

Chapter 2. Production and Processing of Aluminum

2.1 Extraction of Aluminum

The extraction of aluminum from its ore and subsequent processing into finished products takes place in a series of successive operations, each largely independent of the other. Generally the various processes are carried out at different plant sites. A summary of production steps from the bauxite mine through casting is given in Fig. 2.1.

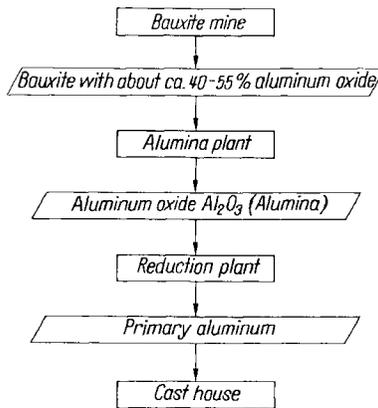


Fig. 2.1: Production steps for aluminum.

2.1.1 Bauxite mining

Aluminum comprises approximately 8% of the earth's crust, making it second only to silicon (27.7%). Iron is third at about 5%. Metallic aluminum is not found in nature; it occurs in the form of hydrated oxides or silicates (clays). The principal ore from which aluminum is extracted is called bauxite after the town of Les Baux in southern France where the ore was originally discovered. Bauxite occurs mainly in the tropics and in some Mediterranean countries. Today, the main mining locations are in Latin America, Australia, India, and Africa.

Bauxite is a weathered rock containing two forms of hydrated aluminum oxide, either mostly a monohydrate $\text{AlO}(\text{OH})$ in caustic bauxite, or mostly a trihydrate $\text{Al}(\text{OH})_3$ in lateritic bauxite. Besides these compounds, bauxite contains iron oxide, which usually gives it a reddish-brown colour, as well as silicates (clay, quartz) and titanium oxide. The crystal structure also contains 12–20% by weight of water. Tropical monohydrate bauxite grades yielding 35–55% Al_2O_3 will no doubt continue to be the most favored aluminum ores for many decades.

Laterite rocks similar to bauxite, but with lower alumina content, are available in large quantities. Clays became a source of alumina to a limited extent in Germany during the

Second World War. In addition, many other types of rock contain considerable amounts of alumina, such as kaolin, nepheline, andalusite, leucite, labradorite, and alunite. The former Soviet Union exploited such ores to maintain partial autonomy, but these ores play no significant role in today's aluminum production. Chapter 16 will show that the world's bauxite supplies are guaranteed into the distant future.

2.1.2 The alumina plant

The starting material for electrolytic smelting of aluminum is pure, anhydrous aluminum oxide (Al_2O_3) called alumina. In the Western World, the Bayer¹ process, invented in the 19th century, is by far the most important process used in the production of aluminum oxide from bauxite. The process has been refined and improved since its inception. Fig. 2.2 shows that the production of alumina is a complex chemical process. The alumina content of bauxite ores varies from one deposit to another, and methods of treatment differ accordingly (see 16.1.2). This means that each alumina plant is almost tailor-made to suit a particular bauxite. The processes are nevertheless basically similar, and a general description is given in the following. The bauxite from the mine is crushed and ground. It is then mixed with a solution of caustic soda and pumped into large autoclaves. There, under pressure and at a temperature of 110–270°C, the alumina contained in the ore is dissolved to form sodium aluminate. The silica in the bauxite reacts and precipitates from solution as sodium-aluminum-silicate. Iron and titanium oxide and other impurities are not affected chemically, and being solid, settle out of solution. This waste material, known as red mud, is separated from the sodium aluminate solution, washed to recover the caustic soda, and then pumped to disposal areas.

The disposal of red mud can present an environmental problem simply because there is so much of it. From a few alumina plants, red mud is deposited on the sea bed under strictly controlled conditions. One very common method of disposal is to contain the mud in an area surrounded by dikes. After an interval of some years, these ponded areas can be recultivated to eliminate “visual pollution.” Although a great deal of effort has been expended on finding and developing various uses for red mud, no bulk application of commercial value has yet been found.

Adding the weak soda washed out of the red mud to the sodium aluminate solution dilutes it and cools it to about 100°C. With stirring and cooling to 60°C, aluminum hydroxide $\text{Al}(\text{OH})_3$ (hydrargillite) precipitates. Seeding the liquor with crystals from a previous cycle helps to control precipitation. Vacuum filters separate the hydroxide precipitate, which is then washed with pure water. Calcination in rotary kilns or in fluidized beds at 1100°C to 1300°C finally converts the hydroxide to a dry, white powder. This powder is technical purity alumina, containing as impurities at most 0.01–0.02% SiO_2 , 0.01–0.03% Fe_2O_3 , and 0.3–0.6% NaO_2 .

The grade of the alumina (particle size, α - and γ - Al_2O_3 content) can be influenced by precipitation and calcining conditions, and it is usual to differentiate between two main grades, i.e. “floury” alumina, which is highly calcined and contains mostly α - Al_2O_3 , and “sandy” alumina, which calcined to a lesser degree with mainly γ - Al_2O_3 in the hydrated

¹ Named after the Austrian K.J Bayer.

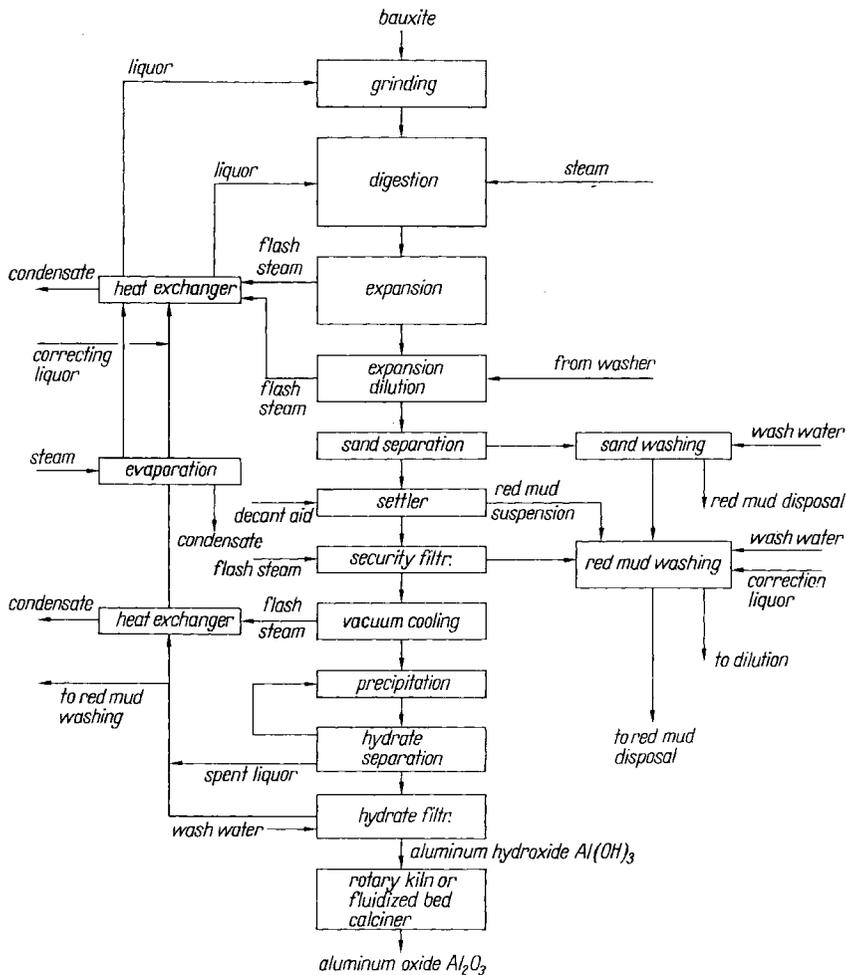


Fig. 2.2: Schematic of the Bayer process.

form. The sandy alumina has a large, active surface area, which makes it suitable for use in dry scrubber systems for fluoride abatement at aluminum reduction plants. There is a clear trend toward the production of increased quantities of sandy alumina.

In Russia, due to a lack of bauxite, a process using nepheline as feed-stock has been used to produce alumina. Essentially the technique consists of sintering a nepheline ore, or concentrate, with limestone. The resultant sinter-cake consists of sodium and potassium aluminates and dicalcium silicate. This material is crushed, ground, and leached. After leaching, the aluminate liquor is desilicated and decomposed by carbonation. Alumina hydrate is separated from the liquor and calcined to obtain alumina. After evaporation and crystallization, the carbonate liquor yields soda and potash. These are centrifuged, dried, and packed for shipment. Limestone is added to the slime from sinter-leaching to

produce Portland cement in a second calcination step. Processing about 4–4.5 tonnes of nepheline ore yields 1 tonne of alumina, 9–11 tonnes of cement, 0.6–0.8 tonnes of soda ash, and 0.2–0.3 tonnes of potash.

According to the grade of the bauxite ore, 2–3 tonnes of ore yield one tonne of alumina and about one tonne of red mud (dry weight). When designing an alumina plant, factors other than the type of bauxite ore to be used as feed material and the form of alumina to be produced have to be taken into consideration. A high silica content of the bauxite is undesirable because insoluble sodium-aluminum-silicate will form, causing losses of caustic soda and alumina which increases input material costs. Energy consumption is another consideration. The economical operation of the Bayer process requires the rational use of energy for steam generation and calcining. Inexpensive fuel is desirable because the process needs a large amount of thermal energy. The end product of the alumina plant is a dry white powder that is the feedstock for aluminum smelting.

2.2 Primary Aluminum Production

Throughout the world, primary aluminum is still produced by the electrolysis of alumina in molten fluoride salt. This is, in essence, the process that Hall and Héroult invented, and which is named after them, but its efficiency has been significantly improved over the years. The electrolysis plant—the aluminum smelter—needs large amounts of electrical energy. Therefore, besides good bulk transport facilities, abundant inexpensive electric power is essential. Because hydroelectric power is a relatively inexpensive and clean source of energy, aluminum smelters are mostly built in countries with readily available hydroelectric power, such as Canada, Norway, Venezuela, and Brazil, or in countries with abundant deposits of low-grade coal such as Australia or the Republic of South Africa (RSA). Furthermore, the same regions lack other local industry to use this energy, and it is impracticable to transport electric power over very long distances to the industrialized regions that could use it. Considering their large energy consumption, aluminum smelters are major customers that guarantee a stable base load and, thereby, help to reduce their power suppliers' unit costs. At present, hydroelectric sources produce the power for about two-thirds of world aluminum production, although placing a smelter next to a nuclear power plant can also be economically attractive, as at Dunkerque in France. Fig. 2.3 shows an aluminum smelter with its long potrooms and tall alumina silos.

2.2.1 The electrolysis process²

In the Hall-Héroult process, the electrolyte is molten cryolite (Na_3AlF_6) in which 2–8% of alumina (Al_2O_3) is dissolved. To lower the melting point, industrial cryolite-alumina mixtures also contain various amounts of other salts, such as aluminum fluoride (AlF_3) and calcium fluoride (CaF_2); sometimes lithium carbonate (Li_2CO_3) is present and, less frequently, magnesium fluoride (MgF_2) is introduced. These additions also improve current efficiency and reduce evaporation losses. For each tonne of aluminum produced, the smelting process consumes, in addition to electrical energy, about 1.95 tonnes of alumina, 0.5 tonnes of anode coke, and small amounts of fluoride salts.

² By G.W. Bulian.



Fig. 2.3: View of a modern aluminum smelter in Canada, showing the harbor and alumina silos in the foreground and the potrooms behind.

The electrolysis cell, or “pot,” shown schematically in Fig. 2.4, is shaped like a shallow rectangular basin. It consists of a steel shell with a lining of fireclay brick for heat insulation, which is, in turn, lined with carbon bricks to hold the fused salt electrolyte. Steel bars carry the electric current through the insulating bricks into the carbon cathode floor of the cell. Carbon anode blocks are suspended on steel rods, and dip into the electrolyte. As the electric current flows through the electrolyte, it breaks down the dissolved alumina into its component elements as metallic aluminum and oxygen gas. The oxygen reacts with the carbon anodes, forming bubbles of CO and CO_2 gas. Liquid aluminum settles on the bottom of the cell since it is denser (specific gravity 2.3 at 960°C) than the electrolyte (specific gravity 2.1). Periodically, this aluminum is siphoned off by vacuum into crucibles. To replace the alumina consumed in the reaction, more alumina must be added. Today, computer-controlled devices called point feeders automatically inject the alumina powder through the top surface crust of solidified electrolyte. Pots may each have two or more point feeders, depending on their size.

At 4–4.5 volts per cell, the operating voltage is considerably higher than the theoretical decomposition voltage of aluminum oxide. The difference is due to various voltage losses, which are unavoidable under industrial conditions. The resulting excess power generates heat, which maintains electrolyte temperature. More heat comes from the slow burning of the carbon anodes.

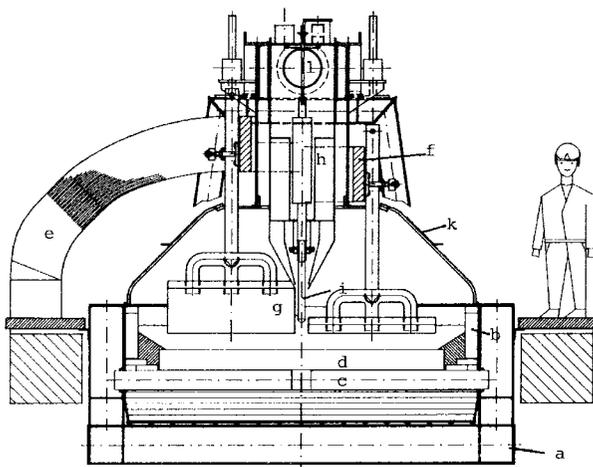


Fig. 2.4: View of the cross-section of an electrolysis cell with point feeding: (a) steel cathode shell; (b) insulation; (c) steel cathode collector conductor bar; (d) cathode; (e) riser conductor; (f) bridge, height-adjustable traverse bar supporting anodes; (g) anode; (h) alumina feed funnel; (i) point feeder; (k) pot covering hood; (l) pot gas and dust extraction. (VAW)

The cell is controlled mainly by regulating the anode/cathode distance and the direct current, which can be up to 300,000 A in modern cells. In modern smelters, process-control computers connected to remote sensors ensure optimal operation, this being one of the main reasons for today's high energy efficiency. The individual cells are connected in series, bringing the supply voltage to over 1000 V, which is the optimum operating voltage of thyristor power supplies. Thus, a modern potline consists typically of 264 cells in series, supplied at 1150 V. Aluminum busbars carry the current from one cell to the next.

As explained above, anode material is consumed in the classical Hall-Héroult reaction. Most smelters use prebaked carbon anode blocks. These are manufactured by first compacting blocks from a paste of calcined petroleum coke and tar pitch. Formerly made by pressing, the blocks were of uneven density, and tended to fail in service. Today, vibrating the paste under load, and often under vacuum, produces blocks of more uniform density. After this compacting process, the anodes are prebaked in a calcining furnace.

Instead of prebake anodes, some older smelters use Söderberg anodes. These are continuously formed in-situ by feeding "green" (raw) paste into the top of a sheet steel shell over the cell. Heat from the process bakes the paste to solid anode coke. There are two variants of the Söderberg process. These are referred to as either vertical- or horizontal-stud processes, depending on the positioning of the steel pins that deliver electric current into the anode. Disadvantages of this process are: low current efficiency of about 86–90% (compared with 95% in modern prebake smelters) and more fume emissions than with prebake anodes. Such fumes create problems with workers' health. No more Söderberg cells are being built, and those existing are progressively being shut down, converted, or replaced. What follows will only deal with modern plant using prebake anodes.

Fumes leaving the cells contain mainly CO_2 , CO, and SO_2 if the anode coke contains sulfur, together with smaller amounts of fluorine compounds and dust. Most of the gaseous fluorine exists as hydrogen fluoride HF, and the dust is mostly fluorine compounds such as cryolite and aluminum fluoride, as well as some alumina.

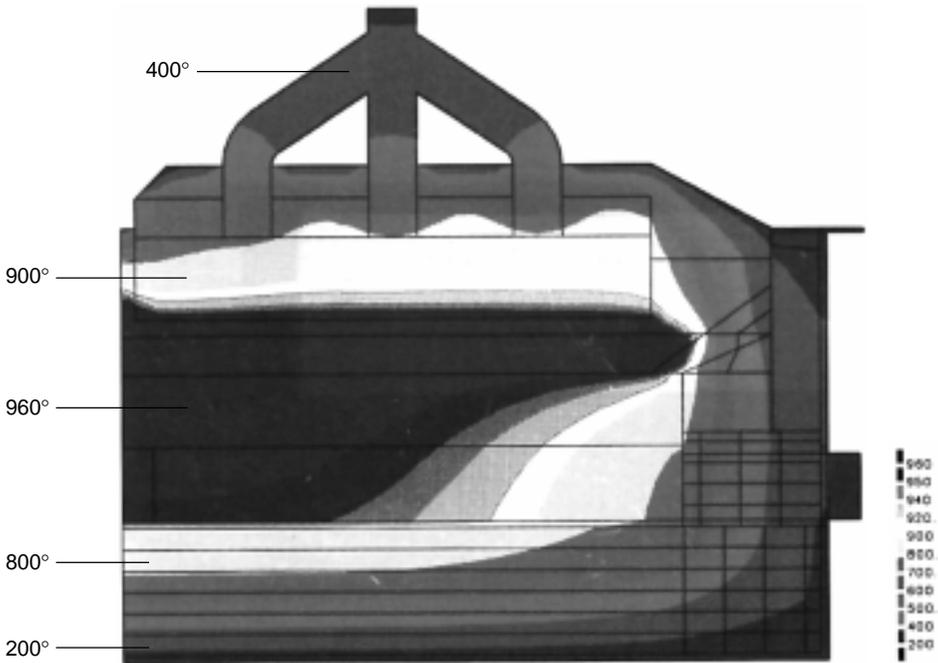


Fig. 2.5: Temperature distribution in a 180 kA electrolysis cell, drawn using a computerized mathematical model. (VAW) A color version of this figure appears on page 425.

Under unfavorable conditions, the pots may produce small quantities of the fluorocarbon compounds CF_4 and C_2F_6 , which are known to take part in the “greenhouse effect” of the upper atmosphere. However, this emission happens only during the so-called “anode effect,” which occurs when the alumina concentration drops below a critical threshold. During the anode effect, the cell voltage climbs from the normal 4.5 volts to over 40 volts. In modern electrolysis pots, which are fitted with pneumatic alumina transport and feeding systems, the alumina concentration can be held at an almost constant level. With the aid of modern, microprocessor-controlled potroom control, the frequency of anode effects, and hence the emission of fluorocarbons, can be much reduced.³ Formerly, about one per day and per cell, anode effects can now be reduced to one every two months by automated alumina feeding.

Since emissions of fluorine compounds, either as gases or dust, can harm the environment, these fumes are collected by hoods over modern cells. In a process called dry scrubbing, the fluorides bind to sandy alumina during intensive mixing. This fluoride-loaded alumina then goes to dust separators and to electrostatic dust filters, and finally back to the potline as feed material. The fluoride-free remainder is exhausted to atmosphere. Although technically difficult and capital intensive, dry scrubbing meets the low emission limits required for modern smelters. In recovering lost fluorine compounds and recycling them to the cell, dry scrubbing shows that environmental protection and economy

³ Such a control system is the “ELIAS” (Electrolysis Automation System) of the VAW Company. Other leading primary aluminum producers use similar or equivalent process-control systems. See also Chapter 16.

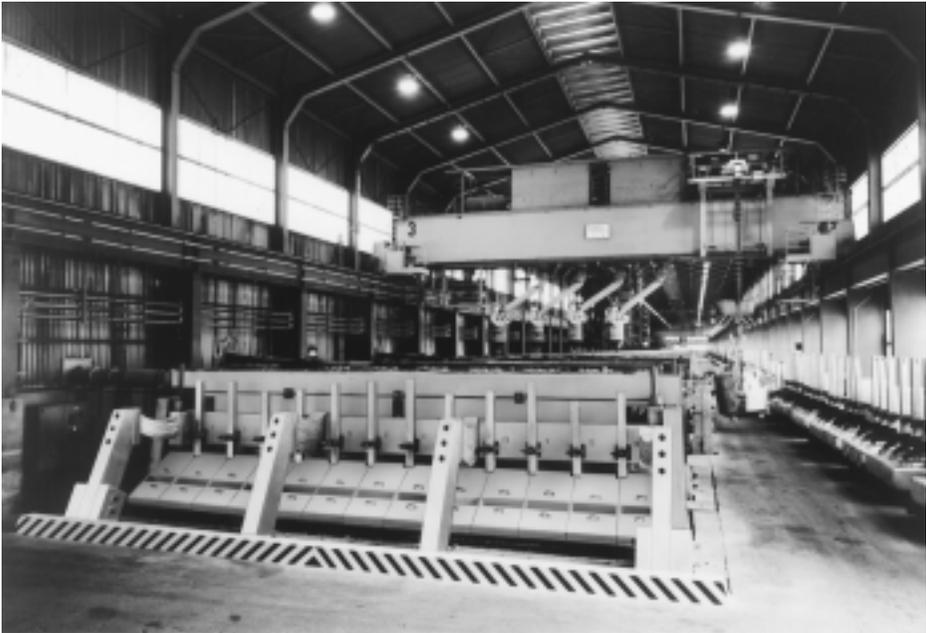


Fig. 2.6: Inside view of a potroom with cells arranged crosswise; in the foreground is a 240 kA pot with electrical connection through risers at the side. (VAW)

are not necessarily opposed, but can aim in the same direction (see Chapter 16).

The aluminum industry has made considerable technical advances since the Hall-Héroult process was introduced and is working on further improvements. Specific energy consumption has fallen in the last 35 years from 21 to almost 13 kilowatt-hours per kilogram of aluminum produced. This was made possible by advanced computer control of all the relevant parameters in the electrolysis cell. Development of new cells today involves computer modeling to optimize chemical, electrical, magnetohydrodynamic, and thermal conditions. Fig. 2.5 shows a calculated temperature distribution as an example of the computer-aided development of electrolysis cells.

Formerly, manual operation of the cells required wide access routes for vehicles between the potlines, but in modern smelters (Fig. 2.6) manipulator cranes perform most tasks. In contrast to the longitudinal alignment of anode beams in earlier potlines, the newer designs have anode beams arranged transverse to the line of cells. This arrangement has several advantages: it better compensates magnetic fields in the cell, requires less floor space in the potroom, and reduces the length of conductors, thereby reducing resistance losses. Computer modeling has shown that to reduce magnetic fields, electrical busbar connections should be through the transverse “risers” rather than as previously through the ends of the anode beams.

2.2.2 Other processes for producing aluminum

Other processes for extracting aluminum have been developed. Here, it is worth mentioning two electrolysis processes (using aluminum chloride or, alternatively, aluminum sulfide electrolytes) and two metallothermic ones (the Toth process, in which manganese reduces aluminum chloride, and the carbothermic reduction process, in which carbon reduces alumina). Except for the aluminum chloride electrolysis, technical or economic reasons have prevented these processes from developing beyond the laboratory or pilot scale.

For a few years from 1976, Alcoa operated an aluminum chloride electrolysis plant with a capacity of 15,000 tonnes per year. However, this was later shut down, the reason given being the excessive cost of producing anhydrous aluminum chloride feedstock by chlorinating alumina. Aluminum chloride feedstock is dissolved in an electrolyte consisting mainly of sodium chloride (NaCl) and potassium chloride (KCl) or lithium chloride (LiCl). Electrolysis releases aluminum metal and chlorine gas. The latter is recycled by chlorinating alumina. The main advantage of the chloride process over the Hall-Héroult process is a saving of 30% in electric power consumption. In addition, the process avoids fluoride emissions and makes more optimum use of anode coke, since it can work with multipolar graphite electrodes. At 700°C, the temperature is much lower than that in the Hall-Héroult cells, so that it needs less heat energy. In spite of these advantages, its chances of success remain uncertain because, as mentioned above, the economics of producing aluminum chloride feedstock remain unclear. Some observers have noted two further disadvantages: the tower-like multistory building, and corrosion problems within the system for circulating the electrolyte.

2.2.3 Primary aluminum

Smelters produce primary aluminum (as opposed to secondary, or recycled, aluminum) with a purity of 99.7–99.9%. The main impurities are iron and silicon, together with smaller amounts of zinc, magnesium, manganese, and titanium. Typical analyses also show traces of copper, chromium, gallium, sodium, lithium, calcium, vanadium, and boron. Passing chlorine gas through the molten aluminum can remove traces of sodium, lithium, calcium, and, if necessary, magnesium. Filtering can remove suspended particles, such as oxides and carbides. Hydrogen, the only gas soluble to any extent in aluminum, can be removed by degassing with chlorine, nitrogen, or, better still, argon (see Chapter 5).

Aluminum for electrical use must not exceed fairly low maximum levels of titanium, vanadium, manganese, and chromium, because these elements greatly reduce conductivity. Conductor-grade aluminum is generally produced by selecting the purer metal available from the best cells. If the level of these elements is still too high, adding boron can precipitate them as insoluble borides, which have little effect on conductivity.

International standards distinguish two types of unalloyed aluminum: “pure aluminum” of 99.0–99.9% and “high-purity” aluminum of at least 99.97%, which is produced by further refinement. Table 2.1 shows the different grades of pure and high-purity aluminum, as classified by Aluminum Association standards.

Table 2.1: Composition of unalloyed aluminum ingots*
(Composition in weight percent; maximum unless a range is shown)†

Al Assoc. designation	Si	Fe	Cu	Mn	Mg	Cr	Ni	Zn	Ti	Others		Al. (min.)
										Each	Total	
1050	0.025	0.40	0.05	0.05	0.05	—	—	0.05	0.03	0.03	—	99.50
1060	0.025	0.35	0.05	0.03	0.03	—	—	0.05	0.03	0.03	—	99.60
1100	0.095 Si + Fe		0.05–0.20	0.05	—	—	—	0.10	—	0.05	0.15	99.00
1145	0.055 Si + Fe		0.05	0.05	0.05	—	—	0.05	0.03	0.03	—	99.45
1175	0.015 Si + Fe		0.10	0.02	0.02	—	—	0.04	0.02	0.02	—	99.75
1200	1.00 Si + Fe		0.05	0.05	—	—	—	0.10	0.05	0.05	0.15	99.00
1230	0.70 Si + Fe		0.10	0.05	0.05	—	—	0.10	0.03	0.03	—	99.30
1235	0.65 Si + Fe		0.05	0.05	0.05	—	—	0.10	0.06	0.03	—	99.35
1345	0.30	0.40	0.10	0.05	0.05	—	—	0.05	0.03	0.03	—	99.45
1350	0.10	0.40	0.05	0.01	—	0.01	—	0.05	—	0.03	0.10	99.50

* From Table 6.2 of *Aluminum Standards & Data* (the Aluminum Association, 1997).

† See original reference for additional limit restrictions

2.2.4 High-purity aluminum

For most applications, the purity of aluminum as it comes from the potroom (i.e., up to 99.9%) is adequate. High-purity aluminum of at least 99.97% aluminum content is necessary for certain special purposes (e.g. reflectors or electrolytic capacitors); for such applications, the potroom metal has to be further refined in an additional process. Less than one percent of the total volume of primary metal undergoes this second stage of refining.

High-purity aluminum is produced by so-called three-layer electrolysis (the Hoopes cell). This cell, in contrast to the two layers of the Hall-Héroult process, operates with three liquid layers. The lowest layer, called anode metal, receives the input of normal primary aluminum to which has been added about 30% copper to increase the specific gravity to 3.4–3.7. The second layer is the molten electrolyte with a specific gravity of about 2.7–2.8, and the uppermost layer is the separated high-purity liquid aluminum with a specific gravity of 2.3. The cell has a siphon chamber for loading the anode metal.

Aluminum produced in this way is 99.99% pure. Higher purities of up to 99.9999% (“six-nines” aluminum) can be obtained using one or two additional zone-refining operations. Zone-refining traps impurities in a molten zone that moves gradually from one end to the other of a specially prepared ingot. Lesser purities in the range 99.97–99.98% are today produced in limited quantities by fractional crystallization. Here, any impurities that form an eutectic system with aluminum can be concentrated in the liquid melt, which can be separated from the primary crystals of aluminum, and the purer aluminum separated once it has crystallized out.

Another way of producing 99.97–99.98% purity is simply to mix higher-purity metal with that of a lower purity. The organic electrolysis which was formerly used for making the highest-purity metal is seldom if ever used because the highly inflammable electrolyte requires extreme safety measures and no economic advantage over zone-refining.

2.3 *The Production of Secondary Aluminum*

A used aluminum part, whether extrusion, sheet or plate, forging or casting, or a used finished product such as a can or a cast wheel, can be efficiently remelted and reconverted via the appropriate fabrication route—ingot casting, extruding, rolling or die-casting—into a new usable form. The resulting material loss by surface oxidation, called melt loss, varies from a few tenths of one percent in the case of clean, uncoated, massive castings or forgings to as much as 10% for light-gage coated packaging scrap. Melt loss depends very much on the type of feedstock: its shape and gage and the type and thickness of lacquer or other form of coating—all of these factors have a major influence on the amount of metal “lost.” Melt loss also depends very much on the chosen method of melting.

The economics of recycling, together with improved techniques of scrap preparation and melting provided higher yields and thus led to the further development of the secondary aluminum industry. This field grew rapidly during the 1950s, with the blossoming of the nonmilitary uses of aluminum; today, it meets 35% of the total aluminum metal demand

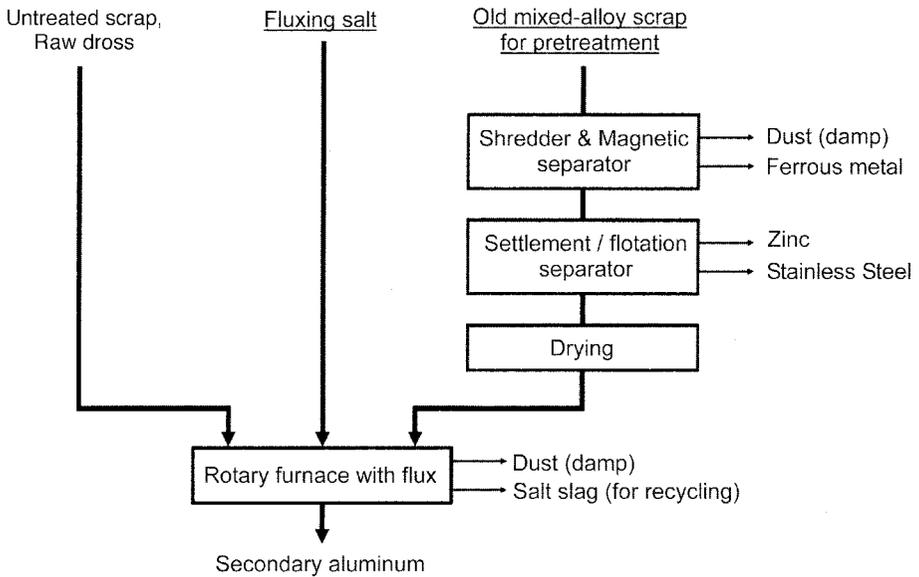


Fig. 2.7: Schematic showing the traditional processing of old scrap for making secondary aluminum.

in Europe. The supply of raw material to this secondary aluminum industry is a highly organized business involving collection and sorting networks and scrap trading.

2.3.1 Feedstock

Aluminum recycling forms the basis of the secondary aluminum industry. Today, secondary smelters serve chiefly to supply die-casting plants with casting alloys, using metal recovered from mixed scrap and dross. Much secondary metal goes into cast parts for the car industry, where demand both from independent foundries and the integrated in-plant casthouses of the car plants themselves has grown steadily over the years. Fig. 2.7 shows schematically the traditional method of scrap preparation. There has been some confusion in the terminology, so it is as well to be clear as to what is meant by “scrap” in the context of recycling. The principal feedstocks for the secondary aluminum industry are:

- Process scrap generated during the manufacture of finished aluminum products. This will be referred to as “process scrap” or “runaround scrap”
- Old scrap arising from products that have reached the end of their useful lives. This, often representing the greater part of the feedstock, will be referred to simply as “scrap.”
- The residues from result of skimming and cleaning furnaces in aluminum casthouses, consisting mainly of a mixture of metal and oxides. This is usually called “dross,” and it will be referred to as such.

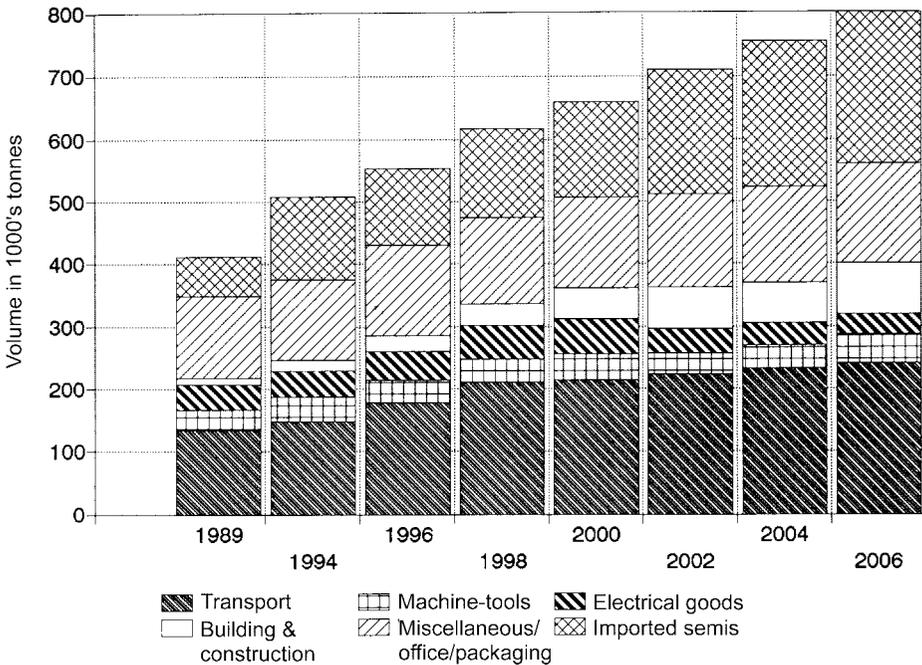


Fig. 2.8: Increase in the volume of scrap in western Europe arising from an assumed growth rate in aluminum consumption of two percent per year. Assumed service life: building—30 years; machine tools—20 years; electrical—15 years; transport—11 years.

2.3.2 Process technologies

Scrapped aluminum products are broken into small pieces and separated from dirt and foreign materials so as to yield feedstock suitable for remelting. This is done using breakers, shredders, magnetic, and settlement/flotation separators. Such scrap typically contains alloys of many types, all mixed together. A more sophisticated kind of recycling was developed in the seventies and eighties for process scrap and used beverage cans (UBC). By selectively collecting scrap in targeted alloy categories, the goal was to recycle the material back into products similar to those from which it originated. Thus, the casthouses of extrusion plants produce extrusion billets from process scrap and from recycled scrap extrusions. Similarly, the high rate of recovery of used beverage cans from the consumer, most notably in the USA, enables a large proportion of canstock coils to be made from UBC.

The demand for more selective groupings of scrap from the growing volume of material available for recycling will drive the scrap metal industry to develop refined and automated techniques of sorting scrap into the various alloy families. The steady growth in the consumption of aluminum in the past few decades will result in a higher rate of aluminum-containing goods reaching the end of their service lives and a correspondingly steady increase in the volume of scrap available for recycling as more and more aluminum-containing goods reach the end of their service lives. This trend will intensify

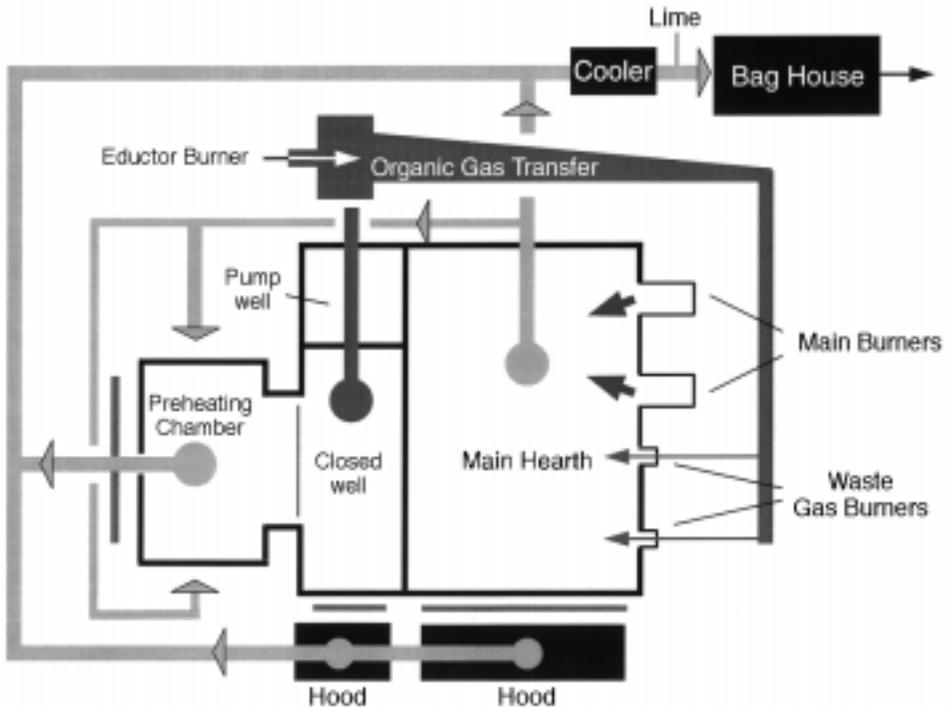


Fig. 2.9: A process for treating coated or lacquered scrap using the energy of gas generated by pyrolyzing the coatings (R-furnace). Capacity: 20,000 tonnes per year; feedstock: 98% scrap, 2% flux; metal recovery: 90%. (VAW)

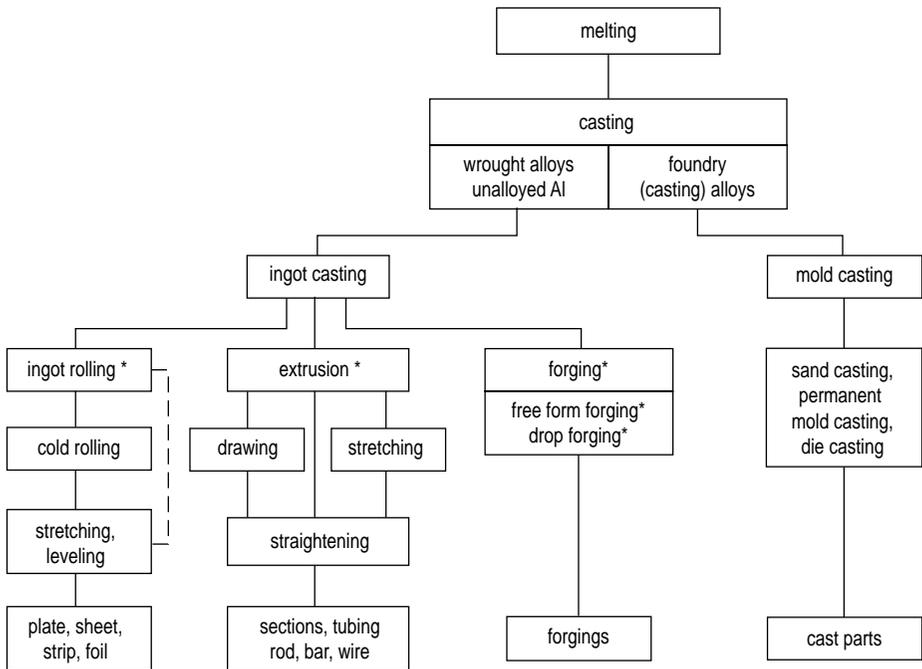
in the near future because of the projected increase in the use of aluminum in cars (see Fig. 2.8). It will no longer be necessary to recycle these larger volumes of scrap only into casting alloys in the traditional way. High-volume products such as cars will be systematically dismantled and their different components collected separately to be grouped together in scrap grades of similar alloy type. Shredded scrap will be subjected to similar sorting processes that will deliver scrap by alloy grade. Future schemes will strive to recover the original alloy from the scrap material and will try to ensure a minimum of process emissions and by-products during the recycling process.

Strong differentiation of aluminum scrap by alloy type favors the development of specialized scrap preparation and melting technologies. This can already be seen in UBC recycling plants that use technology dedicated to that type of scrap. The secondary aluminum industry's standard remelt furnace, the rotary hearth with its molten flux layer, has been replaced in UBC recycling to a very large extent by the delacquering line with specially designed integrated melting furnace. The ultimate goal is flux-free remelting. Contamination from organic coatings tends to be less with castings than with extrusion and sheet scrap, such as coated or insulated building products and car body sheet. In this respect, packaging materials from household refuse present a particular problem in that a relatively small volume of aluminum is strongly bonded to plastic and paper materials. It is essential to pretreat such types of scrap before melting in order to separate the metal

from the organic material. Another technique for handling scrap for recycling in bulk uses some form of rapid analysis method coupled with mechanical sorting. In this way, scrap segregated into the main alloy families can be subjected to special pretreatment and melting processes so as to remove organic coatings of all sorts while ensuring the recovery of a higher fraction of the aluminum content.

Fig. 2.9 illustrates a process known as the “R-Furnace.” Coatings in the form of lacquer or laminated plastic are separated from the metal by pyrolyzation and the resulting gases, rich in energy, burn to supplement the primary fuel. The amount of salt needed to tie up the dross is reduced to a minimum. Comparison with the conventional process makes this clear: the rotary hearth furnace uses 400 kg of salt per tonne of scrap; the R-furnace uses only 25 kg per tonne.

This and similar new technologies for melting coated scrap are environmentally friendly and they do not generate excessive amounts of polluting by-products such as salt slag. They yield high-value aluminum alloys with a good recovery rate, thus enabling a more complete aluminum material cycle than was possible with the older techniques. The arrival of these processes changed aluminum recycling in a fundamental and far-reaching way (see, also, Chapter 16).



* These processes are usually carried out between 350 to 550°C

Figure 2.10: Operations and products in semifabricated products plants and foundries. Special casting processes like strip casting or wire/bar casting are not shown.

2.4 Processing of Aluminum

2.4.1 Cast houses and foundries

2.4.1.1 Ingot casting (DC casting)

Primary aluminum and also scrap are cast into rolling ingot (slab), extrusion ingot (billet) and wire bar ingot, and, to a lesser extent, forging stock in the casthouses of the reduction plants or semifabricated products plants. Appropriate alloying elements are added in the melting or holding furnaces, after which the metal is cleaned and cast. Reduction plant cast houses also produce pigs from a part of the primary metal.

2.4.1.2 Mold casting

In foundries, cast products are usually produced from prealloyed metal supplied by secondary smelters. In some cases, casting alloys are prepared from a primary metal base for products that must meet rigid requirements that can be achieved only with minor amounts of impurities (for example, iron).

There are three main aluminum casting processes: sand casting, permanent mold casting, and die casting, which usually produces a finished part in one step. Unlike semifabricated products plants, foundries may deliver a finished product which requires no further forming. For this reason, foundries are not usually classified as semifabricated products plants and are shown separately in Fig. 2.10.

2.4.1.3 Special casting processes

The continuous casting of strip, wire, and rod belong to this family. Lately, continuous strip casting processes are experiencing the most rapid growth.

2.4.2 Semifabricated products plants

An aluminum plant for the production of semifabricated products (sometimes called a “semis” plant) may receive ingots for fabrication directly from the reduction plant or from their own remelt shop. Typical fabrication steps in a semis plant are shown in Fig. 2.10. The first operation is the hot deformation of the cast ingot at temperatures between 350°C and 550°C. Depending on the process, the deformation may be executed by hot rolling, extrusion, or forging. Such hot-working is often followed by cold deformation such as the cold rolling of sheet or drawing of tube. Some semifinished products are supplied in the as-fabricated condition in the form of extruded shapes, forged parts, and hot-rolled sheet or coils. Prior to delivery, extruded shapes are usually stretched for straightening and stress relief, which imparts a small amount of cold work to the material.

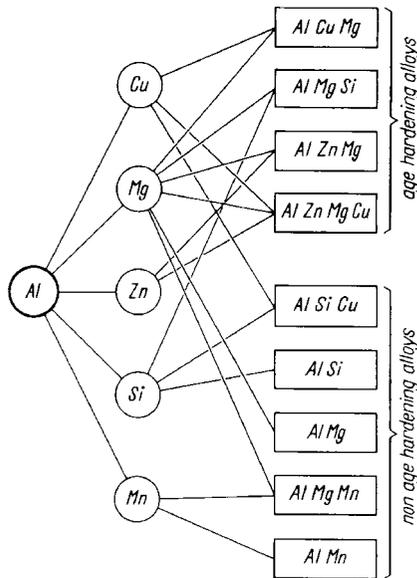


Figure 2.11: Synopsis of the principal aluminum alloys (commercial alloys on the basis of primary aluminum).

2.4.3 Subsequent fabrication of aluminum semifabricated products

Semifabricated products undergo further fabrication before they are sold to the consumer as a finished product. The fabricators use a great number of techniques in finishing aluminum. The primary objective of the fabricator is to impart the desired shape to the work piece. The techniques may produce chips (milling, turning, boring, etc.) or be chipless (deep drawing, stretch forming, impact extrusion, blanking, bending, spinning). Surface treatment of aluminum is of special importance and may include mechanical polishing, etching, brightening of the aluminum by electrolytic or chemical processes and the generation of thicker oxide layers through anodizing.

The picture would not be complete without mentioning joining techniques, which have been greatly improved in recent years, especially in the field of welding under protective gas, as well as in the use of adhesives.

2.5 Types of Aluminum Alloys

As mentioned earlier, the production of semifabricated products utilizes three different types of aluminum, namely super purity, commercial purity, and alloys. Alloys are used for producing castings or fabricating wrought products. The alloys used for castings contain a greater amount of alloying additions than those used for wrought products. The addition of alloying elements has the effect of strengthening the wrought alloys and improving the castability of the casting alloys.

Table 2.2: The Aluminum Association alloy designation system

<u>Wrought alloys</u>	<u>Series</u>	<u>Cast alloys</u>	<u>Series</u>
Al (99.00 % minimum or greater)	1xxx	Al (99.00 % minimum or greater)	1xx.x
Alloys grouped by major alloying elements			
Cu	2xxx	Cu	2xx.x
Mn	3xxx	Si + Cu or Mg	3xx.x
Si	4xxx	Si	4xx.x
Mg	5xxx	Mg	5xx.x
Mg and Si	6xxx	Zn	7xx.x
Zn	7xxx	Sn	8xx.x
Other element	8xxx	Other element	9xx.x
Unused series	9xxx	Unused series	6xx.x

Wrought alloy designations: Four digits are used to identify wrought aluminum and wrought aluminum alloys. The alloy group is identified by the first digit. Modifications of the original alloy and impurity limits are indicated by the second digit. In the case of the 1xxx group, the last two digits indicate the minimum aluminum percentage. For the 2xxx through 8xxx groups, the last two digits serve to further identify individual aluminum alloys. For experimental alloys, the prefix "X" is added, as in a designation (e.g., X2037). When the alloy ceases to be experimental the prefix is dropped.

Cast alloy designations: The designation system for cast aluminum alloys is similar to that for wrought products, in that the first digit indicates the major alloy group. Digits two and three indicate the aluminum purity or further identify the alloy. The digit to the right of the decimal place indicates the product form, either a casting or ingot. Modifications to original casting alloys are indicated by a serial letter before the numerical designation (e.g., A356.0 or B413.0).

Today, more than half of the semi-finished production is delivered in alloys, most of the remainder in commercial-purity aluminum with only a small quantity of super-purity aluminum being produced.

It is necessary to differentiate between wrought and casting alloys. Both of these alloy types are subdivided into those alloys that are solution heat treatable and those that are not. Wrought alloys are generally used for further fabrication, for example, rolling, forging, extrusion, and drawing. Casting alloys are used for cast parts and have the flow characteristics favorable for this process. For example, an alloy with good castability must be able to fill the mold completely and have a low sensitivity toward cracking during casting.

The most important elements that are added to aluminum, in alphabetical order, are bismuth (Bi), boron (B), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), nickel (Ni), silicon (Si), titanium (Ti), zinc (Zn), and zirconium (Zr). Magnesium is the most frequent addition to aluminum. In some alloys, two or more elements are used in combination (e.g., magnesium together with silicon or manganese). There are also alloys of aluminum containing only manganese or only silicon. The alloying elements are added to bring about changes in the properties of aluminum, as described in Sections 2.5.1 and 2.5.2.

Fig. 2.11 shows a schematic survey of the most commonly used aluminum alloys. Table 2.2 illustrates the Aluminum Association and American National Standard Institute (ANSI)

alloy designation system for wrought and cast alloys, described more fully in Appendix C and in full in the Aluminum Association's *Aluminum Standards and Data*. There is an international accord on wrought alloy designations, recognizing the Aluminum Association designations virtually worldwide.

There is not an equivalent international accord on cast alloy designations, so there are not exact equivalents for these alloy designations in different countries. For this reason, at various places in this book, both the US and international designations for alloys and alloy types are sometimes utilized to help the reader. Similarly, there is no international accord on temper designations (also described in Appendix C), so these too may vary from country to country.

2.5.1 Wrought alloys

Strength is increased by the addition of magnesium (up to a maximum of 7%) and also by additions of zinc, copper, and/or silicon in addition to magnesium. Good high-temperature strength is attained by the addition of copper (up to 4%) and/or nickel, manganese, or iron up to one percent each. Good chemical resistance is shown by alloys with additions of magnesium, manganese, or a combination of magnesium and silicon. Machinability is greatly improved by the addition of lead and bismuth up to 0.6% each. A fine-grained structure is obtained especially through the addition of titanium and boron (up to 0.1%). A fine grain upon recrystallization of semifabricated products is often obtained through additions of chromium or zirconium (up to approximately 0.1%). Other elements, for example iron and manganese, have the tendency to act as grain refiners as well.

2.5.2 Casting alloys

Castability is improved through the addition of silicon up to 13%. Dimensional stability upon heating (pistons) is assured by silicon contents up to 25%.

There are also various specialty groups of alloys that make up only a very small part of the total production of aluminum semifabricated products. These are not included in the schematic in Fig. 2.11. Piston alloys and "free-machining" alloys belong to this special group. The latter group includes alloys with lead and other additions that cause the turnings to break into small pieces during machining; this is desirable from a fabricating standpoint. Having covered the main factors in the production and processing of aluminum, we turn now to the main theme of this book.