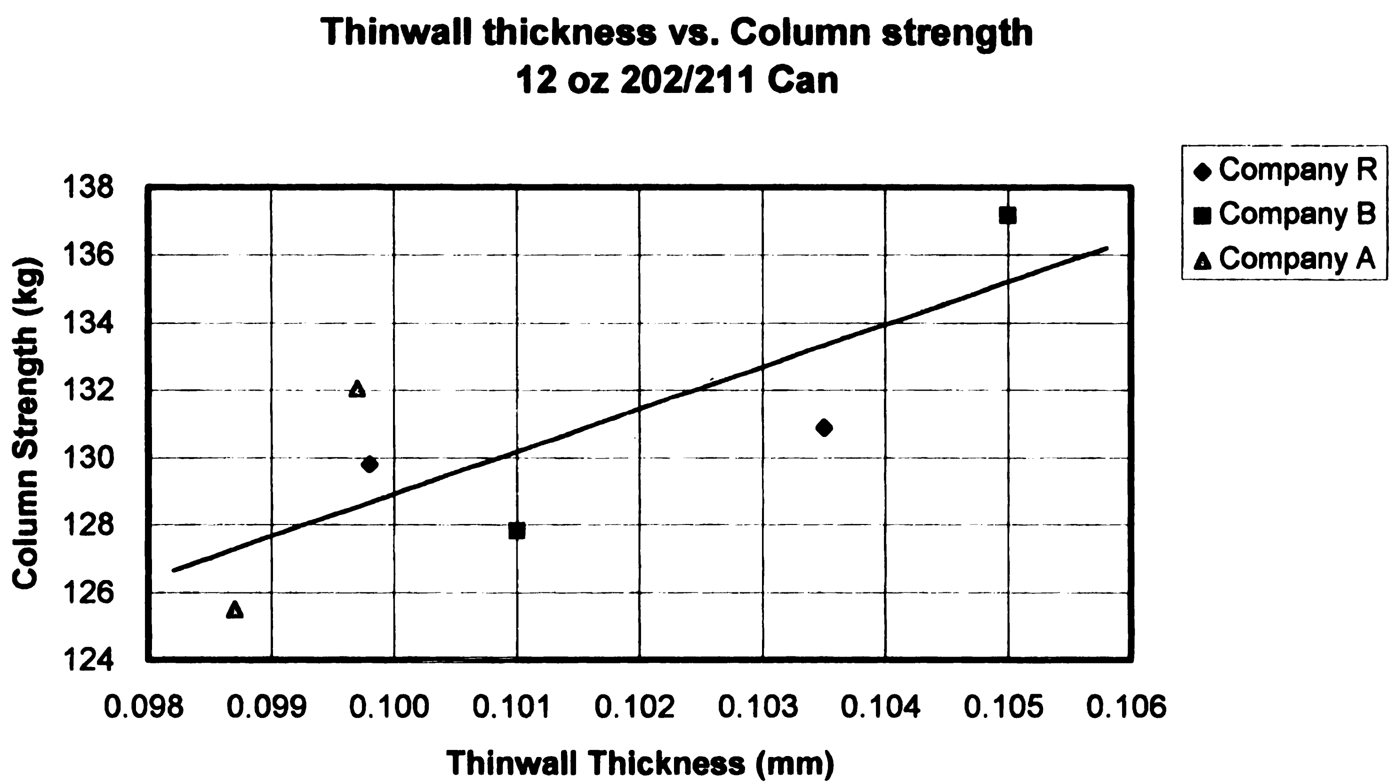
Column Strength (kg) = 1257 $\times$ Thin wall thickness (mm) + 3.3 —(A)

(Column Strength (lb) = 70400 $\times$ Thin wall thickness (inch) + 7.28)

Table 6-2 Can body dimension and performance example (202/211 Aluminum can body)

	USA				Europe		
Company	A	B	C	D	A	B	C
Type of Sample	Empty	Empty	Empty	Empty	Commercial	Commercial	Commercial
Size	355 cc	355 cc	355 cc	354 cc	330 cc	330 cc	330 cc
End Diameter	202	202	202	204	202	202	202
Neck Forming Style	Spin-flow	Spin	Smooth Die	Smooth Die	Spin	Smooth Die	Smooth Die
Bottom Style	R-93	AV	AV	AV	AV	AV	AV
Thickness, Bottom (mm)	0.299	0.289	0.284	0.291	0.307	0.294	0.303
Thickness, Wall (mm)	0.104	0.103	0.099	0.103	0.104	0.108	0.105
Thickness, Neck (mm)	0.176	0.179	0.185	0.177	0.184	0.201	0.185
Buckling Pressure (kg/cm^2)	7.107	6.799	7.723	-	7.815	7.060	7.145
Column strength (kg)	130.35	132.50	129.00	128.70	-	-	-
Can Height (mm)	122.28	122.44	122.35	132.92	115.50	115.83	115.35
Can diameter (mm)	66.13	65.97	66.01	63.29	66.16	65.99	65.96
Flange, Width (mm)	2.24	2.10	2.15	-	-	-	-
Bottom Depth (mm)	10.32	10.01	10.71	9.80	10.03	10.22	9.83
Bottom Base Diameter (mm)	47.69	47.25	48.73	50.46	48.60	48.56	48.10
Volume (ml)	382.83	382.73	382.82	377.01	349.34	349.84	347.72
Head Space (ml)	11.99	11.59	11.95	22.28	22.32	19.62	15.34
Hardness (Vickers) Hv	99.44	97.71	102.00	97.74	97.42	99.40	98.60
Weight (g)	12.064	11.748	11.502	12.238	11.903	12.143	11.477
No. of Sample	3×2=6	3×2=6	3×2=6	5	3	3	3
Date of measure	January, 1995	January, 1995	February, 1995	April, 1994	October, 1993	October, 1993	May, 1994

Source: Mitsubishi Materials Corporation, Japan.



Column Strength (kg) = 1257 × Thin wall thickness (mm) + 3.3 ------ (A)

Figure 6-6 Thin wall thickness vs. Column Strength (Axial Strength)
Each data is the average of three cans in the same lot. Source: Mitsubishi Materials Corp.

Each data value in Figure 6-6 is the average of data for three cans in the same lot. The limitation to the reduction of the thin wall has been the column strength of the can body instead of resistance to rupture during distribution or internal pressure of the product. Column strength is required during distribution and also for the for ability to withstand the load placed on the can when the can body and the can end are seamed together. The rapid rise of the lifter assembly combined with inertia creates high peak loads on the cans which are intensified by rapid acceleration, especially during high speed seaming when processing at a high speed, such as 2000 cans per minute.

Column strength standards for aluminum beverage cans in the US are between 90.7kg ~ 136.1kg (200 and 300 pounds) where peak load is expected to be about 68.0kg (150 pounds) (6-3). The peak load exerted during seaming depends on the adjustment of springs which prevent the cans from rotating against the lifter pads to get satisfactory double seam dimensions. To soften the peak loads, the technologies, including cam profile, which control the lifter movement have been improved. Recently, a new type of seamer, which reduces the peak load to 27 kg (60 pounds) from the conventional load of 68 kg (150 pounds), has been developed (6-3). To compensate for the possibility that some cans have defects or flaws and to guarantee an effective seaming operation at high speed, the specification of the column strength should be higher than the peak load exerted by the seamer.

If the new seamers with low peak load allow cans to be manufactured which have lower column strength standards, further reduction of the thin wall will be possible. Based on the equation shown in Figure 6-6, the thin wall required for 36.3kg (80 pounds) of column strength is 0.026mm (0.00102 inches) and that for 54.4kg (120 pounds) of column strength is 0.041mm (0.00161 inches). Even if the expected peak load continues to be 68 kg (150 pounds) the thin wall requirement will be 0.051mm (0.002 inches), much thinner than the walls on current cans.

Die-necking is another operation which requires that the can have adequate column strength. The collapse mode of the can wall due to an axial load is bending toward the inside of the can in an area of the wall. During die-necking, 2 - 3 kg/cm^2 (28.6 ~ 42.9 psi) of air pressure is applied to the inside of the can body to increase the ability to support an axial load. The die-necking load ranges from 45kg ~ 1kg (100 to 200 pounds) (6-8), significantly less than the column strength with applying inner pressure. Therefore, necking loads don't need to be considered when the thin wall column strength is considered. However, the outer nose wall of the bottom of the can body must have adequate resistance to the necking loads to avoid damage.

After the new type of seamer comes into common use, further reduction of the thin wall will depend on other factors, such as hoop stress resistance to the inner pressure of the products or rupture resistance during distribution.

Resistance to hoop stress

The hoop stress can be calculated as shown below:

$$\text{Hoop Stress} = \frac{(\text{Internal Pressure}) \times (\text{Can Diameter})}{2 \times (\text{Wall Thickness})}$$

The internal pressure depends on the type of product and the temperature. The inner pressure resistance standard in the US is 6.3kg/cm^{2}, so a can should never be pressurized beyond that level. A standard 12-ounce can is about 66.0mm in diameter. The maximum hoop stress, therefore, is a direct function of the wall thickness and is calculated as shown below.

$$\text{Hoop Stress } (kg/mm^2) = \frac{2.079}{\text{Wall Thickness (mm)}}$$

Figure 6-7 shows the relation ship between the hoop stress and the thin wall thickness.

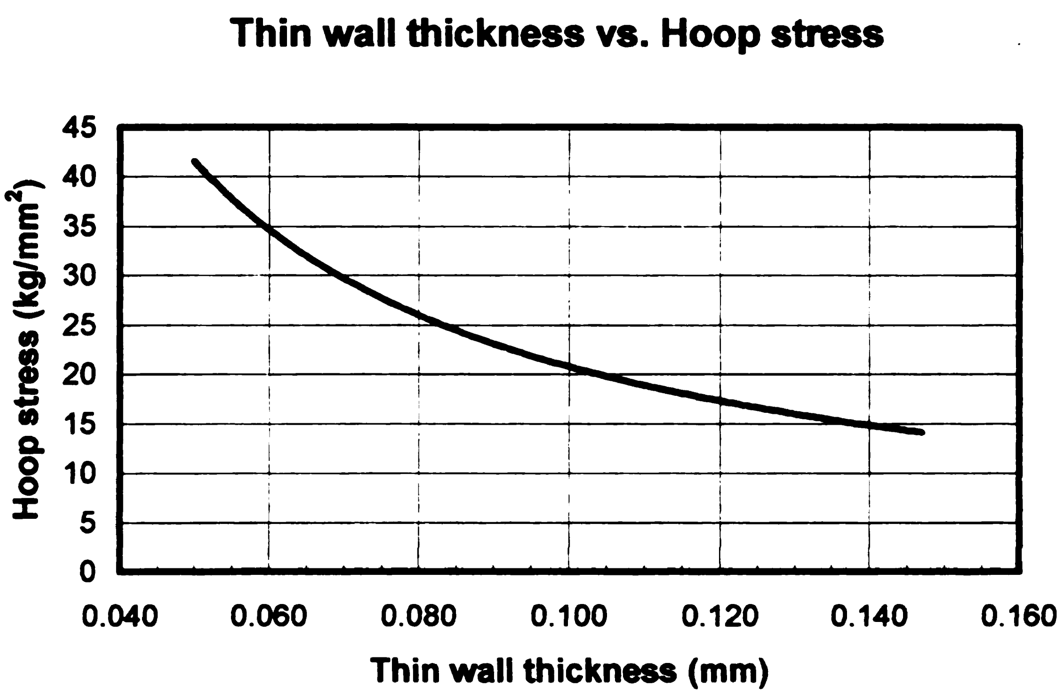


Figure 6-7 Maximum hoop stress (at 6.3 kg/cm^2) vs. Thin wall thickness

If the tensile strength of the aluminum can body metal is given, the required wall thickness can be calculated. The tensile strength of the common aluminum metal used for can bodies in the US is 28.1kg/mm^2 ~ 30.6kg/mm^2 (40.1 kpsi ~43.7 kpsi) (6-4).

The tensile stress can also be estimated from the hardness of the metal if data is available for calibration of the relationship between the hardness and tensile strength. Figure 6-8 shows the relationship for a particular aluminum alloy, 3004-H19. Usually, the tensile strength is not necessarily related to hardness. However, when working with aluminum can metals, the compositions, rolling conditions and heat treatments are all similar. Therefore, the tensile strength can be estimated from hardness which is easier to measure than tensile tests using real can body walls.

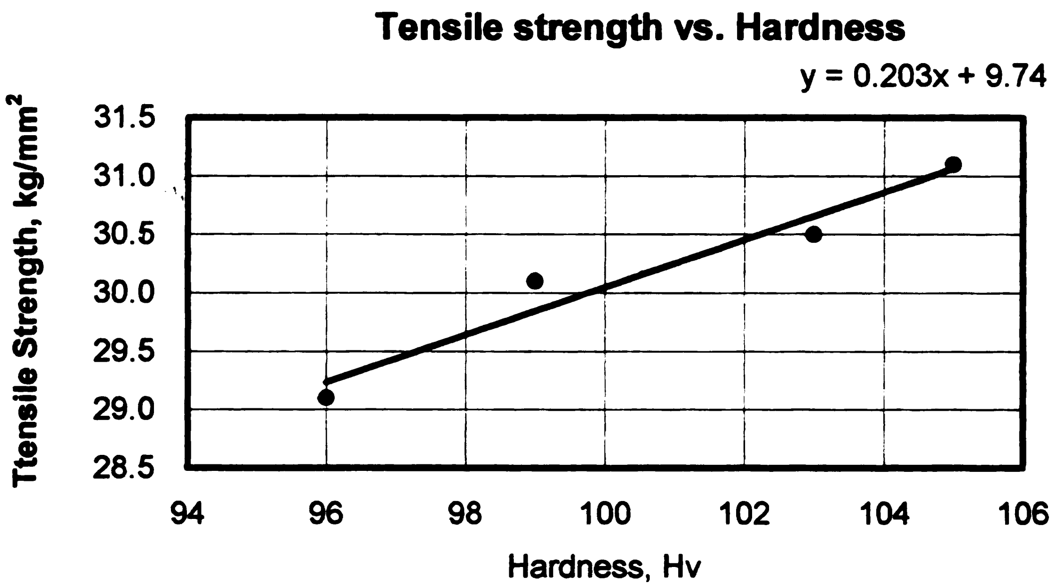


Figure 6-8 Tensile strength and hardness, 3004-H19

Source: Mitsubishi Materials Corporation

The tensile strength of aluminum sheet before forming can be estimated from the graph if the hardness is known. The strength of the metal changes during forming because of work hardening and the thermal effects of the can manufacturing line. Therefore, compensation should be considered when these data are used. Figure 6-9 shows the effect of work hardening of the aluminum in a can body due to ironing. Samples A and D are common can body alloys. Samples B and C are special alloys developed to reduce the work hardening rate and give better neck formability. The thin wall and thick wall are harder than the bottom, approximately as hard as the aluminum sheet before forming. The thin wall is harder than the thick wall because it is ironed more than the thick wall.

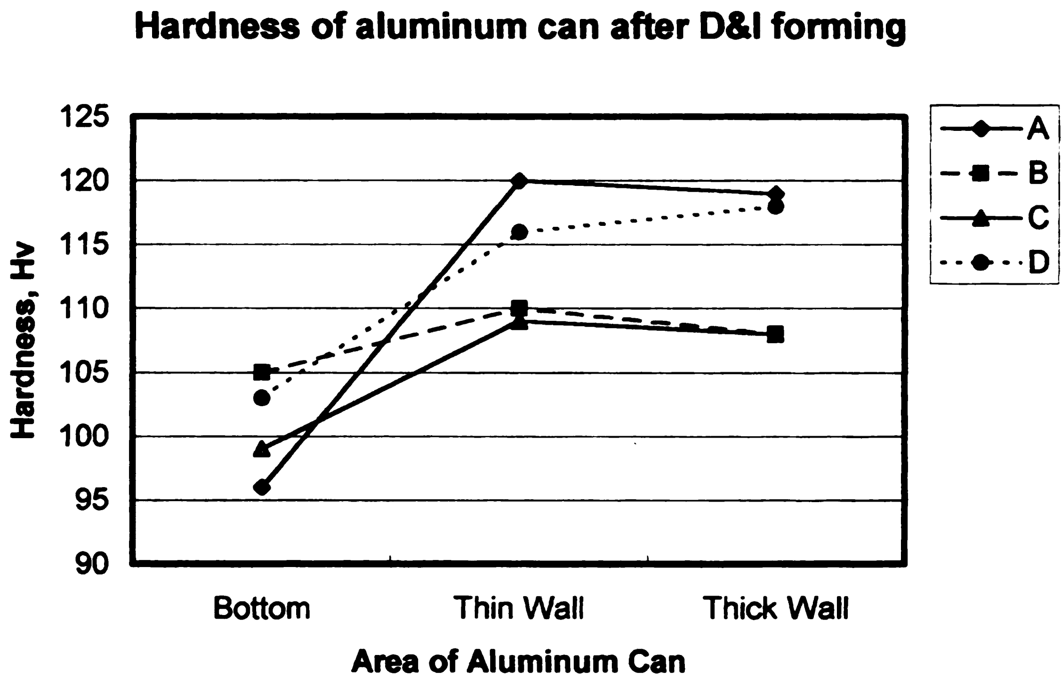


Figure 6-9 Work hardening of can body

Source: Mitsubishi Materials Corporation

After forming, the can body is moved to other processes: washing, drying, printing, drying, inside coating, drying and neck forming. The three drying ovens give the can body a slight heat treatment. The temperatures of the ovens are controlled to the minimum level for drying or curing, usually lower than 200°C, but high enough to affect material properties. Figure 6-10 shows the hardness after baking and drying of each section of cans made of different materials.

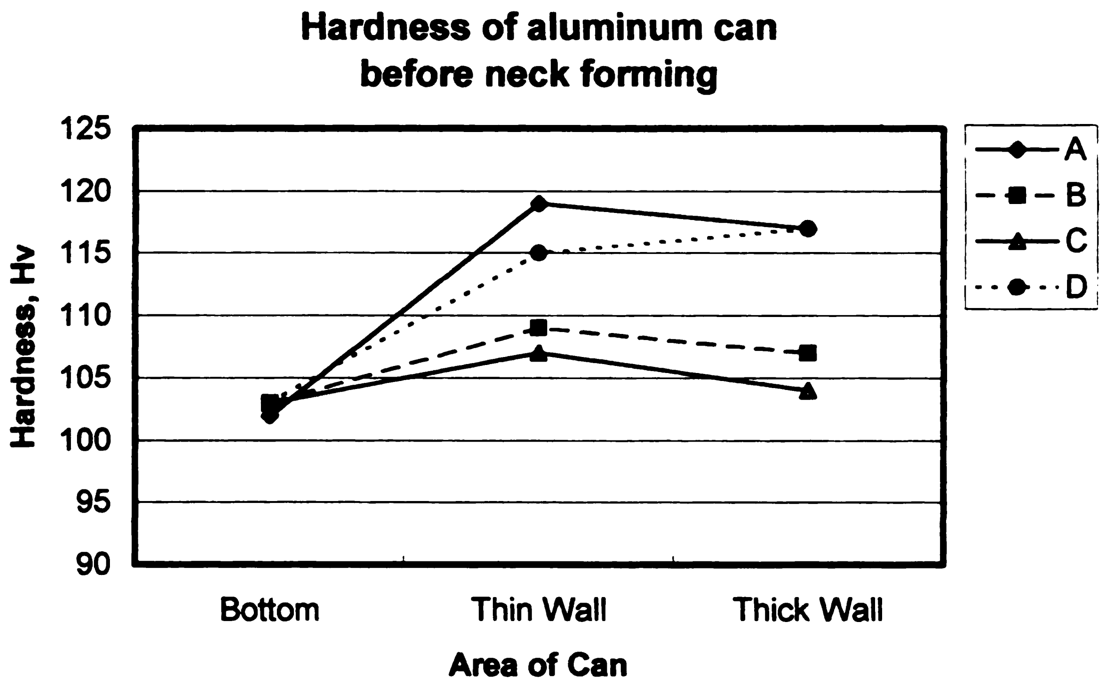


Figure 6-10 Can body hardness after baking and before necking

Source: Mitsubishi Materials Corporation

The materials (A, B, C, and D) are the same as shown in Figure 6-8. From the graph, it can be seen that the thin wall hardness is 5 ~ 10 percent higher than the hardness of the bottom, about 10 percent for the usual can body materials and about 5 percent for the low work harden materials.

The tensile strength plotted in the graph was measured along the rolling direction. The anisotropy of the aluminum alloy also has to be considered. The tensile strength in the rolling direction is higher than in the perpendicular direction. The difference varies from alloy to alloy, but is usually less than 10 percent for aluminum can body alloys.

The tensile strength in rolling direction of the material at the bottom of the can body can be assumed to be approximately equal to the strength in cross direction of the wall which resists the internal pressure. The tensile strength of the bottom of can bodies can be approximately calculated with the following equation, based on Figure 6-7.

Tensile strength (kg/mm^2) = 0.203 × Hardness (Hv) + 9.74

(Tensile strength (psi) = 290 × Hardness (Hv) + 13900)

The average hardness of the bottoms of cans in Table 6-2 is 98.9 (Hv), the tensile strength can be calculated to be 29.8 kg/ mm^2 (42.6 kpsi) and the thin wall thickness can be calculated to be 0.070 mm (0.00276 inches). Therefore, the theoretical minimum thin wall thickness is 0.070mm (0.00276 inches) to resist the internal pressure of 6.3 kg/cm^2(90 psi).

A factor which must be taken into consideration, in addition to the axial load resistance during seaming and the resistance to the inner pressure, is damage during distribution. Ruptures or holes caused when the cans impact on sharp objects are the most probable types of damage that can be directly related to thin walls. Damage during distribution is highly dependent on the total packaging system including the corrugated box or tray, secondary packaging (Hi-cone rings), shrink film and pallet, and the method of shipping or transportation. Because of the number of variables, it is difficult to predict the level of damage analytically. Testing is almost always required.

It can be predicted that further reduction of the thin wall will be possible after introducing the new seamer which places less axial load on the can during seaming. The factor which will limit the reduction will be burst resistance including resistance to pin hole or rupture. On this basis, it may be possible to reduce the thin wall to 0.090 mm (0.00354 inches) or less.

Figure 6-11 shows the thin wall weight as a function of wall thickness, based on the can dimensions in Figure 6-4. The thick wall and thickness of each transition area are assumed to be proportional to the thin wall.

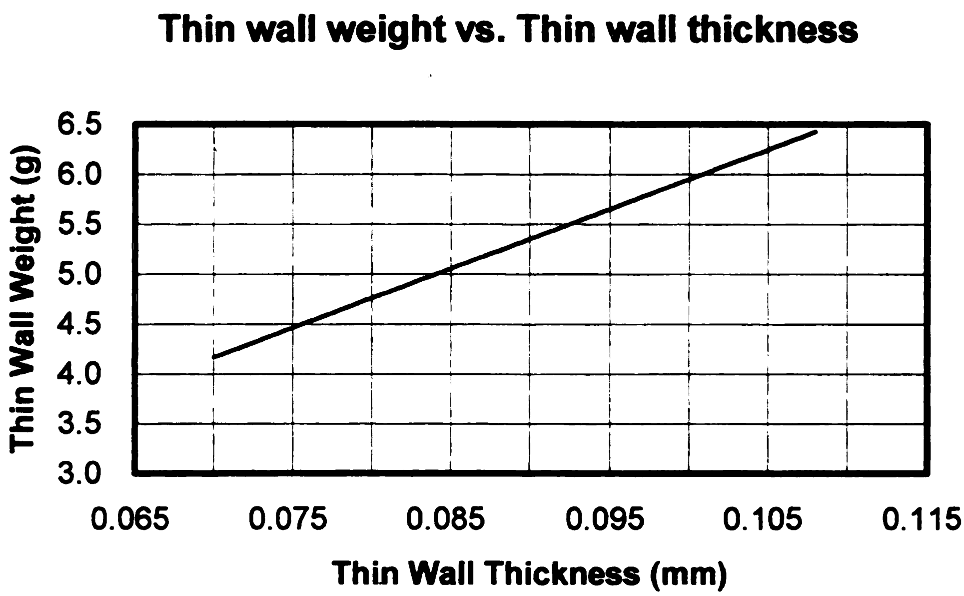


Figure 6-11 Thin wall weight vs. thin wall thickness

Neck wall weight and thick wall thickness

The neck wall, also called the thick wall, is the upper part of the can wall where the thickness is greater than the thin wall. The thick wall is required to achieve easy of reduction of the neck diameter from 211 to 206, 204 or 202. The neck wall extends from the top of the can body to the beginning of the neck curve. Therefore, the lightweighting of the thick wall depends on the neck forming technology.

Before neck forming, the thickness of the neck wall is constant along its length. After necking, the thickness is increased proportional to the reduction in diameter. Table 6-3 shows an example of this increase in thickness caused by neck reduction. In 1965, the thick wall was around 0.229mm (0.0090 inches) (6-5). It has dropped to 0.155mm ~ 0.160mm (0.0061 ~ 0.0063 inches). The history of the thick wall thickness is shown in Table 6-4.

Table 6-3 Example of Neck thickness

Die No.	1	2	3	4	5	6	7	8	9	10	11	12
Neck Diameter (mm)	64.14	63.01	61.87	60.74	59.61	58.47	57.34	56.20	55.07	54.20	53.34	52.50
Thickness (mm)	0.169	0.170	0.172	0.174	0.176	0.178	0.179	0.181	0.182	0.184	0.185	0.187
Increase in thickness (mm)	0.002	0.003	0.005	0.007	0.009	0.011	0.012	0.014	0.015	0.017	0.018	0.020

Initial thickness: 0.167mm　　Type of neck forming: Die necking

Source: G.L. Smith, "Barriers to Lightweighting of Aluminum D&I Beverage Can", SME Can Technology, 1995

Table 6-4 Example of thick wall thickness (Neck wall thickness) history

Year	1965	1975	1982	1986	1993	1995
Neck Diameter	211	209	207.5	206	204	202
Thick Wall Thickness (mm)	0.229	0.200	0.185	0.178	0.165	0.158

Source: G.L. Smith, "Barriers to Lightweighting of Aluminum D&I Beverage Can", SME Can Technology, 1995

The required thickness of the thick wall depends on the neck forming technology, the extent of diameter reduction and the formability of the aluminum alloy. The thickness and the length of the neck wall have to be carefully designed, looking at both the cost saving due to the reduction of the neck weight and the loss of production efficiency and the quality problems due to low neck formability such as neck wrinkles caused by the too thin thick wall.

There are three methods to reduce the neck diameter, die-necking, spin-necking and spin-flow necking. Each forming method has advantages and disadvantages. Spin-necking and the spin-flow necking processes require the die-necking process for pre-neck-forming. Table 6-5 shows the neck forming steps for each type of forming to go from the 211 diameter to 206,204 and 202. There are other combinations, but the ones shown in Table 6-5 are common examples.

Table 6-5 General Necking Steps for Each Reduction

Type of Forming	Neck reduction	Style of Neck	Number of Neck Forming Step
Die-necking	211→209	Single Neck	1 Die-necking
	211→207.5	Double Neck	2 Die-necking
	211→206	Triple neck	3 Die-necking
		Quad Neck	4 Die-necking
		Smooth Neck	6 Die-necking
	211→204	Smooth Neck	8~10 Die-necking
	211→202	Smooth Neck	10~12 Die-necking
Spin—necking	211→206	Smooth Neck	2 Die-necking + 1 Spin-necking
	211→204	Smooth Neck	2 Die necking + 2 Spin-necking
	211→202	Smooth Neck	3 Die-necking + 2 Spin-necking
Spin-flow-necking	211→204	Smooth Neck	3 Die-necking + 1 Spin-flow-necking
	211→202	Smooth Neck	4 Die-necking + 1 Spin-flow-necking

Source: The Canmaker February 1993 (6-6)
Reynolds Metals Company
L. Smith, "Barriers to Lightweighting of Aluminum D&I Beverage Can", SME Can Technology 1995,Singapore (6-7)

After the introduction of the 211/206 can, the appearance of the neck became one of the most important factors which determined the necking process. Triple neck or quad neck was considered to be less attractive than a smooth neck in some places. Six stacks of die-necking for 211-206 neck forming resulted from the intention to improve the bumpy neck appearance of the quad neck and triple neck. However, smooth die-necking required too many steps to be practical. By using the spin-necking or spin-flow-necking processes, the number of die-necking steps could be decreased. The magnitude of the reduction which can be applied in each die-necking station depends on the thickness of the thick wall. It is easier to form the neck from a thicker wall.

Die-necking process

Die-necking is the conventional forming method and is the oldest in these three methods, as shown in Figure 6-12. Die-necking tooling was used for the first neck reduction of aluminum two-piece cans, 211 to 209. Reducing can necks to smaller and smaller diameters is accomplished by progressively stacking one neck forming step onto another. The thick wall is forced into the clearance between a necking die and a knock-out die. Plastic metal flow occurs along the profile of the necking die. Processability depends on the profile of the necking die, the clearance between the necking die and the knock-out die, the can dimensions, such as thickness, and the metal formability. Smaller reductions are easier to form. However, the use of smaller reductions requires more steps to reduce the neck to a specific diameter.

Die-necking is more likely to cause wrinkles than other neck forming methods. The important factors to eliminate the wrinkles during the die-neck forming process are: the amount of reduction in diameter, die geometry, aluminum alloy properties, and the thick wall dimension (thickness and variation of the thickness). Examples of the effects of each factor are given below.

Diameter reduction: The less reduction, the better for wrinkles.

Die geometry:	The radius of the shoulder of a necking die affects wrinkle problem. A smaller radius tends to prevent wrinkles, but increases the necking load. Then the outer nose wall of the can bottom is must be stronger.
Aluminum alloy properties:	Generally, wrinkles are more likely to occur in stronger material. However, the stronger materials are preferable for bottom weight reduction. Material which has less tendency to work harden is preferable.
Thick wall:	A thicker wall is easier to neck down. Variation of wall thickness tends to cause wrinkles in the thinner areas.

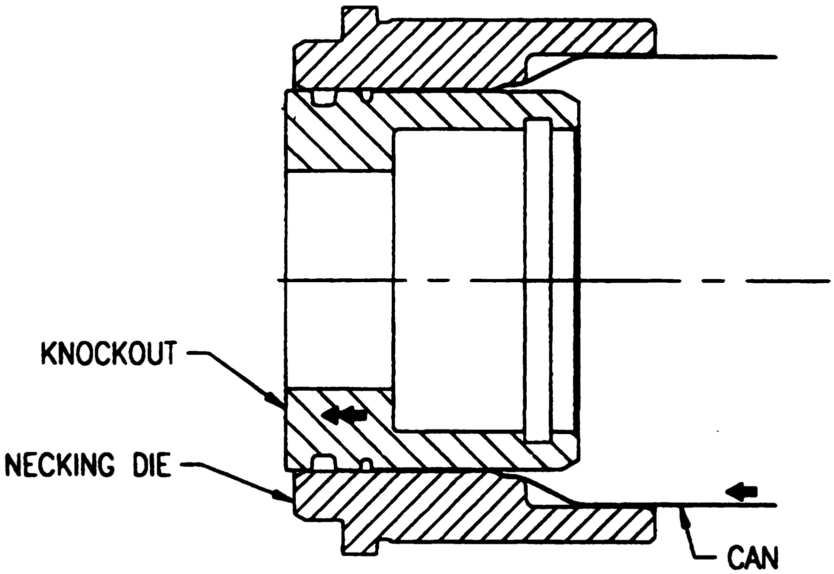


Figure 6-11 Die-necking process

Spin-necking process

The spin necking process, shown in Figure 6-13, has been used for more than 10 years, after introducing 211/206 neck reduction. Spin-necking is done under a lower axial load than die-necking. The can experiences an axial load of less than 100 pounds (6-9). However, the small contact area between the rolling die and the neck raises concerns about coating adhesion. Applying lubricants to varnishes and internal coatings can reduce the problem.

The control ring controls flange width variation. If all specifications are implemented properly, flange width variation should be on the order of 5 percent (6-9).

An advantage of spin necking compared to die-necking is can height growth. Die-necking decreases can height because of the high compressive load. Spin necking, on the other hand, increases can height (about 0.75 mm for reduction from 207.5 to 204) (6-12). The height increase is preferable for lightweighting can bodies.

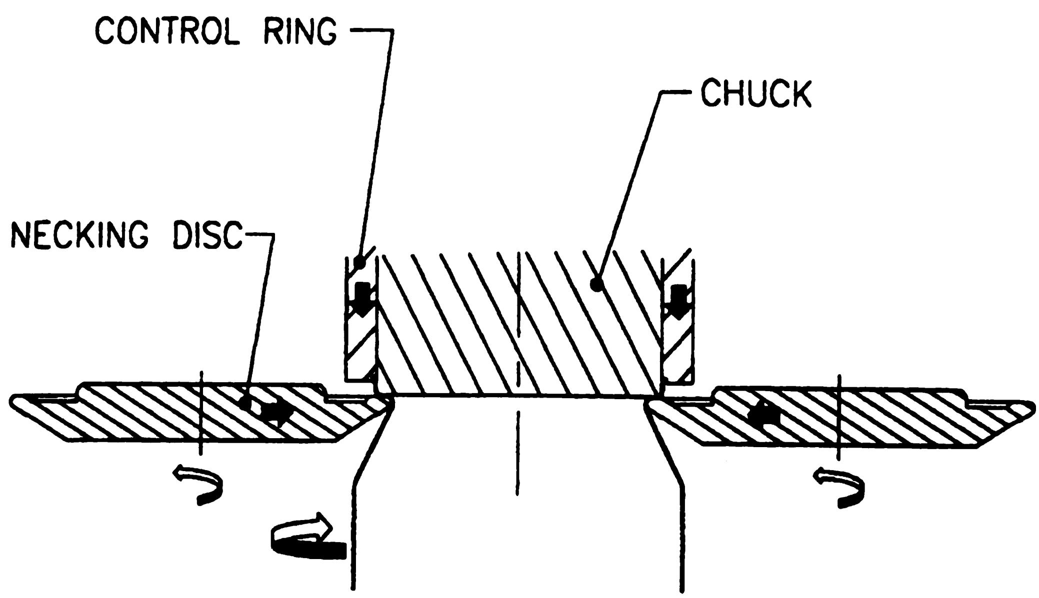


Figure 6-12 Spin-necking process

Spin-flow-necking process

Spin-flow-necking, shown in Figure 6-14, is the newest method for necking two-piece cans. It has several advantages. A noticeable advantage is the ability to make the reduction through a tension necking process. Spin-flow-necking can make a 8.9 mm (0.350 inches) diameter reduction in one shot, compared to the 1.9 ~ 2.8 mm (0.075 ~ 0.110 inches) that can be accomplished in a single step with die-necking or spin-necking, (6-10). Because an internal tool is used in the spinning operation, spin-flow-necking is can spin through more than one die-necking bump.

The height of a 204 can made by spin-flow-necking is 0.381 mm (0.015 inches) shorter than one made by spin-necking and 0.635 mm (0.025 inches) shorter than one made by die necking (6-18). Spin-flow-necking is the preferred technique for lightweighting can bodies.

There are always some die-necking steps, usually 3 steps for 204 neck and 4 steps for 202 neck from 211 can body, prior to spin-flow-necking. Spin-flow-necking can roll out some of the defects that are result from die-necking.

On the other hand, the spin-flow-necking process is new and not fully understood. Spin-flow-necking is more complicated than other necking processes.

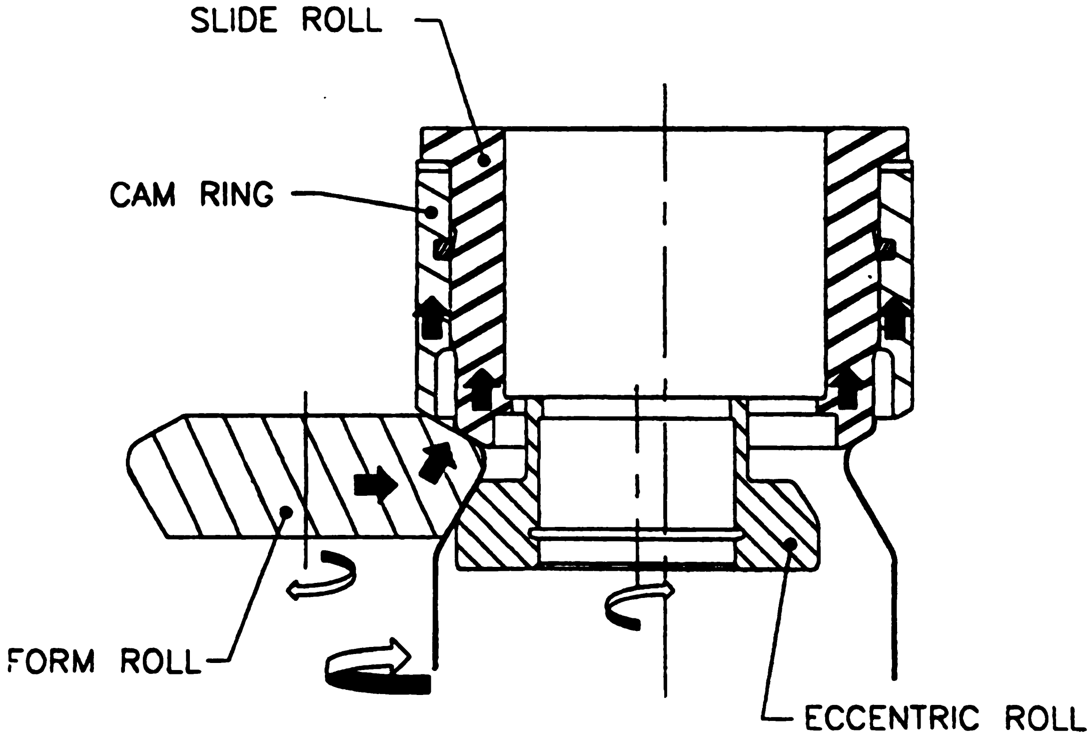


Figure 6-13 Spin-flow-necking process

Neck wall weight reduction

It is difficult to find the neck wall thickness limit. Increasing the number of steps in the necking process allows a thinner neck wall to be produced as shown in Table 6-6.

Table 6-6 The number of the die necking process required to make 204, 202 neck with various thick wall thickness

Number of necking process required			
Initial thick wall Thickness	0.147mm	0.157mm	0.167mm
From 211 to 204 Diameter	11	10	9
From 211 to 202 Diameter	14	13	12

Source: G.L. Smith, ALCOA, "Barriers to lightweighting of aluminum D&I beverage can"

It requires 14 steps of the necking process, larger space, a bigger or longer machine, and many dies to make a 202 diameter neck on a 211 diameter can with 0.147 mm (0.0058 inches) thick wall thickness. The usual die necking machine has 12 -15 spindles for one necking, so 168 - 210 sets of dies are required for 14 steps. There may be problems in can quality or production efficiency when this equipment is applied to a real can line. It often happens that the conditions which were expected before mass production was initiated have to be changed to actually make products.

A necking method which produces no compression stress in the neck wall would be most advantageous for reducing the thick wall thickness. Spin-flow-necking is promising because it uses inner rolling dies. However, this process also has some disadvantages. For example, earing, can height variability, and variation of flange width can occur during neck forming because of anisotropy of the material. To control earing, three or four steps of die-necking are usually used before spin-flow-necking. Even considering the disadvantages, spin-flow-necking is the most promising necking process for the future.

Recently, the thinnest thick wall which was could be manufactured was 0.150mm (0.0059 inches) (6-7, 6-12). Lacking any further information, this thickness is considered to be the limit for the 202 can body with current technology. Even if technology is developed which makes further reduction of the thickness possible, it will probably continue to be more cost effective to reduce the end diameter further, working toward the 200 diameter.

Neck length is another significant factor affecting neck weight. The die necking process requires the thick wall to extend over the entire neck area. Neck length can be reduced with improved technology, but a neck which is too short spoils the appearance of the can and ease of pouring. Therefore, there is little possibility of further reduction in the neck length.

There also is little possibility of eliminating the die necking process step preceding spin necking or spin-flow necking because of roundness of can tops and earing or variation of can height.

Spin-flow necking doesn't apply an axial compression load to the can body because it uses the inner rolling die. As a result, it causes less increase in the neck thickness. Therefore, when spin-flow necking is applied, the can body can be a little shorter before neck forming than when the die-necking or spin-necking processes are used. The difference in height depends on the amount of neck diameter reduction. In one case, when spin-flow technology was used, trim height (can height before necking) for the 204/211 12-ounce can was about 0.38 mm (0.015 inches) shorter than when the spin-neck technology was used and 0.64mm (0.025 inches) inches shorter than when die neck technology was used(6-11). For a 202/211 can, when spin-flow is compared to die-necking, the difference is about 1mm (0.039 inches). Therefore, it can be concluded that use of the spin-flow technology can reduce the thick wall length by about 0.064mm (0.0025 inches) for 204/211 and about 1 mm (0.039 inches) for 202/211 can body. The can height used in Figure 6-4 is for the 202/211 can body intended for spin-flow-necking. It can be assumed that the minimum thick wall length is 21.1mm (0.83 inches). However, if the appearance of the can body can be changed then the neck length can also be changed and the thick wall length will change.

Figure 6-15 shows the neck weight which results from changes in the thick wall thickness.

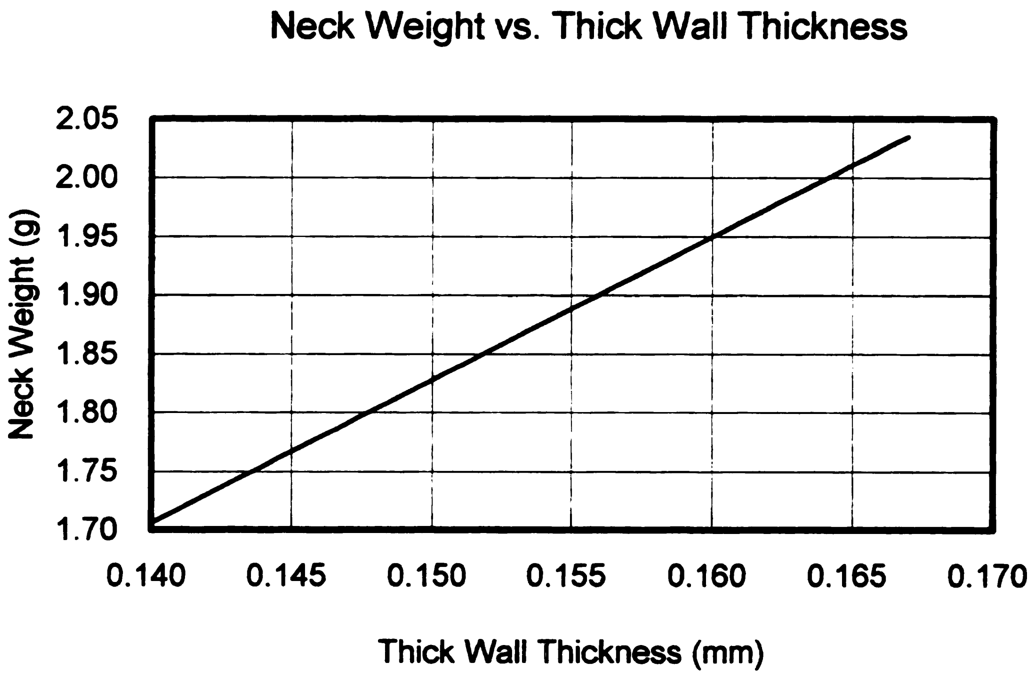


Figure 6-15 Neck weight (Neck length is 21.1mm)

Can body bottom weight

The bottom of a can is designed primarily to resist the internal pressure. The factors which determine the resistance are bottom thickness, shape of the bottom and the strength of the aluminum alloy used for the can body. The amount of plastic forming at the center of the bottom is very small and it can be assumed that the center bottom of the can body has the same thickness as the aluminum sheet before forming. Therefore, the thickness of the bottom of can bodies can be assumed to be the same as the thickness of the aluminum sheet before forming.

In 1965, when the aluminum can was introduced, the thickness of the aluminum sheet used for can bodies was 0.495 mm (0.0195 inches). Recently it has been reduced to around 0.285 mm (0.0112inches) (6-5).

Bottom shape

In the US, aluminum beverage cans are designed to resist an inner pressure of 6.3 kg/cm^2 (90 psi). The can bottom should be designed to have adequate strength to resist the pressure with minimum thickness of metal. The stability of the can body when being conveyed in a can making line or a filling line and the stackability when cans are stacked on one another are also important factors to be considered. Since the end diameter has been reduced to decrease the overall can weight, the newer bottom designs have reduced the base diameter of the can bottom. Finite element modeling (FEM), which has been used to analyze the stresses in the can body, is the most effective technique to use to evaluate the effects of each dimension on the performance of the can bottom.

Computer soft-ware for FEM is readily available today and it has become relatively easy to predict the stresses in cans under various loading conditions. However, the process of the bottom forming also has to be taken into consideration when designing the bottom because of work hardening and other effects. Figure 6-16 shows a typical bottom shape.

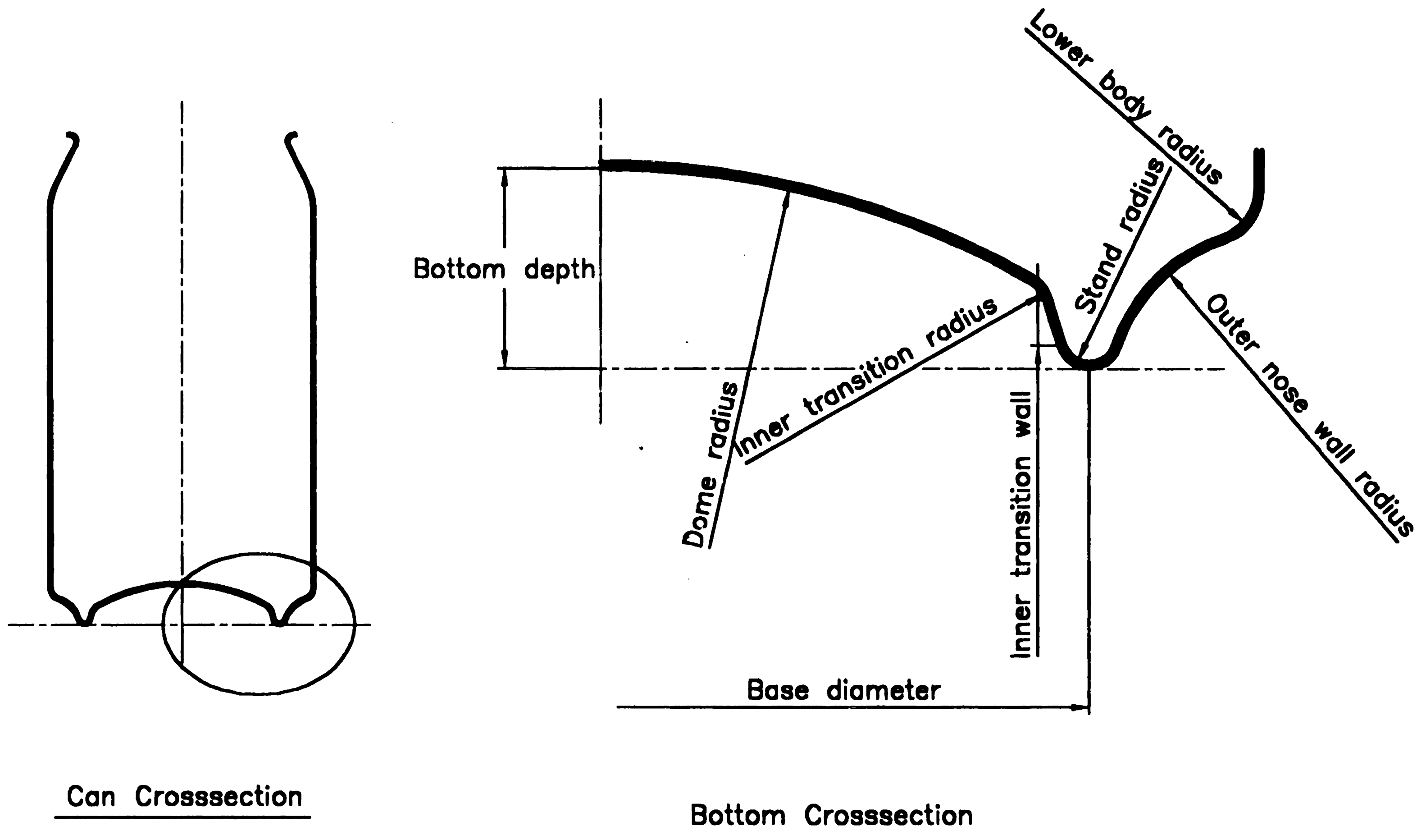


Figure 6-16 Typical can bottom shape

The use of a smaller dome radius, stand radius and inner transition radius tends to increase the ability of the bottom to resist the inner pressure. A smaller angle between the inner transition wall and the axial direction also contributes to the strength of the bottom. The smaller base diameter also increases the buckling pressure of the bottom.

The lower body radius and the outer nose wall radius affect the axial load resistance. Each dimension has limitations. A small dome radius increases the bottom depth, resulting in lowered efficiency of the can volume and surface area. A stand radius which is too small increases the likelihood of cracking in the inner transition wall when the bottom is formed because the sharp edge of the stand radius on the punch prevents smooth flow of the aluminum metal from the outer stand radius to the inner transition wall. If the angle of the inner transition wall to the axial direction is too small, inaccurate die alignment tends to create cracks. A small base diameter reduces the resistance to axial loads and the stability of the can, leading to problems in the can making and product filling lines.

For these reasons, the shapes of the bottom of aluminum cans made by different can manufacturers look similar to each other even though they are all individual designs.

Bottom thickness and metal strength

Bottom thickness and the strength of the aluminum metal used for the can bodies are other factors which affect the inner pressure resistance. The strength of the aluminum metal can not be easily changed because formability during wall ironing and neck reduction are more important considerations. The strength of the metal has been increased since the initial introduction of aluminum cans. However, since switching to the 206 end diameter, it has been difficult to find ways to apply stronger metal because of the large amount of neck forming. Aluminum companies have continued research aimed at finding a new alloy which has a low work hardening rate, and is easy to form into a neck, such as sample B and C shown in Figure 6-9.

Figure 6-17 shows the relationship between bottom thickness and bottom buckling pressure. The data are for commercial cans in USA, Europe and Asia (6-13) including those shown in Table 6-2.

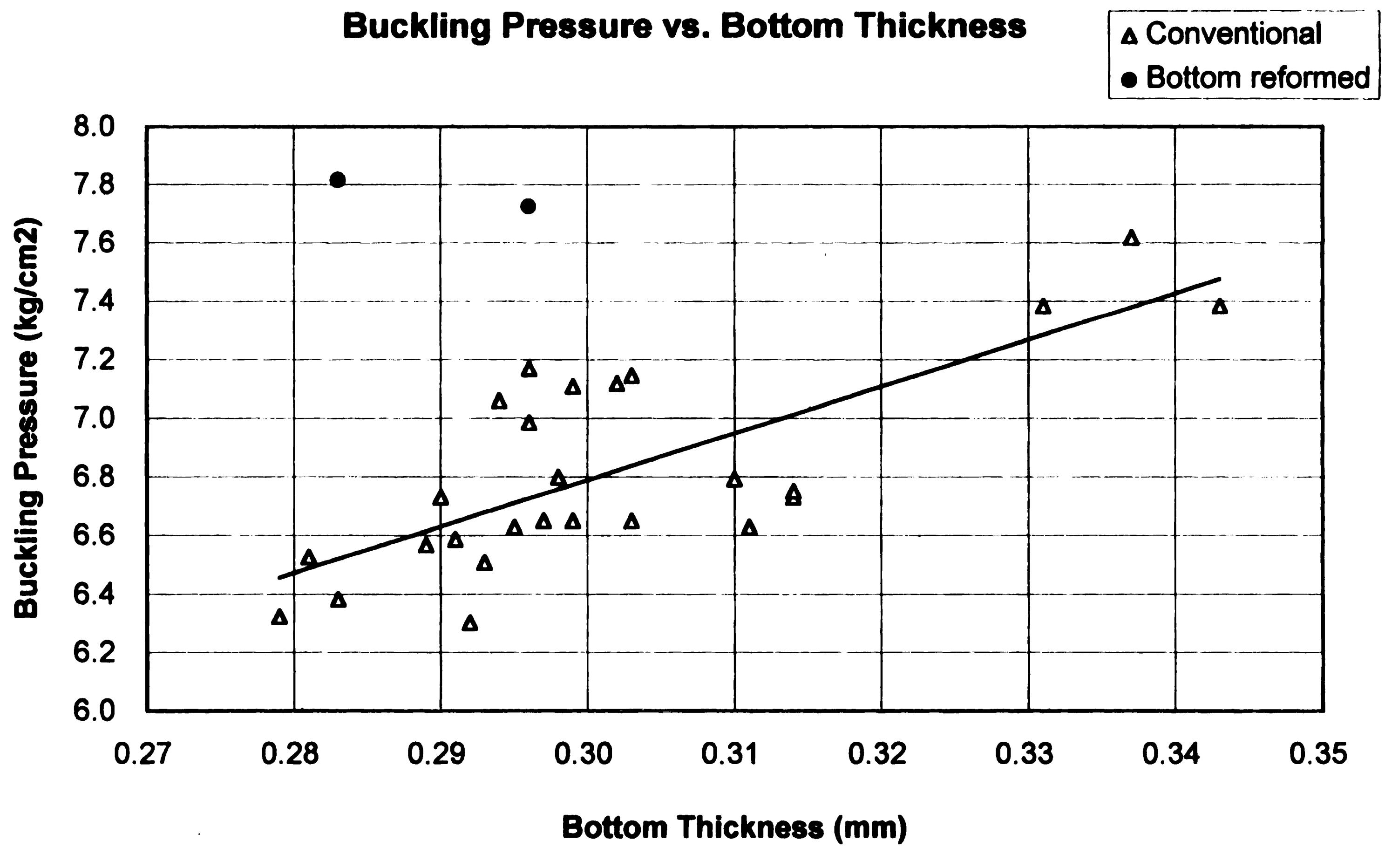


Figure 6-17 Buckling pressure vs. bottom thickness for commercial can bodies

Source: Mitsubishi Materials Corp. and Sumitomo Light Metals Corp (6-13)

The resistance to the inner pressure of the bottom, called bulge strength, has to be guaranteed to be greater than 6.3kg/cm^2 (90 psi). As shown in Figure 6-16, the bucking pressure is higher than 6.3 kg/cm^2(90 psi). but some can bodies have much higher pressure resistance than 6.3kg/cm^2(90 psi). There are two data points which are significantly different from the rest. The can bottoms represented by those points were made in different way, by reforming.

Bottom reforming

The conventional bottom is formed by a body-maker, a redraw-and-ironing press, immediately after wall ironing. It is difficult to make the stand radius small enough to increase the bulge strength of the can bottom because a small stand radius, less than 1.0 mm (0.039 inches), leads to cracking at the inner transition wall.

Forming the bottom in a separate operation after necking makes it possible to decrease the stand radius of the bottom. This process is shown in Figure 6-18.

Further reduction of the bottom thickness requires an extra bottom forming process, called bottom reforming. There are two bottom reforming approaches: forming the outer nose wall and forming the inner transition wall. In Figure 4-2, further lightweighting of the can body in 1995 was done by this process. Bottom reforming can also be used to decrease the base diameter.

As the diameter of the end was decreased from 206 to 204 or 202, the need arose for bottoms with better stacking capability. For better stacking, the bottom of one can should lock into the top of another. To achieve this goal, the base diameter needed to be reduced. Unfortunately, smaller base diameters have often lead to bottom wrinkling, caused when the metal is not sufficiently restrained during the redraw operation.

The primary advantage of a smaller base diameter is increased resistance to internal pressure, making a lighter bottom possible. Disadvantages include decreased column strength because of deformation of the outer nose wall and increased tendency of cans to tip over in conveying systems. Table 6-7 shows an example of test data of the reformed bottom (6-12).

Table 6-7 Bottom performance of reformed bottom

Bottom Thickness	Buckling Pressure	Column Strength	Drop resistance
0.269 mm	6.74 kg/cm^2	140 kg	152.4mm

Figure 6-19 shows the bottom weight corresponding to the bottom thickness based on data from Chapter 4. The weight of a 0.299 mm (0.0118 inches) thick bottom is 3.33g (0.00734 pounds), assuming the area of the cup which is formed into the can bottom is constant. In reality, a deeper can bottom or a more complicated shape can increase the area somewhat.

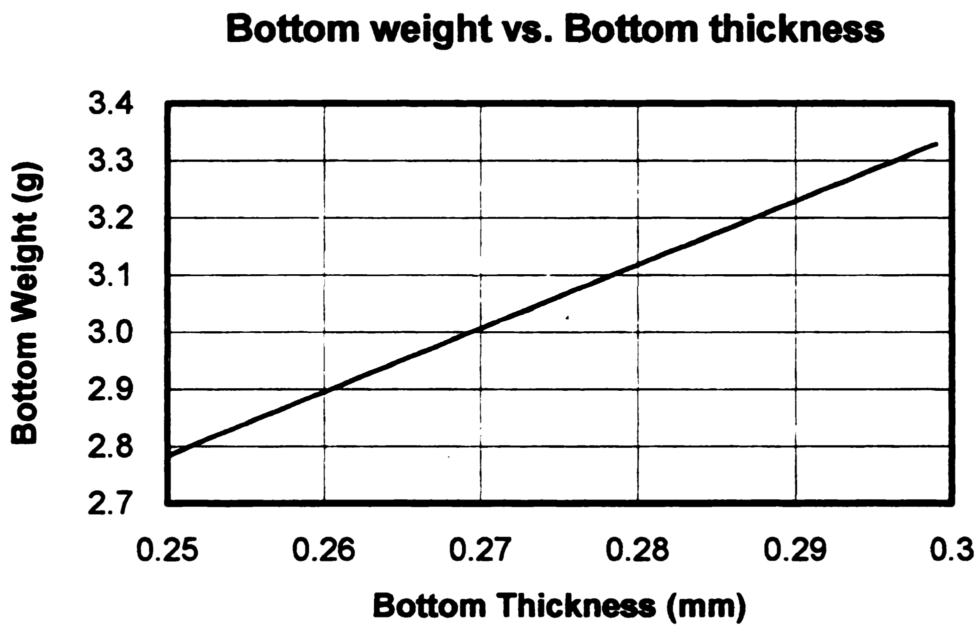


Figure 6-19 Bottom weight vs. Bottom thickness

In the future, through the use of bottom reforming, aluminum beverage can bodies with bottom thicknesses less than 0.270 mm (0.0106 inches) may be common. In the case of 0.265 mm (0.0104 inches) thickness, the bottom weight will be 2.95g (0.00650 pounds), a reduction of 11.4 percent.

Can End weight reduction

As discussed in Chapter 4, lightweighting of can ends has been accomplished by reducing both the end thickness and the end diameter. A decrease in the thickness of metal used has accompanied the reduction in end diameter. It has changed from the 0.33mm (0.0130") in 209 diameter ends to 0.22mm (0.0088") in 202 diameter ends. Further reductions in can end diameter and thickness are anticipated as the effort to lower costs continues.

Further decreases in end diameter would allow for the use of lighter gauge metal even if the basic design of the end were unchanged. However, by modifying the geometry of the ends, additional lightweighting can be achieved.

The buckling strength of can ends can be increased by changing their shape. A recently developed end has a deeper profile than the older ends, with a deeper countersink, a panel wall that is more perpendicular to the horizontal plane, and a smaller bend radius. In summary, the newer design enhances resistance to buckling by changing the geometry of the end.

The conventional press method of manufacturing can not accommodate the complicated geometry, so reforming of can ends has become a common manufacturing technique. In addition to being able to manufacture the more complicated end, reforming puts more work hardening into the end metal at some locations such as small radii than conventional designs.

Lightweighting of the can ends is well underway in the US. All of the major beer companies have changed end diameters from 206 to 204. Soft drink companies are changing from 206 to 202. There was a controversy among the can manufacturing and beverage industries, whether switching from 206 to 204 or 202 was the best way to reduce cost. There is still some uncertainty about both can making and beverage filling technology. The first change was made by a large beer company which switched to 204. Other beer companies soon followed. One of the concerns was settled by successfully filling more than 2000 cans per minute. A large soft drink company switched all of their US plants to 202 ends in 1995. Other soft drink companies are joining the movement.

The further reduction of the can end diameter will be difficult because of problems with both can making and can filling, but the big problem will be the smaller size of the aperture to pour the product which can be fitted into the can end. Significant change in can end design will be required.

End designs which don't use the conventional "stay-on-tab" have been developed. The present can end design requires a large enough diameter to accommodate the tab and the aperture. A 200 end does not have enough room for a conventional tab. There have even been complaints about pouring difficulties even with the 202 ends.

Figure 6-20 shows the trend in end thickness (6-14). From Figure 6-20, the 200 can end can be reduced in thickness to 0.203 mm (0.0080 inches). If the shape is the same as the present 202 end with 0.224 mm (0.0088 inches) thickness, the weight will be around 2.12 g (0.00467 pounds).

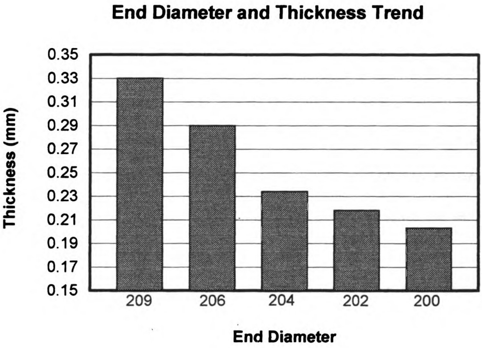


Figure 6-20 End diameter and thickness trend
Source: Dr. David R. Sergent, International Can Manufacturing Technology, Chicago, September 1995.

Aluminum metal for cans

As noted in Chapter 4, the largest fraction of the total cost of an aluminum can is the aluminum metal, 56.7 percent for the can body and 78.2 percent for the 206 can end (Table 4-1 and 4-2). Over the years, the price of aluminum has been affected by various factors. The price decrease in the early 1990's may have been the result of excess supplies from Russia. Similarly, the price increase in 1995 may have been because of supply restriction by Russia. Figure 6-21 shows the aluminum metal price for the past fifteen years. As can be seen, there have been large price fluctuations. The difference between the highest and lowest prices was about 0.6 dollars per pound (1.3 dollars/kg). The price in 1988 was more than twice as high as in 1985 or in 1993.

It is not easy to reduce the weight of aluminum cans. Even a 10 percent reduction requires extensive research and testing and heavy capital investment. The savings achieved can easily be counteracted by metal price fluctuations. A decline in the price of aluminum will decrease the cost of aluminum cans without any further effort. An increase in the price of the metal will raise the can cost, even if extensive efforts are made to control the costs.

Aluminum is relatively expensive compared to other packaging materials. Therefore, recycling of aluminum is an important business for the aluminum can industry. Figure 6-22 shows aluminum can recycling rates and aluminum can shipments for the last 23 years. As shown in the Figure 6-22, following the steady increase of the aluminum can shipments, recycling of aluminum has increased. In 1994, the rate reached 65.4 percent. This high recycling rate was the result of the value of aluminum metal from used beverage cans (UBC) and the amount of UBC available. The value and volume of UBC made the recycling of the aluminum cans into a profitable business. Figure 6-23 shows the price of aluminum on the London Metal Exchange (LME) and the price for aluminum from UBC. The prices of aluminum UBC follow the LME prices.

However, it should be noted that the difference between the LME price and the UBC price has been almost constant for four years. The average of the difference was 0.124 dollars per pound. This number can be assumed to be the cost of recycling UBC's. The recycling cost, including profit for the recyclers, is much lower than the UBC price.

It is expected that the UBC recycling rate will increase further in the near future. If the recycling rate increases significantly, the overall supply of aluminum will increase. A high recycling rate will contribute to the stability of the aluminum prices. However, a large volume of recycled aluminum will be needed to influence the aluminum market.

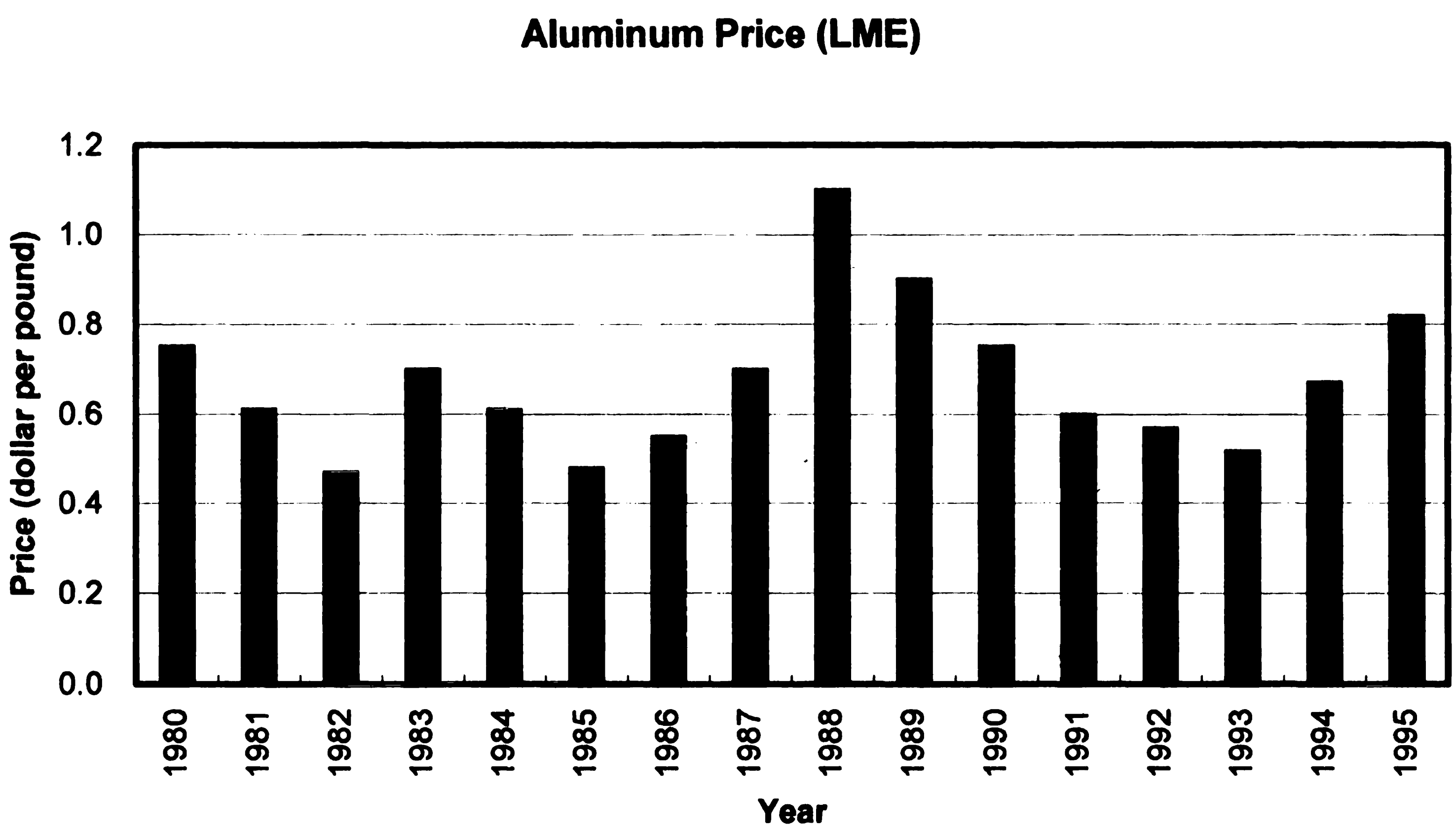


Figure 6-21 Aluminum Metal price
Source: The Canner, June 1995 (6-15), (6-16)

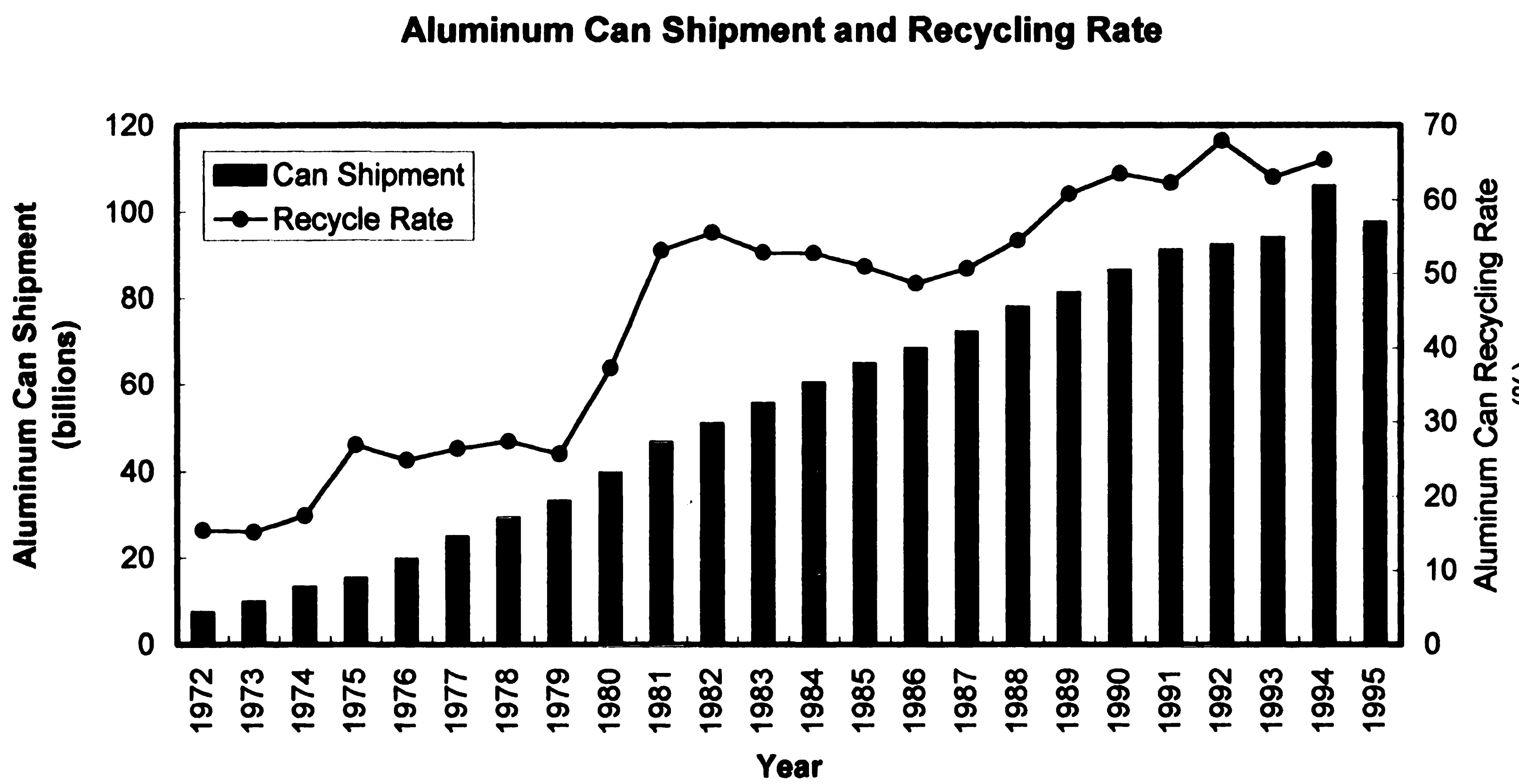


Figure 6-22 Aluminum can shipment and recycling rate
source: Aluminum Association Inc.
Can Manufacturers Institute
US Department of Interior, Bureau of Mines

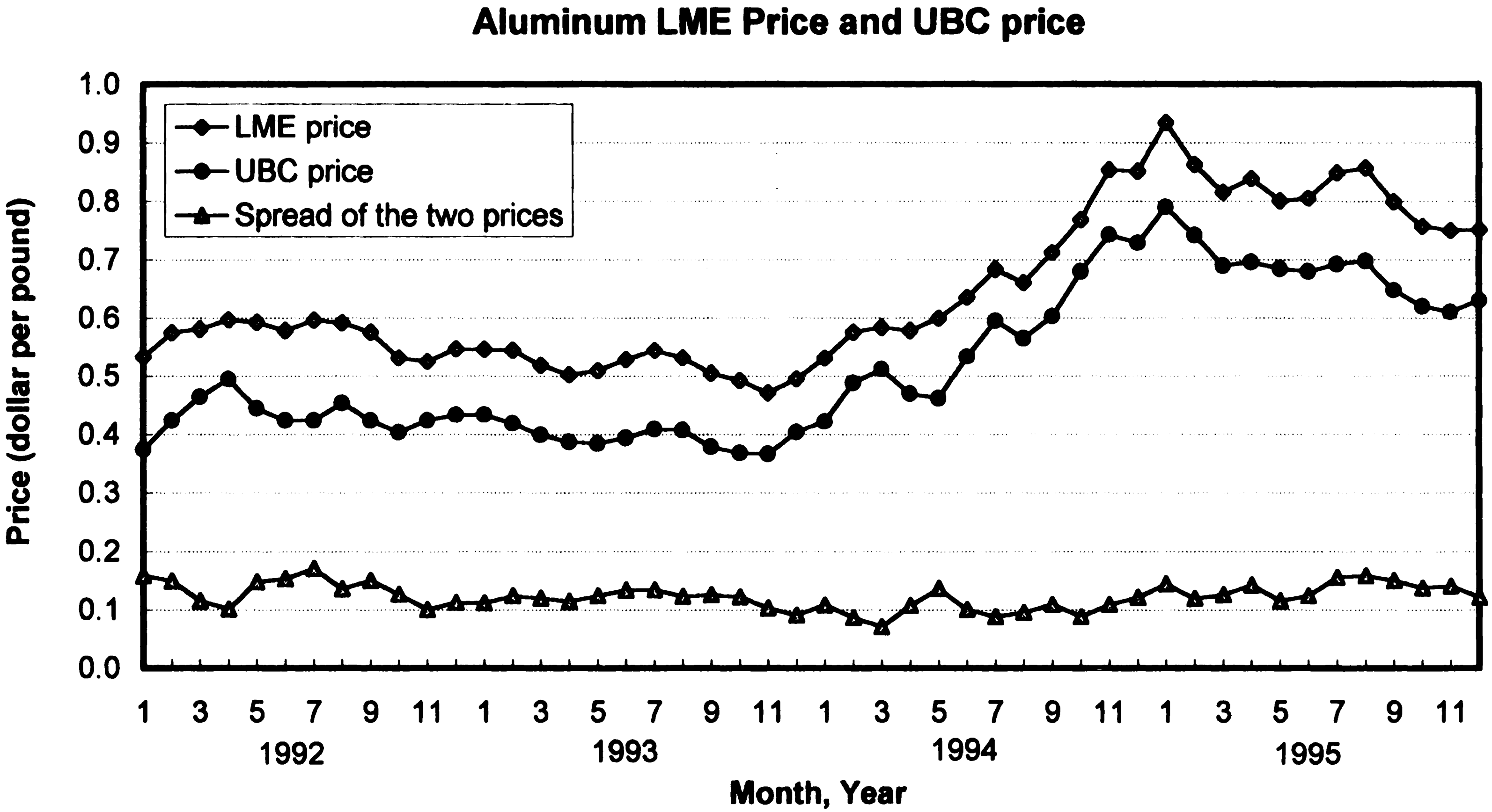


Figure 6-23 Aluminum metal price and UBC (used beverage can) price
Source: Resource Recycling, June 1995 (6-16), (6-17)

Chapter 7

Discussion and conclusion

Aluminum can market

Metal cans were the second largest sector in the packaging industry in 1993. About 73 percent of total can shipments in 1994 were aluminum cans. Aluminum can shipments are still increasing, but the rate of increase is getting small. The competitors are PET bottles for soft drinks and non-returnable glass bottles for beer. The use of PET bottles is increasing faster than the use of aluminum cans.

Cost of aluminum can

The costs of aluminum can bodies and ends have been reduced, primarily by the reduction of the metal weight. The metal cost is the highest component in the total cost. The metal in a 12-oz aluminum can accounts for about 56 percent for the cost of the can body, and 78 percent of the cost of the can end (206 diameter).

Reduction of aluminum weight

An aluminum can consists of two parts, a can body and a can end. The can body can be further divided into three parts, a thick wall area, a thin wall area and bottom area. The possible techniques to reduce each weight or thickness are as follows.

Thick wall thickness:

The thick wall thickness must be thicker than the middle of the can wall to get better neck formability. Therefore, the thickness depends on the neck forming technology. There are three neck forming processes; die-necking, spin-necking and spin-flow-necking. Spin-flow-necking, the newest necking process, is the most promising process to reduce the weight of a thick wall area.

Thin wall thickness:

The limitation to reduction of the thin wall thickness has been the column strength of the can body. The column strength standard in the US is 90.7kg/cm^2 ~ 136kg/cm^2 (200 lbs ~ 300 lbs), required to resist axial loading during the seaming process on the filling line. However, new types of seamers have recently been developed which apply lower axial loads during seaming. It is anticipated that the column strength standard will be lowered significantly after the introduction of the new types of seamers, and factors other than column strength will limit the thin wall thickness. Resistance to hoop stress caused by internal pressure is one factor that will limit further reduction of the thin wall.

Bottom weight:

The bottom weight is determined by thickness and shape. The bottom is designed primarily to resist internal pressure, up to 6.3 kg/cm^2 (90 psi). Well designed can bottom shapes allow a light-weight can bottom. The bottom reforming process is the most promising method to reduce the bottom weight further.

Can end weight:

The weight of can ends has been reduced by reduction of the end diameter and reduction of the end thickness. Reducing of the end diameter enables reduction of the thickness of the can ends because a smaller can end has a higher inner pressure resistance compared to a larger one with same thickness and similar shape. Historically, the weight reduction of can ends has been done drastically by reducing the diameters. The weight of the can end was reduced by 9.2 percent by switching from 206 to 204 and 26 percent by switching from 206 to 202. Assuming the metal cost of a 206 can end is 78.2 percent, it can be estimated that the cost of a 204 can end will be 7.2 percent lower and that of the 202 end will be 20.3 percent lower.

Future weight reduction

The typical 355 ml can body weighs about 11.3 g. The weight of a can body can be reduced to around 10.1 g using new technologies in the near future. It would be about an 11 percent weight reduction, and about 6 percent of total cost reduction.

There are uncertainties about future can end weight reduction. Switching to smaller ends from the 202 end will require that some problems be solved. New type of ends may be required for further diameter reduction, such as from 202 to

200. The most immediate problem limiting size reduction below the 202 diameter is the loss of aperture area on the end. Consumers may find that the aperture is too small for convenience when pouring the contents into a cup or when drinking from the can.

There are many cans with a 200 can end on the beverage market in other countries, including Japan. Most are steel can bodies with aluminum ends, but some are aluminum two-piece cans. The Japanese experience may not be directly applicable to the US market. The Japanese cans, 160 to 250 ml, are smaller than the standard 12 oz US cans (355 ml). Also, the products in the cans are coffee or fruit cocktail drinks, not carbonated beverages.

Research is underway to develop a new can end which does not use a tab. However, to date, there has not been a promising development. Time will be required to develop an effective end at the 200 size. If using a similar shape of shell, the shell weight reduction will be 14.5 percent. The goal of the end weight reduction at the next step will be more than 12 percent.

Therefore, the future possible total can weight reduction will be 11 ~12 percent.

Effect of aluminum metal price

It has been shown that the cost reduction of the can body and the can end by lightweighting, can yield a total cost reduction of about 11~12 percent. However, the percentage change in the price of aluminum metal has been greater. The average of low prices of aluminum metal in 1982, 1985 and 1993 was around

0.5 dollars per pound, but the average of high prices in 1988, 1989 and in 1995 was around 0.9 dollars per pound (Figure 6-20). The price of aluminum cans depends primarily on the price of the aluminum metal.

Stability of the aluminum metal price is a basic requirement for stability of aluminum can prices. The price of aluminum is based on the relationship of supply and demand. If a new use of aluminum metal for a big industry, such as the automobile industry, develops, the price of aluminum may increase due to larger demand.

The supply condition isn't likely to change significantly because aluminum refining requires a large supply of electricity and huge capital investments.

Aluminum recycling will be a very important factor to help stabilize the price of aluminum metal in the future. The recycle rate of aluminum has been increased since the introduction of aluminum cans. The prices of UBC (used beverage cans) fluctuate according to the LME (London Metal Exchange) prices. As seen in Figure 6-22, the difference of the UBC prices and the LME prices is almost constant. The average of the difference of those two prices is about 0.124 dollars per pound. Therefore, it can be assumed that the cost of recycling the aluminum UBC is 0.124 dollars per pound including the profit for recyclers. The high recycle rate of aluminum cans will help to control the price of aluminum. Most of the recycled aluminum comes from UBC's. The recycle rate of the aluminum cans in 1994 was 65.4 percent. The fraction of aluminum used for cans in the total aluminum market is about 15 percent (7-1). This amount is not enough to contribute to the price reduction of aluminum metal. However, in the future, a considerable amount of used aluminum from other products will start to be recycled and if the recycle rate of aluminum UBCs increases significantly, such as above 80 percent, recycling should lower the price of aluminum metal.

The situation is different for other packaging materials, such as PET bottles. Recycled PET is more expensive than virgin PET (7-2) because the recycling cost is higher than the cost to make virgin material. A higher recycling rate may mean an increase in price.

The aluminum recycling system will be an important factor for aluminum cans in the future to maintain competitiveness.

Future aluminum can

Cost reduction of aluminum beverage cans to maintain competitiveness has been discussed. Cost reduction by reducing the can weight will continue gradually. The biggest factor of the aluminum can cost is the price of the aluminum metal. To improve competitiveness of aluminum cans, actions other than reducing costs will have to be taken. One is to increase the value of an aluminum can as a beverage container, that is, by enhancing the attractiveness of aluminum cans. The summary of present advantages and disadvantages of aluminum cans in the beverage containers market compared to other packaging is as follows.

Advantage	Disadvantage
Consumers viewpoints:	Consumers viewpoints:
• Hermetically sealed • Good shelf life • Light weight • Quick chill • Good recyclability	• Perception of metallic taste • Not resealable • Not see-through
Beverage marketers view points:	Beverage marketers view points:
• Long shelf life • Good tamper resistant • Light weight • Stackable	• Limited shape option • Limited size option • Limited graphic option • Not resealable

Some of the disadvantages shown above will have to be reduced to maintain or increase the competitiveness of aluminum cans. Among the items which can improve the attractiveness of aluminum cans significantly are "resealability", "shape option" and "graphic option". PET bottles for soft drinks are resealable, an attractive feature. If a resealable aluminum can is developed, a bigger market will be available. Shape options will also increase the variety and attractiveness of aluminum cans. Simple and plain shapes of aluminum cans are apparently less attractive in terms of appearances compared to glass or PET bottles. The graphic options available for the aluminum can is better than for glass or PET bottles. But when compared to other packaging, such as flexible film or paper boxes, graphics on aluminum cans are less attractive. Improving the graphic options for aluminum cans definitely increases their attractiveness.

The three approaches discussed above will increase the attractiveness and competitiveness of aluminum cans. However, those improvements may also increase the cost of the cans. Simply reducing the cost of aluminum can is not adequate to maintain or increase competitiveness. Some method to increase the value of the cans will be essential to maintain or increase the competitiveness of aluminum cans in the future.

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