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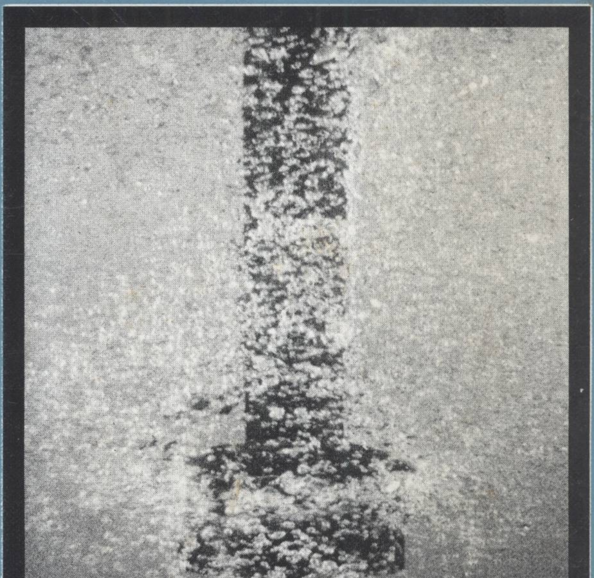

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Foreword

This is an excellent basic text which covers melt processing of aluminum silicon alloys. All principal processes—modification, degassing, fluxing, grain refining and filtration are covered in sufficient detail to enable a technically oriented foundryman to establish practices that will produce high quality melts.

While defect analysis *per se* is not a principal focus of the book, the knowledge conveyed on melt processes can assist in developing solutions for many metallurgically related defects, and the causes of less-than-optimum mechanical properties.

The reader will find this volume to be a very useful addition to their library on aluminum casting practices.

D.V.N./D.E.G.
Reviewers

Preface

This book is the result of ten years of collaboration between the authors on research related to the aluminum foundry industry. Our decision to write a book on liquid metal treatment arose from two factors. One of these was the spectacular growth in the aluminum casting industry since 1980, due to the general acceptance of cast aluminum alloys as high quality, light weight engineering materials. The other driving force behind our decision was the realization that while many facets of the aluminum casting business are quite advanced, most liquid metal treatments are less sophisticated. By and large, aluminum foundries know how to make beautiful and intricate molds. Significant time and money are expended on the molding process, while, until recently, only a limited effort went into controlling the quality of the liquid metal poured into those molds. We believe strongly that in order for the aluminum casting industry to prosper and to grow, much more attention must be paid to the quality of the liquid alloy.

Our purposes in writing this book were several. We wished to present the founder, in one volume, with a description of the various melt treatments that are available. We wanted to explain clearly why these treatments are performed, and their effects on the structure and properties of the final casting. It was also our desire to point out the strong and the weak points of melt treatments, along with some of the pitfalls, and to show that the same result can often be obtained by different routes.

The book is written primarily with the practicing foundry engineer in mind. While it will be useful to many students of metallurgy and foundry science, it is not intended as a detailed research textbook. Consequently, we have not attempted to present a comprehensive survey of the voluminous literature on aluminum foundry alloys. The state of the art in liquid metal processing is described, and the effects of liquid treatment on structure and properties are emphasized. Ultimately, it is casting quality which must be the prime concern of the foundry engineer. We sincerely hope that our efforts will help to achieve the desired quality level.

Acknowledgements

The authors are indebted to all of those societies and publishing houses that have kindly agreed to let us use material from their publications to illustrate the text. The source of all material used in the many figures is given in the references listed at the end of each chapter.

Much of the manuscript was written while one of the authors (JEG) was on sabbatical leave from McGill University. This leave was spent at the research center of La Société d'Aluminium Pechiney in Voreppe, France, and in the Department of Materials Science and Engineering, University of Arizona. The cooperation of each of these organizations in providing an atmosphere conducive to writing is gratefully acknowledged.

To Timminco Limited we owe a deep debt of gratitude. It was at Timminco that we first worked together. Their support of aluminum foundry research over the past decade has allowed many interesting and important questions to be raised and answered.

Finally, we would like to thank our two dedicated typists, Olga Gruzleski and Lucille LeBlanc who typed and re-typed the manuscript into its final form.

John Gruzleski
Montreal

Bernard Closset
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Contents

Chapter 4: Modification and Porosity

Chapter 5: The Properties of Modified Alloys

Chapter 6: Interactions of Modifiers

Chapter 7: Refinement and Modification in Hypereutectic Alloys

Chapter 1

Introduction

1.1 Commercial Importance of Aluminum Foundry Alloys

The casting of metal has evolved tremendously from its origin in prehistory. The earliest metal objects were wrought, casting having evolved as a fabrication process approximately 5000 years ago. Bronze, the first metal widely cast, was used to make bells, statues and guns. Like preceding epochs, the Industrial Revolution in Europe and North America is synonymous historically with the development of a casting process, in this case cast iron and steel. Tremendous expansion in the metal casting industry resulted from the need to produce new machinery of all types for the growing manufacturing and transportation industries.

Aluminum casting became affordable only after the invention of aluminum refining by the Hall-Heroult process. In the earlier part of the 20th Century, the application of aluminum castings was limited to decorative parts and cooking utensils. After World War II, a dramatic expansion of the aluminum casting industry occurred. New alloys were developed and casting processes were implemented to comply with engineering specifications, and to extend the range of commercial and technical applications. The recent "energy crisis" of the 1970s led to greater use of cast aluminum in many vehicles, because of its excellent strength-to-weight ratio.

A wide range of metals can be added to aluminum[1]. Among those regularly added and controlled as alloying elements are zinc, magnesium, copper, silicon, iron, lithium, manganese, nickel, silver, tin and titanium. The solid solubilities of these elements in aluminum vary considerably (Table 1.1). Some are used as solid solution strengtheners, while others are added because they form various desirable intermetallic compounds.

Aluminum alloys constitute a group of cast materials which, in tonnage terms, is second only to ferrous castings (Figures 1.1 and 1.2). In 1986, U.S. shipments of aluminum-based cast alloys were slightly above 1,000,000 tons, while shipments of copper- and zinc-based alloys were in the order of 250,000 tons each. Aluminum cast parts represented approximately 10% of the total tonnage of U.S. casting shipments in 1986. World-wide, approximately 20% of total aluminum production is, on average, converted into cast parts.

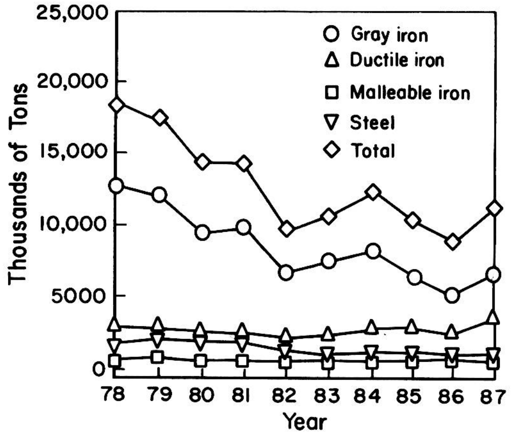

Figure 1.1. U.S. ferrous casting shipments from 1978.

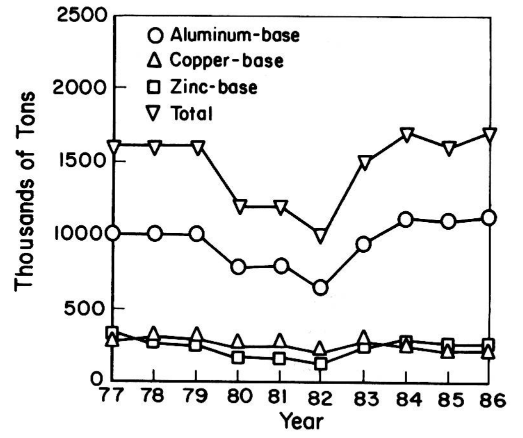

Figure 1.2. U.S. nonferrous casting shipments from 1977 to 1986.

Table 1.1. Solid Solubility of Elements in Aluminum

Element	Temperature (°C)	Maximum solid solubility (wt %)
Cadmium	649	0.4
Cobalt	657	<0.02
Copper	548	5.65
Chromium	661	0.77
Germanium	424	7.2
Iron	655	0.05
Lithium	600	4.2
Magnesium	450	17.4
Manganese	658	1.82
Nickel	640	0.04
Silicon	577	1.65
Silver	566	55.6
Tin	228	0.06
Titanium	665	1.3
Vanadium	661	0.4
Zinc	443	70.0
Zirconium	660.5	0.28

Table 1.2. Production of Cast Parts as a Percentage of Total Aluminum Products

Country	Percentage
United States	15 %
Britain	23 %
West Germany	23 %
Japan	27 %
France	29 %
Italy	37 %

Table 1.2 shows recent figures representing the percentage of aluminum production transformed into cast products. The large differences from country to country can mainly be attributed to variations in the amount of aluminum alloy used in vehicle applications. For example, in Europe and Japan, 60% and 75% respectively of all aluminum cast parts are used in the transport industry, compared to 44% in the U.S.

Casting Alloy Designation

Specifications for casting alloys are clearly distinguished from those of wrought alloys, and are defined by their chemical compositions. Foundry alloys are obtained either from electrolytic aluminum to which are added the constituent elements or from recycled aluminum metal. Presently it is estimated that more than 50% of aluminum cast parts are made from recycled metal.Each country has developed its own aluminum casting alloy nomenclature and designation, and so far no internationally accepted system has been adopted for identification. In the U.S. the Aluminum Association has adopted a four digit numerical system to identify aluminum casting alloys. The first digit indicates the major alloying element in the group, as follows:

1xx.x	Unalloyed composition; aluminum 99.0% or greater
2xx.x	Copper
3xx.x	Silicon with magnesium and/or copper
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused
7xx.x	Zinc
8xx.x	Tin
9xx.x	Unused

In the 1xx.x group, two digits to the left of the decimal denote the minimum of aluminum content. For example a 190.x designation corresponds to an aluminum of a 99.90% grade purity. The digit on the right of the decimal point indicates the product form, 0 and 1 respectively for castings and ingots.

In the alloy groups from 2xx.x to 9xx.x, the second two digits have no specific significance and serve only to identify the different alloys in the group. The last digit on the right of the decimal point identifies the product form.

Aluminum Cast Alloy Properties

Aluminum alloys are characterized by their low specific gravity which can vary slightly above and below the specific gravity of pure aluminum depending on the major alloying elements. In addition to their light weight, other advantages of aluminum casting alloys include relatively low melting temperatures, negligible gas solubility with the exception of hydrogen, excellent castability especially near the eutectic composition of 11.7%, good machinability and surface finishing, good corrosion resistance, and good electrical and thermal conductivity. A volumetric shrinkage of between 3.5% and 8.5% occurring during solidification constitutes the major drawback of aluminum castings. The shrinkage coefficient should be taken into account during mold design in order to obtain dimensional accuracy and to avoid hot tearing and shrinkage porosity. While the mechanical properties are usually inferior to those of wrought products, the heat treatment of some alloys considerably improves the mechanical properties, and will be discussed in Chapter 2.

The selection of an alloy composition for a particular application is based on three parameters:

- castability (a complex property depending on drossing tendency, mold geometry and alloy solidification characteristics);
- mechanical properties;
- usage properties.

The castability of aluminum alloys is determined by using specific sample molds which are able to evaluate the fluidity, hot tearing and shrinkage characteristics. Foundry properties depend mainly on the alloy composition and the solidification interval which can vary from 0C (eutectic alloys) to 140C (B390 alloy).

The best mechanical properties are generally obtained with heat treatable alloys which include eutectic alloys (A356.0, A357.0) and solid solution alloys (201.0). In the aeronautic and aerospace industry, the demand for greater casting quality and integrity has led to the concept of premium quality castings. Quality assurance for premium quality castings signifies that a specified minimum level of mechanical properties be obtained within various locations in a casting. Through a strict control of melting and pouring practices, impurity level control, grain size refinement and eutectic modification, mechanical properties far superior to those previously available can be obtained. Many commercial castings are approaching the premium quality level as the state of foundry technology improves. The nominal level of mechanical properties is generally well above that obtainable as recently as 15 years ago. The current goal is to control the quality and to maintain it at a high level 100% of the time.

Casting alloys for general use are selected according to such characteristics as machinability, corrosion resistance, hardness and mechanical properties. Alloys for special purpose applications are selected for their unique properties, such as high temperature resistance, low thermal expansion coefficient (390.0), or bearing properties (high Sn alloys).

Casting Processes

In general, aluminum castings can be produced by more than one process. Quality requirements, technical limitations and economic considerations dictate the choice of a casting process. The three main casting processes are as follows:

- sand casting: large castings (up to several tons), produced in quantities of from one to several thousand castings;
- permanent mold casting (gravity and low pressure) : medium size castings (up to 100 kg); in quantities of from 1000 to 100,000;
- high pressure die casting: small castings (up to 50 kg); in large quantities (10,000 to 100,000).

These castings and production sizes are typical, but of course exceptions are always possible. Other casting processes include: investment casting (lost wax), lost foam casting, plaster molding, ceramic molding, centrifugal casting, and new and emerging processes such as squeeze casting, and semi-solid casting.

1.2 Current Market for Aluminum Castings

The current market for aluminum castings is supplied by the most commonly used processes which are sand casting, permanent mold casting and high pressure die casting. Table 1.3 shows the tonnage of aluminum castings shipped in the U.S. in recent years. In 1986, a total of 1,080,000 tons of aluminum castings were produced by the three major processes. High pressure die casting accounted for the largest share of shipments with 76.4%, while permanent mold casting and sand casting were used for 15.7% and

7.8% respectively. It is estimated that in the U.S., casting by the three major processes represents 90% of all aluminum cast parts production. Table 1.4 shows the casting production in Europe (France and West Germany) by the three main casting processes. In West Germany, castings poured by processes other than the three major ones represent less than 1% of the total tonnage. High pressure die casting in Europe accounts for 40% to 60% of aluminum parts production with significant variations from country to country.

Since 1945, the growth of aluminum casting in the U.S. has been mainly due to the expansion of the permanent mold and high pressure die casting industries (Table 1.3). Between 1955 and 1986 production of high pressure die castings increased from 178,000 tons to 825,000 tons which corresponds to an average annual growth rate of 11.7%. In other developed countries, growth in the high pressure die casting industry was also very substantial as shown in Table 1.5. The rapid expansion of high pressure die casting production can be directly related to the automotive industry especially in a country like Japan where the growth rate over the last 17 years was 13.8% on an average annual basis.

Aluminum Casting in the Automotive Industry

The sharp oil price increase in the early 1970s resulted in a trend to lighter, smaller and more economical automobiles. Aluminum is one of the materials being substituted in automobile production in order to reduce weight. Others are magnesium, plastics, and high strength, low alloy (HSLA) steels. Cast aluminum substitutions for cast iron have proved to be very cost effective, especially for cylinder heads.

Ford and Alusuisse have published estimates of fuel savings through the use of aluminum. Ford has shown that a fuel reduction of 1 liter every 120 km is obtained by 200 kg weight reduction. This amounts to 1000 liters over the life of the vehicle. A study by Alusuisse demonstrates that the replacement of steel components by 50 kg of aluminum results in an 850 liter fuel saving over a ten year period.

The data presented in Table 1.6 illustrates the steady rise in the aluminum content of American automobiles. Between 1975 and 1985, the proportion of aluminum contained in a complete automobile more than doubled from 2% to 5%. By 1982, castings accounted for the majority (60%) of this content.

In Europe and Japan, automobiles are generally smaller and hence lighter. The average weight of an automobile in Europe in 1982 was only 900 kg which is considerably less than the average weight of 1147 kg for a U.S. vehicle in 1985. The aluminum content in a European automobile is close to 4%. In Japan, the aluminum content of a typical vehicle has increased from 3% to 4-5% from the early- to mid-1980s.