SESSION IV

April 25, 1989

Chairmen: W.F. Porter, The Ferroalloys Association - United States
J. Finardi, Associacao Brasileira dos Produtores de Ferroligas - Brazil

Introductory Address:

"Trends and Developments in the Aluminum Industry",
E.L. Rooy, Manager - Metallurgy and Quality Assurance, Aluminum Company of America - USA.

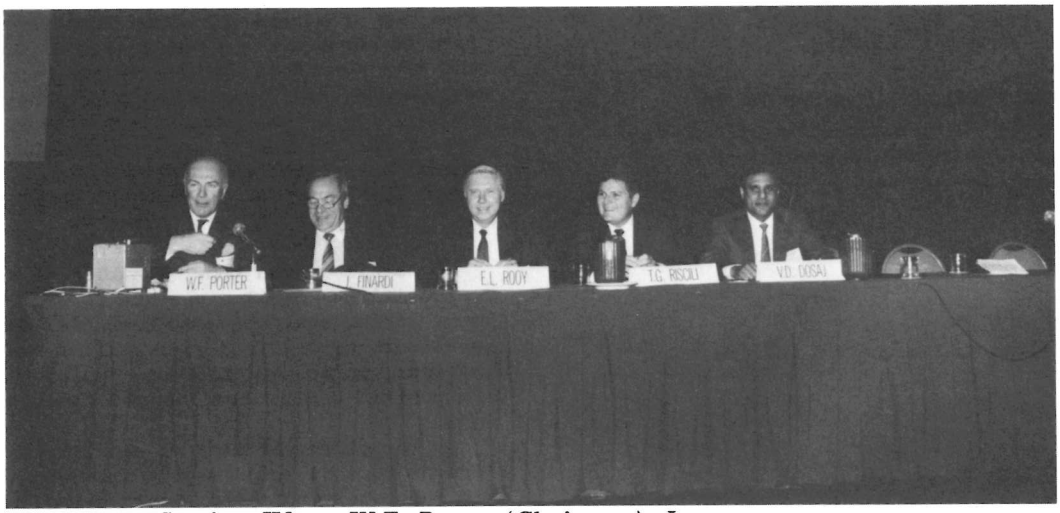
*1. **"Camargo Correa Metais S.A. - Brazil's Most Modern Ferroalloy Facility",** T.G. Riscili, SKW Alloys, Inc. - USA.

*2. **"Plasma Smelting of Silicon",** V.D. Dosaj, Dow Corning Corporation - USA.

*3. **"Silicon Smelting Using Self-Baking Electrodes",** J. Persson, Consultant - USA.

*4. **"The Soderberg Electrode System: Recent Research and Development - New Challenges",** R. Innvaer, Elkem - Norway.

*Papers are found in Volume I of the Proceedings



Speakers at Session IV are W.F. Porter (Chairman), J. Finardi (Co-Chairman), E.L. Rooy, T.G. Riscili, and V.D. Dosaj.

John Persson and Reider Innvaer discuss their papers on self-baking electrodes before making their presentations in Session IV.

Registrants enjoy lunch at the Fairmont.

TRENDS AND DEVELOPMENTS IN THE ALUMINUM INDUSTRY

Elwin L. Rooy

Aluminum Company Of America

INTRODUCTION

The Aluminum Industry has just celebrated two centennials. In 1986 we honored the 100th anniversary of the nearly simultaneous discovery by Charles Martin Hall and Paul Heroult of an economic and practical method for separating aluminum from its oxide. Last Thanksgiving day marked one hundred years since the first commercially produced aluminum was tapped from an electrolytic cell of the Pittsburgh Reduction Company which became the Aluminum Company of America.

The growth that followed (Fig.1) could not have been achieved without the contribution and support of a much older industry, the ferro-alloy, master alloys, and metallurgical metals firms that had served the needs of the metals industry even before the advent of the industrial revolution.

It's not surprising that alloys of the infant metal would rapidly exceed in importance the unalloyed or relatively pure product of the smelting process. The surprising fact was how much was known at the moment Arthur Vining Davis and Charles Martin Hall labored to pour those first aluminum ingots one hundred years ago about the engineering characteristics, fabricability, and castability of aluminum when alloyed with other elements. Knowledge that manganese additions produced work hardening alloys displaying an excellent range of properties, that copper was a potent hardener, that silicon improved casting characteristics, could be immediately applied to the development of applications for the new metal, and to spur an expansion that remains one of the dramatic sagas of modern industrial experience. The alloy based materials knowledge that existed in 1888 as a result of the earlier pioneering efforts of Oersted, and Sainte-Claire DeVille would continuously expand to fuel and support growth of the Aluminum Industry, but not in the absence of sources of vital alloying elements.

In time an extremely valuable relationship of aluminum producers and alloy suppliers would form to enhance the product capabilities of the aluminum industry, foster new product developments, and improve the competence and reliability of the manufacturing process. It's been a partnership of interests with unusual mutual advantages and benefits.

ALLOYING ELEMENTS

As all of you know, established alloy compositions for aluminum are in use. With some variations, the most common alloys and even more specialized compositions are international in scope. Elements employed in these compositions fall into several categories.

The first contains major alloying elements, one or more of which may be intentionally added in substantial proportions to bring about controlled changes in engineering performance. Elements in this category are copper, lithium, magnesium, manganese, silicon, tin, and zinc.

Another category of elements added to aluminum may be described as minor alloying elements. To some extent these elements, added in smaller concentrations, alone or intermetallic form, are notable as a means of controlling or influencing metallurgical structure already dominated by the presence of major alloying elements. Their contributions may be minor in name only. In many cases these additions are not simply desirable but are essential in the development of required material characteristics. Examples of minor alloying elements are: beryllium, bismuth, boron, chromium, lead, phosphorus, sodium, strontium, titanium, vanadium, and zirconium.

Curiously, my third category,significant traces, is largely populated by elements already listed in the first two categories. In metallurgy, as in all of nature, little exists that is not a mixture of blessings. Lithium and sodium that offer legitimate advantages in certain alloys are destructively harmful in others. Magnesium, as ubiquitous as its value in both wrought and cast alloys, must be severely restricted in most die casting compositions and in products for porcelain enameling. The following list of significant trace elements must therefore be considered on the basis that more than one metallurgical purpose may be served, and that implications are not necessarily harmful: antimony, beryllium, calcium, iron, lead, magnesium, phosphorus, silicon, sodium, strontium, and zirconium.

Certain of these elements are more important than others. Only a few will be discussed more fully in this presentation.

NEW PRODUCT DEVELOPMENTS

The aluminum industry takes pride in its history of achievement in the development and exploitation of material advantages in conquering markets. While the rate of new product development has slowed, largely because of a shift to a non-product oriented focus that in part reflected a belief that the industry and its markets had matured, there has been a refreshing resurgence in activity which will lead to renewed vitality and an increased rate of industry growth. This change in management strategies does not deemphasize process development and improvement but underscores the product development opportunities that have always existed for our metal, and the qualities of leadership necessary to exploit them.

Most notable of current major development programs are the aluminum food can, aluminum-intensive automobile, aluminum-lithium alloys, and various material composites.

The food can, with an annual potential of 400 million pounds, will probably not depart from the alloys that have succeeded in the beverage container market. As in the case of the beverage container, recycling will be a critical issue.

The use of aluminum in automobile construction is already a success story. The average automobile now contains about 150 lbs. of aluminum in various forms that include such diverse components as pistons and brake calipers, permanent mold cast or forged wheels, intake manifolds, transmission cases, body sheet, and decorative trim. This can't be nearly enough, given the weight savings and corrosion virtues of aluminum that are directly translatable into fuel efficiency and long-term value. For these reasons, a number of automotive programs involving suppliers and manufacturers in intensive cooperative concept and manufacturing studies now exist. Recognize that the most aluminum-intense production passenger vehicles on the road today comprise over 600 lbs. of our metal and still fall far from the unit utilization of aluminum projected in the most aggressive and exciting of these programs.

It's equally interesting and reassuring that the applications that will be important in the expanded future role of aluminum in automobiles are traditional in both process and alloy: castings in hypoeutectic and hypereutectic silicon ranges, common alloy extrusions, and aluminum-magnesium-manganese and aluminum-magnesium-silicon alloy sheet.

The aluminum-lithium alloy development programs involving aerospace/airframe manufacturers and high strength aluminum semi-finished extrusion, forging, sheet, and plate producers, target a potential market of over 150 million pounds per year. But much of this market is already satisfied through existing aluminum alloy products, so success of the lithium containing alloys can be viewed as one more step in meeting the never-ending demands of our customers for down-weighting and higher strength/weight ratios. It may also be considered a successful defensive strategy for the aluminum industry in its competition with emerging material alternatives, especially composites, laminated structures, and polymers.

With the exception of the lithium alloys, there are only a few new compositions of potential significance. Alcoa has developed a range of powder metallurgy based compositions. One of particular interest is an aluminum-iron-cerium alloy for elevated temperature use. An aluminum-copper-nickel-magnesium alloy with 17% silicon was also developed specifically for its unique elevated temperature properties and advantages of such a composition in high specific output engines. Composites are coming along, but progress has been slow, especially in applications development. These technically intriguing materials offer reassurances; nearly all characteristically incorporate traditional matrix alloys.

Elements relatively new to advanced research are germanium and scandium, neither of which can be considered commercially important at this time.

Aside from the emerging materials and alloy aspects of aluminum technology, I'm sure you've noted that the most significant development in our industry is the drive for higher quality, more consistent and reliable property development, and reduced variability in product performance. Mechanical and physical property control and development are, increasingly, functions of the alloy consistency, improved metallurgical structure control, and minimization of the harmful effects of hydrogen and inclusions. In each of these areas suppliers of alloying products to the aluminum industry are indispensably involved.

INDUSTRY TRENDS

Any discussion of new product and alloy development is technically interesting and exciting, but understanding the magnitude and scope of forces acting on the aluminum industry today overpowers the importance of all other considerations. Examine with me a few observations:

1. The aluminum industry is today truly international.

2. Domestic primary aluminum production will not be expanded beyond the capacities of existing smelting facilities.

3. The European and, to a lesser but significant extent, the U.S. aluminum industry face new risks caused by the growing geographic separation of primary production from major fabricating and consuming markets.

4. Primary aluminum is a U.S. dollar-based commodity. The impact of exchange rate fluctuations must be considered a major complication in stabilizing prices and in creating the conditions that regulate international competition.

5. Longer term, the industry must accept and prepare for the possibility that the governments of energy-rich aluminum-producing countries will determine that their electric power advantages are national resources that justify an OPEC-style cartel with the power to dramatically affect pricing and world supply.

6. There will be an expansion of world aluminum production capacity but such expansion will take place in low energy cost nations such as Canada, Venezuela, Brazil, and Australia.

7. For the United States, and ultimately for the rest of the aluminum consuming world, recycling and resource recovery will become increasingly important.

8. No new smelting technologies will be introduced in the foreseeable future.

9. On the basis of the best assumptions, the United States will become an importing nation with respect to aluminum requirements exceeding domestic smelting capacity. Most imports will be of unalloyed smelter ingot for remelting, casting, and fabrication in North American facilities. Semi-finished products will be imported but only for specialty applications with unique or cost/value advantages over domestic products.

10. Emphasis on quality will place new demands on aluminum suppliers and will become an international competition as critical as cost. For those converting solid and molten aluminum to remelt or wrought compositions, these pressures will translate to an emphasis on chemistry control, uniformity, and the reproducibility of metallurgical features. Many parameters of quality measurement will directly concern the chemistry and process performance of metallurgical metals and master alloys employed in our operations.

11. No producing firm in the industry today has an ability to effectively influence pricing; only firms better or more poorly disposed to exploit price movements.

Pricing strategies and systematic pricing movements which could be controlled, influenced, or projected in the past are no longer viable. Government subsidized smelters in third world nations, consortiums, partnerships in new internationally based smelting facilities, and international agencies of exchange now impact trading, pricing, manufacturing, and marketing, to bring about the new rules under which we operate.

Labor and energy costs in the United States make it unlikely that any expansion of aluminum production could take place in the United States. This conclusion is supported by the improbability of new technologies altering the balance in favor of domestic production. The reinforced conclusion forces our attention on new world sources of aluminum production.

Figure 2 describes world aluminum production and trends so strongly influenced by manufacturing costs. Another analysis of value in understanding domestic trends is presented in Fig.3, which compares imports, secondary recovery, and primary production.

The situation interestingly is a two-way street though it's not usually viewed this way. When we think of new smelting capacity in Latin America, along the Persian Gulf or in Oceania, we view this activity as a threat to domestic aluminum production and to the world supply-demand relationship. Inevitably, the relative wealth and consumption rate of the United States and other more highly developed regions have caused production from new currency hungry international smelters to find its home in our markets. It is, as Theodore Tschop stated, the growing separation of areas of Primary Production from the metal's (aluminum's) main consuming markets.

The sword also can cut in the other direction.

The 1987 per capita consumption of aluminum in the United States was about 60 lbs. Compare that rate with the rate at which aluminum is consumed in the less-developed regions of the globe. In Brazil, 6.4 lbs. per capita per year; in Mexico, only 2.6 lbs. What we can only estimate to be the total amount of aluminum used in China per year would be significantly increased if just one aluminum can of beverage was consumed each day by each of its one billion citizens. Table I provides some further insight on this critically important issue.

With the right market development emphasis and with the determination to become aggressive exporters of semi-finished aluminum products, the global market growth opportunity for the aluminum industry is seen to be immense. The domestic industry need not fear long-term

penetration of valuable markets here, nor should we be anything but enthusiastic about our own opportunities to expand internationally.

Instead of the despair often expressed over the conditions of international competition, we should resolve to serve our own and world interests through promotion of our manufacturing and marketing strengths. Our objectives should be to achieve the most rapid growth in the use rate of aluminum in all product forms throughout the world; to absorb regional production capacity at its source; and to capitalize on our own manufacturing strengths in developing and expanding export markets.

If we consider ourselves to be the pacesetters in industry developments, then resource recovery, primarily in the recycling of aluminum, can be expected to grow in all regions in which aluminum is consumed. It makes such good sense that we should be dedicated to the task of extracting from civilization's waste, usable components which fortunately feature large quantities of essentially uncorrodible aluminum.

In the U.S. today, scrap consumption is at approximately 40%; in Europe, only 10%; in other parts of the world, waste recovery or recycling is practically non-existent. We are currently recycling more than half of the beverage cans produced in the United States. That rate will not decline and can only increase with mandatory recycling legislation and local waste segregation efforts. The exciting recent history and dramatic growth of can recycling in the U.S. are described in Fig.3.

Let me now review two metals of particular importance to the Aluminum Industry.

MANGANESE

As previously mentioned, manganese is one of the more valuable alloying elements known to be useful in aluminum. Alloys of aluminum and manganese display a high degree of corrosion resistance, and attractive physical and mechanical properties. Formability in deep drawing and drawn and ironed applications is excellent. Light gauge products such as beverage containers emphasize the value of manganese in alloy construction.

But even before the emergence of the drawn and ironed container as the industry's most significant product, manganese was widely used in a large number of wrought compositions, for extrusion, as well as flat-rolled products including sheet, plate, and foil. For wrought alloys, the element has been recognized as being second only to magnesium in breadth and quantity of usage. Of course, manganese is thought of primarily as a means of improving response to work hardening. There is little justification for its presence in the absence of work hardening such as in engineered castings, although Alcoa research has established the basis for increased tolerance for manganese in casting compositions.

Manganese for alloying has been in a number of forms. Initially and for many years, ferromanganese proved acceptable. Later, alloying in the smelter by the charging of electrolytic manganese to the bath became preferred. Iron contamination was avoided in dilute hardener compositions of this type.

More recently, producers determined that a pure master alloy approach was preferable to tying up large amounts of smelter grade metal with as low as 2% manganese content. That time coincided with a tremendous surge in manganese use associated with the growth of the beverage container market. It was a matter of desperate importance that a sufficient supply of manganese be established for alloying to support this growth. For this reason, Alcoa and no doubt other primary producers scrambled to work with suppliers in the development and qualification of manganese-containing master alloys and other alloying forms capable of meeting the industry's volume, quality, cost and operating requirements.

One of the truly important developments was the high concentration powder briquette in which electrolytic manganese was blended and then briquetted with aluminum powder or other aluminum forms such as chopped foil to produce what began as a 50% master alloy and rapidly moved to the 75% level.

The reason neat manganese powder or electrolytic manganese flake could not be used successfully was inadequate solution rate. The dissolution rate of elemental manganese based on diffusion criteria is poor, and inadequate for metal constrained high capital cost casting facilities. In Alcoa's case, an emphasis on truly continuous casting exacerbated the solution rate dilemma. Low cost manganese forms were available, but the time required for solution in production was not. Salt coated, and spatter products were only marginal improvements whose solution performance could not address the full range of operating requirements. The injection of manganese in powdered form was advanced as a means of reducing solution time but limited use of this method commercially suggests again only a marginal improvement in solution rate.

After the ferro alloy producers of the world responded to the significantly increased demand of the aluminum industry for manganese in beverage container sheet, a startling new

development influenced the supply-demand relationship. While it may have been anticipated by some, most felt in the early days that recycling would never play a significant role in marketing or manufacturing. As a matter of fact, there was a lot of initial industry resistance to the idea that recycling should play any role at all. It took a few visionaries to recognize that recycling would be aluminum's greatest weapon in the materials competition for the container market, and could be used effectively in the development of additional mass markets.

With recycling, however, came a built-in supply of alloying elements consistent with the compositions used in can manufacture. The higher the recycling rate, the less manganese required by the primary industry to regenerate can sheet. The result was a significant fall-off in demand for manganese in master alloy form. With the recycling rate now approximating 50% (Fig.4), and with some evidence that recycling rate will reach no significantly higher level, continued market growth is again placing pressure on suppliers for master alloy supply (Fig.5). One might also expect the internationalization of the beverage container market to influence the trend for increased manganese usage.

Recycling is also a mixed blessing. It is a self-generating process involving every link in the consumption chain: can maker, brewery, consumer, collector, recycling center, and the secondary as well as primary producer. It's as though the perpetual motion machine has finally been developed and the benefits to each link in the chain are sufficiently powerful that no regression in this cycle can be predicted.

Unfortunately, recycling poses another challenge: the avoidance of contamination which detrimentally affects the recycling loop. When contamination takes place in any form, the recycler must purify the stream or accept contamination that may adversely affect fabrication or product characteristics. If purification must be obtained by dilution, then recycling rate must be reduced to maintain acceptable product chemistries. If, for example, a furnace charge made up of recycled metal contains an abnormally high level of iron or silicon additions of prime unalloyed metal are required to develop an acceptable chemistry. This, of course, also requires the addition of master alloys to compensate for the reduced recycling rate.

In the same way, legislation which will place additional responsibilities on industry to meet limits pertaining to certain sensitive elements will restrict recycling rates unless sources of contamination by these elements can be eliminated. It's then a dynamic situation in which increasingly restrictive limits will be imposed by internal pressures, and by legislation, with the probability that the recycling rate will decrease and the purchase of master alloys for can sheet production will correspondingly increase. And all this is taking place at a time when we are attempting to tighten capabilities with respect to chemistry control for optimum and the most reproducible possible product performance.

The important criteria for manganese in aluminum remain solution rate, chemistry, cost, and recovery.

SILICON

It was established early on that silicon was the most beneficial element available for improving engineered casting results. The aluminum-silicon eutectic is friendly to the foundryman; fluidity is improved with increasing silicon content, tear resistance at elevated temperature is enhanced, and feeding characteristics for gravity casting are excellent. For die casting, exceptionally good casting results and acceptable properties are obtained in aluminum-silicon alloys containing greater than approximately 8% silicon. These compositions most frequently also contain copper for improved strength and hardness.

The true value of silicon to the foundryman was only exploitable after the discovery that certain compositions of aluminum are heat treatable. This took place in the third decade of this century when aluminum-copper alloys were largely displaced by alloys containing silicon which had earlier been too soft for structural applications. But with the addition of a small amount of magnesium for magnesium-silicide formation and the application of solution heat treatment and again principles, the most popular alloys registered and used today for the widest variety of applications resulted.

Certainly, silicon is the most important element in the aluminum castings industry but it is not the only use of silicon in aluminum alloying. Brazing sheet is traditionally comprised of aluminum/silicon alloys. At some time, the American automobile industry will catch up with the rest of the world and we'll begin to see aluminum radiators on our automobiles with the tremendous cost and weight savings that transition from copper represents.

The most common extrusion alloys are alloys containing far less silicon than those of the casting compositions but are nevertheless of the silicon/magnesium heat treatable type.

The use of silicon in aluminum is more tied to the transportation and automotive industries than to any other market. As previously mentioned, aluminum-intensive vehicle programs that emphasize extrusion, castings, and sheet, all concern alloys that contain silicon. Many of the casting applications will specify hypereutectic silicon alloy compositions containing typically from 16 to 25% silicon.

Observations on the impact of recycling in the case of manganese most certainly apply to silicon containing alloys. It could be said that the secondary smelting industry has thrived on a diet of casting and extrusion alloys. And the importance of secondary operations on domestic metal supply has already been emphasized. For further emphasis refer to Fig. 6 which describes the relationship between primary and secondary production through the years. Implications for silicon demand are obvious.

I'd like to digress for a moment into some of the technical aspects of aluminum-silicon casting alloys, because I think these considerations are extremely important both to supplier and consumer. It turns out that there is not one silicon metal composition for use in casting but many with varying impurities having particular relevance to casting results. The foundryman endeavors to obtain specific metallurgical structures in hypoeutectic and hypereutectic compositions that improve casting performance and coincidentally improve the mechanical characteristics of the product. In this country, we refer to the development of a fibrous eutectic metallurgical structure as modification. The elements useful in promoting the formation of a modified eutectic are sodium, calcium, strontium, and antimony. While many other elements are claimed to influence the form of the eutectic, these are potent modifiers and commercial practice is confined to their use.

Refinement of the primary silicon phase in hypereutectic aluminum-silicon alloys, an essential step in producing acceptable castings, is induced by phosphorus additions.

It is pure serendipity that calcium and phosphorus are naturally occurring impurities in available and cost-competitive silicon forms. Unfortunately, all structural modifiers react with phosphorus with harmful consequences. The converse is also true: that the common modifiers, sodium, calcium, strontium, and antimony interfere with the mechanism of primary phase refinement by phosphorus in the hypereutectic alloys.

It is beyond the scope of this presentation to explore these interactions, but their understanding is vitally important to the supplier as well as consumer, and ignoring the importance of impurity levels in the metallurgical metals and master alloys that are used invites process and product related difficulties. For the supplier, failure to recognize the contributions they can make to enhance alloy performance also denies the range of actions they may take to establish product superiority in the marketplace.

Isn't it strange that we choose to categorize our products as commodities when so many opportunities exist for performance differentiation, not only in cost or physical form, but in optimized structure and chemistry for each application.

The pattern of acceptability established for manganese applies as well to silicon, and to most other alloy forms used to establish metal chemistry.

Solution rate, recovery, chemistry, and cost are of essential importance with only small variations or tolerances based on the manner in which the product is used. The uniformity of alloy product, reflected in minimal variations in performance, is becoming increasingly the critical criterion. Sound and aggressive Total Qualtiy efforts are being demanded of our suppliers, exactly as the same demands are being made of us by our customers.

While manganese and silicon have been emphasized in this presentation, it would be wrong to leave an impression that any alloying product used in the aluminum industry today could be considered less critical or less important. In every instance, more uniform, more reliable and predictable, cleaner, more chemistry compatible, more structure-controlled, faster reacting, more fully recoverable, more efficient, and more cost-effective products are demanded by the world competition in our industry.

If our relationships have been exceptional, it's because we have shared mutual objectives, and have worked cooperatively to develop and prove new products for use in aluminum alloying as new market opportunities developed. The greatest progress has been achieved through the closeness of supplier and consumer as the need for new alloying materials were recognized. The increasingly global competition for existing and future aluminum markets demands a responsiveness to industry needs that will be based on an even closer cooperative relationship, more open exchanges, and more mutural understanding and appreciation of technical, economic, and quality consideration.

It's reassuring that your industry has never failed to play its vital role in assisting us in meeting these challenges.

FIGURE 1
GROWTH OF WORLDWIDE PRIMARY ALUMINUM PRODUCTION
1890 - 1990

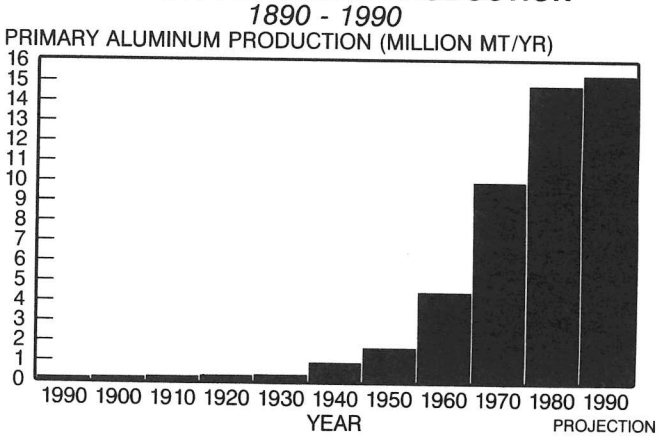


FIGURE 2
WORLD PRIMARY ALUMINUM PRODUCTION
1977 - 1987

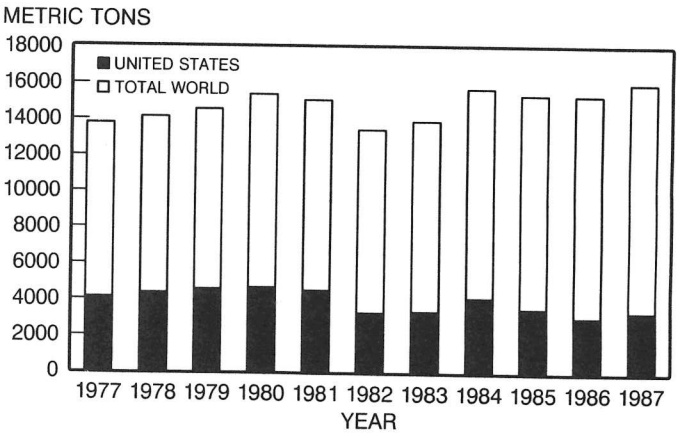


FIGURE 3
U.S. ALUMINUM SUPPLY
1977 - 1987

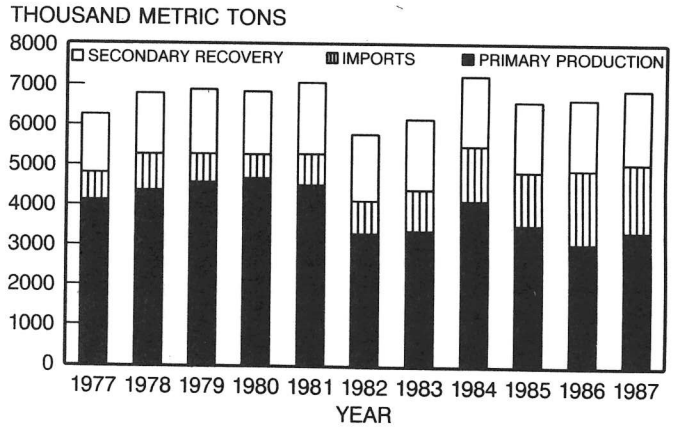
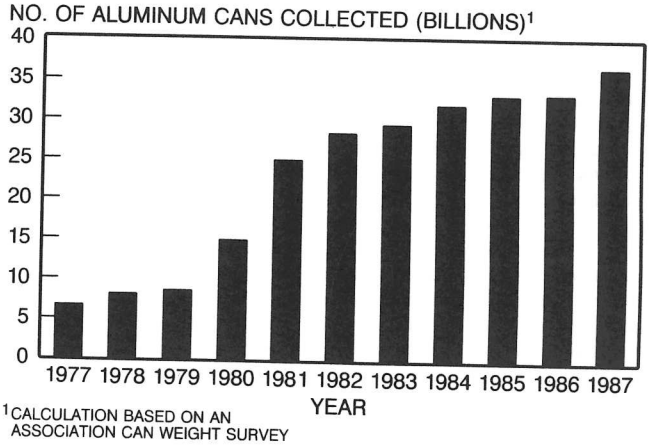


FIGURE 4
ALUMINUM CAN RECLAMATION DATA
1977 - 1987



[1]CALCULATION BASED ON AN ASSOCIATION CAN WEIGHT SURVEY

FIGURE 5
MANGANESE TRENDS
1977 - 1987

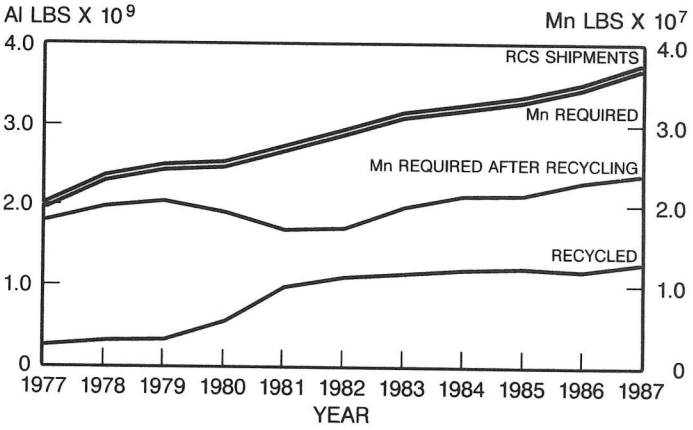


FIGURE 6
PRIMARY AND SECONDARY ALUMINUM PRODUCTION
1942 - 1988

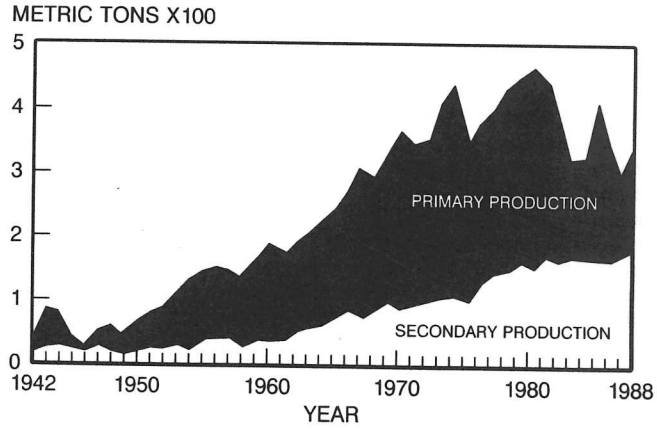


TABLE 1

PER CAPITA CONSUMPTION OF ALUMINUM

1987

	POUNDS
ARGENTINA	5.5
AUSTRALIA	41.4
BRAZIL	6.4
FRANCE	31.5
GERMANY (F.R.)	57.8
ITALY	36.2
JAPAN	49.2
MEXICO	2.6
NORWAY	32.0
SPAIN	14.1
SWITZERLAND	41.7
UNITED KINGDOM	24.0
UNITED STATES	60.4
VENEZUELA	≃ 14.8

SESSION IV - DISCUSSION

"TRENDS AND DEVELOPMENTS IN THE ALUMINUM INDUSTRY"

Q. R.F. Silver, Elkem Metals Company - USA. I believe you stated there would be no new process for the manufacturing of aluminum. Does this mean the aluminum industry has ruled out the possibility for development of direct reduction of aluminum silicon?

A. E.L. Rooy, Aluminum Company of America - USA. I don't think it would be appropriate to rule any possibilities. Tomorrow is always a new day, but after one hundred years of trying with carbothermic systems and with gaseous systems such as the Alcoa Smelting Process that was only recently abandoned, I think that for the foreseeable future will not see any replacement of capital facilities in the type that now exist for smelting aluminum. And, in fact, the new smelters that are going in, committed dollars for Becancour and other expansions taking place in Venezuela and in the Middle East, are applications that will only utilize the Hall-Heroult Process.

Q. O. Metelmann, Mannesmann Demag - West Germany. What kind of solution, or what kind of compound is manganese going into with aluminum? Is it some kind of intermetallic compound or is it just a solution?

A. E.L. Rooy. The ultimate form of the manganese in the aluminum structures that are produced are aluminum manganese intermetallics. These intermetallics when present in normal form under DC, EMC and other forms of solidification are very finely distributed in metallic particles that are extremely attractive from a forming standpoint, for earing control, for drawing and iron operations where tool cleanliness is a factor. The original step, however, is to dissolve the manganese in aluminum. The manganese must be in solution in the furnace on composition before casting operations begin. It is during the solidification process that intermetallics reform.

Q. N.A. Barcza, Mintek - South Africa. Are there going to be trends and change in the microalloying additions as zirconium and titanium in particular as a result of the changing scrap situation of these two materials in the future?

A. E.L. Rooy. I think that the greater opportunity for the use of these elements lies in titanium. I think the entire world stands at the verge of far greater understanding of its role in grain refining mechanism. There has already been a great deal of change in the use of titanium as a grain refiner from different ratios and different qualities of material. I think your question is more broadly stated that these peritectic elements can be a factor by contamination of existing compositions and that they would be a natural background built. The fact that there are peritectic elements, however, does allow some opportunity for precipitation through the use of boron additions to control chemical compositions. The possibility that zirconium might find some broader use is limited by the fact that at relative high concentration levels, and

we are really talking about very low values, perhaps 0.1%-0.2% fairly massive intermetallics are possible and these are extremely harmful, destructively harmful, to hard alloy compositions where zirconium is used as a grain pinning intermetallic. I have covered the grain refining aspects that on titanium could also apply to zirconium with improved understanding.

"CAMARGO CORREA METAIS S.A. - BRAZIL'S MOST MODERN FERROALLOY FACILITY"

Q. W.G. Porter, Shieldalloy Metallurgical - USA. While the presentation was on describing the facilities and the mode of operation, can you give us any ideas as to what marketing arrangements have been made, and how the production is being targeted to come into the world market?

A. T.G. Riscili. The only thing we would like to say is that arrangements have been made and we are targeting to export out of Brazil.

Q. W.G. Porter. Could you expand a little bit about what it was like to train and organize, let's say a relatively inexperienced labor force?

A. T.G. Riscili. The advantage that we had was bringing in 30% of the technical personnel from the south. We are very impressed, at the great technical ability that they have in Brazil. The young metallurgists that are coming out of school, with very short experience, are very intelligent and very industrious people.

"PLASMA SMELTING OF SILICON"

Q. W.G. Porter. I understand Dow Corning is putting in an installation for silicon metal production in Manitoba, and I am curious whether this technology is far enough advanced to be a part of that, or do you feel you have additional developments that have to be done prior to commercialization?

A. V.D. Dosaj, Dow Corning Corporation - USA. We do need additional effort. Anytime one goes into a new area of technology, there are a lot of barriers one has to overcome. So we don't believe we are ready at this time to take this technology for a scale up.

Q. C. Shukers, American Alloys, Inc. - USA. My question has to do with the amount of argon used for the silicon production. Could you tell us the standard cubic feet associated or the cubic meters associated with the production of one kilogram of silicon metal?

A. V.D. Dosaj. I could express it in terms of the flow rate of argon which was used. I do not have exact figures for the flow rate of argon for the production of one kilogram of silicon. For the two hundred

KVA we use 900 normal liters per hour of argon. If you are getting at the cost involved of argon towards the cost of silicon, we believe that the cost of argon is minimal.

Q. J.K. Tuset, Sintef - Norway. I have a couple of questions. It was not quite clear to me how you charged your quartz. Was it together with the silicon carbide through the shaft, or was it separately charged into the arc zone?

A. V.D. Dosaj. Quartz was mixed with silicon carbide and charged together. We believe that the contact and mixing of quartz and silicon carbide in the plasma zone is very important, especially in a small-scale reactor.

J.K. Tuset. It means that you carried out the process in two steps. First you produced the silicon carbide in a separate operation, and then you mixed the silicon carbide with the quartz and continued your production of silicon.

V.D. Dosaj. That is not correct. The process starts by feeding the bottom of the reactor with equal molar quantities of quartz and silicon carbide. That is what you charge in the bottom of the reactor. Assume that you are in a continuous mode of operation, in the bottom of the reactor is quartz and silicon carbide. In the shaft of the reactor is a stoichiometric amount of carbon. Once you apply the energy and smelt for two hours or so, you produce silicon and the shaft of the reactor is converted to silicon carbide. The silicon is tapped, the materials in the plasma zone have been consumed, the silicon carbide in the shaft is mixed with an equal molar quantity of quartz. It is mixed because the silicon carbide is free flowing by putting the quartz right into the top zone the mixture descends together, and the mixing takes place in that process. So there was some development which was carried out to perfect this technique.

Q. J.K. Tuset. So it is sort of a semi-batchwise operation isn't it?

A. V.D. Dosaj. That is correct. Today it is a semi-batchwise process. We believe that the next step is for continuous feeding and charging of the materials.

Q. J.K. Tuset. You mentioned three reactions that were producing silicon monoxide, and you said that the reaction between quartz and carbon was the fastest one of them. Is that on the basis of experimental results?

A. V.D. Dosaj. Yes. We conducted kinetic studies in a TGA reactor, and we studied all three silicon monoxide producing reactions in the temperature range of 1400° to 1900°C and we find that the reaction of quartz with carbon is the fastest of the SiO producing reactions in that temperature range.

Q. J.K. Tuset. Could it be that with your carbon you had a stepwise reaction so that you produced also the silicon carbide, so it was in fact a reaction between quartz and secondary silicon carbide produced by

the reaction between silicon monoxide and carbon? I find it quite difficult to understand that you should be able to have the carbon present together with silica at the temperature of more than 1500 or 1600°.

A. V.D. Dosaj. To explain again, what we measured for kinetics. We did three separate tests. In the first test we took an equal molar mixture of quartz and carbon. We heated the mixture to a temperature as fast as one can in the temperature range of 1400 to 1800°C. We measured the weight loss and generation of SiO. We repeated the same test with a mixture of quartz and silicon carbide in a separate test. In a third test we repeated the same test with silicon and quartz, and in all these three tests we explored the whole range of putting materials together using briquettes, lumps and different size powders. Based on those results of approximately 15 to 20 tests, we consistently found that the reaction of SiO_2 with carbon was the fastest production of SiO when you use equal amounts of quartz and carbon.

Q. G. Rath, Mannesmann Demag Huttentechnik - West Germany. If I understand it right, in this process the silicon monoxide production is part of the process. It will work only to a limited extent when you don't have this silicon monoxide because you don't get your silicon carbide, at least not in a desired range. So it is basically you always have a recycling of your silicon monoxide which seem to be necessary, how is the energy consumption in this respect? The recovery seems to be fine, but when your always recycling monoxide as part of the process you always have to produce it. In the conventional process this silicon monoxide production is limited. But here it seems to be a major portion of the process.

A. V.D. Dosaj. If you look at the process, when one feeds quartz and silicon carbide in equal molar amount of quantities, it is not really very different from what happens in the arc furnace, deep in the reaction zone. Except in an arc furnace one can get non-reactive carbon in the deep zone of the furnace where it reacts with silicon to form silicon carbide. By using the carbon bed concept, one can eliminate or minimize unreacted carbon getting into the reaction zone. Now silicon carbide and quartz react to produce silicon and equal molar quantities of silicon monoxide and carbon monoxide. Quartz and silicon carbide also produce silicon monoxide if one was to put two moles of quartz and one mole of silicon carbide you would produce three moles of SiO and so on. But we are controlling the mixture for equal amounts of quartz and silicon carbide. To some extent one would capture any SiO that has not reacted the silicon carbide in the shaft of the reactor. In an arc furnace silicon carbide and quartz or SiO reacts to form silicon. Here we have deliberately been able to operate the reactor with three active moles of carbon at all times. Silicon carbide having one mole of carbon in the reaction zone with quartz and two moles of carbon, one of which is excess in the shaft zone. And this process carbon is only fed back down into the reaction zone after it has been converted to silicon carbide. The other advantage one sees of this process is one mole of CO has already been removed in the shaft zone and your partial pressures of SiO in the reaction zone are higher. Consequently, you can convert silicon carbide to silicon at lower partial pressures of SiO than you can in a conventional process.

Coming back to your question on energy consumption, the tests we have conducted have been in the 200 KVA reactor. In this 200 KVA reactor we have a lot of exposed area and we are only producing silicon at a production rate of 3 to 5 kilogram an hour, and consequently it is very difficult to project from these rates of silicon production what kind of energy consumption one can expect on a commercial size reactor. Projection of energy consumption from a small reactor to a commercial scale is the only parameter which is extremely difficult. However, to give you a feel for it, the energy consumption in our reactor was of the order of 50 kilowatt hours per kilogram. To compare that we have a similarly sized silicon furnace which is single electrode bottom return, and when you are smelting silicon in that reactor, the energy consumption for that reactor is not too far different from what we have observed.

Q. C.N. Herman. Could you tell us what type of carbon material you utilized? What is the purity of that carbon whether there is any ash forming impurities in it or not?

A. V.D. Dosaj. Carbon we have used in this reactor so far has been limited to charcoal. In our previous tests we have used coalchar as well. Some tests were done with coal and the results, you have seen today, were limited to the charcoal work.

J. Finardi, Bozel Mineracao e Ferroligas - Brazil. I do not agree well with the low silicon recovery when using regular melting process. Fundamental research shows the most important thing for achieving a good silicon recovery is having a very good reducer. In Brazil for example charcoal. When we are running a silicon metal furnace usually with very good conditions with 100% charcoal, we achieve silicon recovery far above 90%.

"SILICON SMELTING USING SELF-BAKING ELECTRODES"

Q. A. Arnesen. Am I right in assuming that the electrode now being tested in Argentina has no graphic core whatsoever, has a steel casing without fins? And has material balance substantiated that the casing which is burned away below the clamps, really is not contaminating this silicon metal? My experience is that carrying an iron spade past the silicon metal furnace will reflect in the iron analysis.

A. J. Persson, Consultant - USA. Yes, you are right when there are fins that are carried down with the casing, but here the casing disappears. Once it leaves the region of the electrode clamps it is gone. It has formed iron oxide which is carried off with the furnace gases.

Q. You mentioned that the presence of an arc can be determined by the shape of the trace on the oscillascope screen. Is there any method of quantifying this? In other words, determining how much arc there is, or how much power is generated in the arc relative to the power that is generated by the resistance component?

J. Persson. Yes, there is. Keyser (Electric Furnace Proc (1987) 203) showed how this is done. It

involves some fairly simple mathematics, but what he calls the arc distortion factor is an indication of how much arc and proportion of joule heating to arc heating. So it can be done, but the computation is a little bit too much to present at this meeting. It will be presented in another forum.

Q. It has been my experience on stubbing electrodes that something happens in the slipping mechanism or you slip a little bit too much, and don't bake properly. Consequently, you get a weakness and stub the electrode. Now with this type of self-baking electrode, I visualize that the length of the baked area is much greater than it would be in a conventional furnace. Is that right or wrong?

J. Persson. If I understand you correctly, I disagree. It is the same situation as in a conventional electrode whatever height of baked electrode you have in a conventional furnace you have here. The column is supported by a graphite core to which the baked material adheres. We have the same geometry of baked electrodes in this electrode as we do in the conventional electrode.

Q. I was concerned about the fact that the working electrode would be heavier than a conventional type self-baking electrode, and therefore it would be more susceptible to breakage.

J. Persson. It is the same size electrode and the same weight of baked material. It all has to be supported by a mechanism from up above, but instead of having fins carry the tensile load we have a graphite electrode. There have been no engineering problems with the electrode, but the concern on the part of the user has been the slipping rate, and this is what we are addressing by baking higher in the electrode.

Q. C.F. Fulgenzi, Union Carbide Corporation - USA. You talked about a 610 and a 700 millimeter system - one with a graphite core, one with a casing that disappeared and because it had no fins the iron didn't get into the furnace. Are these both operating now?

A. J. Persson. Not both running at the same time because they take attention. When it was convenient we ran one on one furnace and followed that, when the opportunity arose on the other furnace.

Q. C.F. Fulgenzi. What are you making silicon metal or ferrosilicon?

A. J. Persson. We are doing the test work on 75% and we also have operated the furnace on calcium carbide.

Q. M. Scairone, CMI - South Africa. How do you handle a break and have to make a very long slip or a start-up? Is that any problem in your system?

A. J. Persson. Well I have mandated no breaks! In start-up we have the same situation as when you have a break. During start-up you provide a temporary casing and bake in the electrode to get a start-up, or

we have done in another case, we have an especially designed stub-electrode of graphite.

"THE SODERBERG ELECTRODE SYSTEM: RECENT RESEARCH AND DEVELOPMENT - NEW CHALLENGES"

Q. K. Festoy, Tinfos Jernverk - Norway. You showed a picture of a new modular holder. Would you elaborate on this? How far have you come with this holder, is it in regular production?

A. R. Innvaer, Elkem - Norway. It is in regular production today in three furnaces: one in Norway and two in Australia. Our Technology Department is about to deliver it to several other furnaces.

Q. K. Festoy. For how long a time have you had it in regular production?

A. R. Innvaer. The first one was installed two and a half years ago.

Q. N.A. Barcza, Mintek - South Africa. Yesterday afternoon in the last session there was discussion about the DC graphite electrode which has been used at Middelburg Steel & Alloys on their Plasma Arc Furnace in an open-bath configuration. There were some potentially negative comments with regard to switching from the graphite electrode to Soderberg electrodes. What is your opinion on that subject?

A. R. Innvaer. The main difference between the two electrode systems, the Soderberg and the graphite, is of course dimension, quality and of course, cost. Electrodes can be produced or can be designed for a diameter up to two meters, but for graphite limit at this point is 0.7 meters. But your question concerns the baking zone and the possibility for baking the electrode.

Q. N.A. Barcza. Can you bake an electrode, in an open arc furnace, made from Soderberg paste? Certainly, you have to go to a larger diameter Soderberg electrode because of its current carrying capability compared with the graphite electrode, although the DC appears to offer, because it doesn't have the skin effect, the ability to distribute the current more evenly, and therefore one presumably doesn't have to go to the same diameter as you would have had to for an AC furnace. The diameter is certainly as issue, but perhaps more importantly, can you actually bake a Soderberg electrode under these operating conditions with some of the technology you mentioned this afternoon? Or how much does the I^2R heating from the current in electrode assist its baking and how much comes from the burden which is present in the submerged-arc furnace, but not present in the open-arc furnace?

A. R. Innvaer. In most processes the Soderberg electrode is mainly baked by the electrode current, as for instance in the ferrosilicon process. But we have slag processes, ferronickel for instance, with gas temperature, between the furnace roof of 1000 to 1200 degrees, and there the electrode will be baked by heat from the process, because in these cases they are often operated with a very low current density. But

regarding Soderberg electrodes and use of DC, we have made some model simulations and found, that the current is more evenly distributed. That means that we will get much higher temperature in the center part of the electrode. DC could be an advantage for the baking of the electrode. That means improved slipping rate, but it would be a disadvantage regarding thermal shock and high stresses after shut-off.