

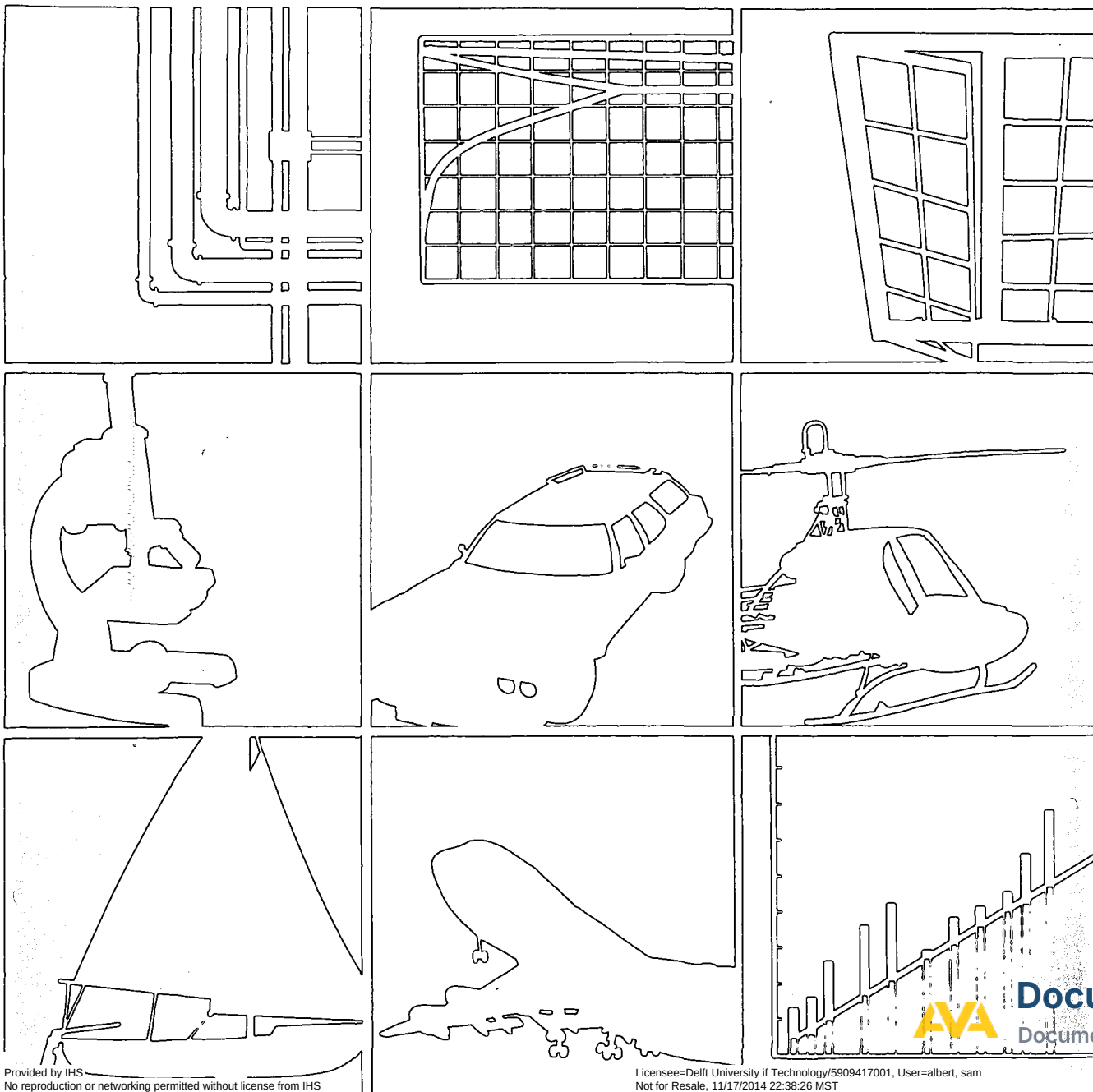
Aluminum and its alloys

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The Aluminum Association
Incorporated



Technical Report:
Aluminum and its alloys



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TECHNICAL REPORT: ALUMINUM AND ITS ALLOYS THIRD EDITION

SHEET & PLATE TECHNOLOGY COMMITTEE
THE ALUMINUM ASSOCIATION, INC.

ABSTRACT

Aluminum, especially when alloyed with one or more of several common elements, has been increasingly specified and used in packaging, architectural, building product, transportation, chemical, electrical, heat exchanger and many general applications. Today, aluminum is surpassed only by steel in its use as a structural material. The properties of aluminum and its alloys, which give rise to their widespread usage, with particular emphasis on corrosion resistance, and the designation systems for aluminum alloys and applicable tempers are briefly described in this report. Several references are provided for the reader who may desire more detailed information.

PREFACE

The first edition of this report was prepared by Seymour Epstein, Technical Director of The Aluminum Association, Inc., and presented at The Annual Liberty Bell Corrosion Course, sponsored by The National Association of Corrosion Engineers in Philadelphia, Pennsylvania in September 1978. The current edition has been updated by members of the Sheet & Plate Division's Technology Committee.

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Alcoa Inc.	Kaiser Aluminum and Chemical Corp.
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TABLE OF CONTENTS

	Page
Abstract	1
Preface	3
A. Introduction	7
A.1 The Oxide Layer	7
A.2 Properties of Pure Aluminum	8
B. Aluminum Alloys	9
B.1 Alloy Designation System	9
B.2 Temper Designation System	11
B.3 Effects of Alloy Additions	13
C. Properties of Aluminum Alloys	16
C.1 Mechanical Properties	16
C.2 Comparative Characteristics	23
C.3 Typical Applications	26
D. Corrosion Behavior	29
D.1 General Corrosion	29
D.2 Galvanic Corrosion	30
D.3 Pitting Corrosion	31
D.4 Intergranular Corrosion	31
D.5 Exfoliation Corrosion	32
D.6 Stress Corrosion	32
E. Summary	33
F. Bibliography	34

A. INTRODUCTION

A.1 - THE OXIDE LAYER

To a student of chemistry it might seem strange that aluminum, one of the most chemically active elements with a very strong affinity for oxygen, could be such a commonly used metal. And yet one sees aluminum being used every day, unprotected, in every common environment. In fact, aluminum is second only to steel in tonnage produced and used each year.

What makes aluminum so usable is that oxygen, a deadly enemy and destroyer of other reactive metals such as sodium, and even of less reactive metals such as steel, is a friend and protector of aluminum. Possibly every chemistry student has witnessed in a laboratory the spectacular reaction between sodium and moisture, rendering sodium unrecognizable and even more unusable. Certainly everyone has seen a rusty steel surface. Neither of these conditions occurs with aluminum. Indeed, a freshly produced aluminum surface reacts instantly with oxygen, but once a thin oxide layer has formed, it very effectively protects the base metal, not only from attack by many other agents, but also from further oxidation.

The oxide coating invariably found on aluminum is so important to its usefulness that one must first consider this coating in order to understand many of aluminum's properties, especially corrosion resistance. Among the properties of the natural oxide coating on aluminum are:

1. It is extremely thin - normally about 50 to 100 Å thick. Once formed, the film tends to prevent further oxidation of the metal..
2. It is tenacious. Unlike iron oxide, which tends to spall from the base metal leaving a fresh surface to oxidize, aluminum oxide tightly adheres to aluminum.
3. It is hard. Aluminum oxide is one of the hardest materials known.
4. It is relatively stable and chemically inert. As a rule, the oxide is stable over a pH range of about 4.5 to 8.5 but is dissolved by most strong acids and alkalis. However, some chemicals will attack the oxide near the neutral point (pH7), while it is resistant to concentrated nitric acid at pH1 and to ammonium hydroxide at pH13.
5. It is transparent and does not detract from the metal's appearance.
6. The thickness, appearance and properties of the oxide layer can be modified by a deliberate anodizing process to improve resistance to corrosion and abrasion and / or to enhance the esthetics of the product.

Since the natural oxide coating is so thin, it has a negligible effect on the properties of aluminum, other than providing corrosion and oxidation resistance.

A.2 - PROPERTIES OF PURE ALUMINUM

It is well known that aluminum is lightweight as compared to most other metals. Its specific gravity is only 2.7 times that of water and is roughly one-third that of steel. An easy number to remember is that one cubic inch of aluminum weighs approximately one-tenth of a pound ($2.7 \times 10^{-3} \text{ kg/m}^3$), a cubic foot (0.028 m^3) weighs 170 pounds (77 kg) compared to 62 pounds (28 kg) for water and 490 pounds (223 kg) for steel. Pure aluminum melts at 1220°F (660°C), which is considerably lower than the melting point of most other structural materials. It is an excellent conductor of heat and electricity. On a volume basis, the electrical conductivity of pure aluminum is roughly 65% of the International Annealed Copper Standard, but pound-for-pound aluminum is a better conductor than copper and is surpassed only by sodium.

As far as mechanical properties are concerned, pure aluminum is a relatively low strength but highly ductile metal. Its modulus of elasticity is approximately $10 \times 10^6 \text{ psi}$ ($70 \times 10^3 \text{ MPa}$) compared to $30 \times 10^6 \text{ psi}$ ($210 \times 10^3 \text{ MPa}$) for steel which means that, for a given size and shape and under comparable loading, aluminum will elastically deform three times more than steel and absorb three times more energy. Aluminum is very tough, and, unlike steel and titanium, aluminum and most of its alloys do not lose ductility and become brittle at cryogenic temperatures.

Aluminum, like most metals, can be strengthened to a significant extent by strain hardening or cold working. However, much greater strengthening is provided by alloying aluminum with a variety of elements. While commercially pure aluminum (99+% Al) is used for electrical conductors, chemical equipment and sheet metal work, aluminum alloys are much more widely used, especially where strength is an important consideration.

B. ALUMINUM ALLOYS

B.1 - ALLOY DESIGNATION SYSTEMS

The principal alloying additions to aluminum are copper, manganese, silicon, magnesium and zinc; other elements are also added in smaller amounts for grain refinement and to develop special properties. Since there is a wide variety of aluminum alloys, special designation systems were developed by The Aluminum Association to distinguish the alloys in a meaningful manner and, further, to indicate what metallurgical condition, or temper, has been imparted to the alloy.

Aluminum and its alloys are divided into two classes according to how they are formed: wrought and cast. The "wrought" category is indeed a broad one, since aluminum can be formed by virtually every known process; wrought forms include sheet and plate, foil, extrusions, bar and rod, wire, forgings and impacts, drawn and extruded tubing, and others. Cast alloys are those specially formulated to flow into a sand or permanent mold, to be die cast, or to be cast by any other process where the casting is the final form.

Each wrought or cast aluminum alloy is designated by a number to distinguish it as a wrought or cast alloy and to broadly describe the alloy. A wrought alloy is given a four-digit number. The first digit classifies the alloy series or principal addition. The second digit, if different than 0 (zero), denotes a modification in the basic alloy. The third and fourth digits form an arbitrary number that identifies the specific alloy in the series.* A cast alloy is assigned a three digit number followed by a decimal. Here again the first digit signifies the alloy series or principal addition; the second and third digits identify the specific alloy; the decimal indicates whether the alloy composition is for the final casting (.0) or for ingot (.1 or .2) to be remelted. A capital letter prefix (A, B, C, etc.) indicates a modification of the basic alloy.

The designation systems for aluminum wrought and cast alloys are shown in Tables 1 and 2, respectively. (A more complete description of the system can be found in ANSI H35.1 - American National Standard Alloy and Temper Designation Systems for Aluminum.)

* Note: An exception is for the 1xxx series alloys, where the last two digits indicate the minimum aluminum percentage. For example, alloy 1060 contains a minimum of 99.60% aluminum.

Note: A complete listing of registered wrought aluminum alloys can be found in The Aluminum Association's registration record "International Alloy Designations and Chemical Composition Limits for Wrought Aluminum and Wrought Aluminum Alloys" (Teal Sheets). A similar listing of registered casting alloys can be found in the registration record "Designations and Chemical Composition Limits for Aluminum Alloys in the Form of Castings and Ingot" (Pink Sheets).

TABLE 1
DESIGNATION SYSTEM
FOR WROUGHT ALUMINUM ALLOYS

<u>ALLOY SERIES</u>	<u>DESCRIPTION OR MAJOR ALLOYING ELEMENT</u>
1xxx	99.00 Minimum Aluminum
2xxx	Copper
3xxx	Manganese
4xxx	Silicon
5xxx	Magnesium
6xxx	Magnesium and Silicon
7xxx	Zinc
8xxx	Other Element
9xxx	Unused Series

TABLE 2
DESIGNATION SYSTEM
FOR CAST ALUMINUM ALLOYS

<u>ALLOY SERIES</u>	<u>DESCRIPTION OR MAJOR ALLOYING ELEMENT</u>
1xx.x	99.00 Minimum Aluminum
2xx.x	Copper
3xx.x	Silicon plus Copper and/or Magnesium
4xx.x	Silicon
5xx.x	Magnesium
6xx.x	Unused Series
7xx.x	Zinc
8xx.x	Tin
9xx.x	Other Element

B.2 - TEMPER DESIGNATION SYSTEM

Specification of an aluminum alloy is not complete without designating the metallurgical condition, or temper, of the alloy. A temper designation system, unique for aluminum alloys, was developed by The Aluminum Association and is used for all wrought and cast alloys. The temper designation follows the alloy designation - the two being separated by a hyphen. Basic temper designations consist of letters; subdivisions, where required, are indicated by one or more digits following the letter. The basic tempers are:

- "F" as fabricated: Applies to products of forming processes in which no special control over thermal or work hardening conditions is employed. Mechanical property limits are not assigned to wrought alloys in this temper, but are assigned to cast alloys in "as cast," F temper.
- "O" annealed: Applies to wrought products which have been heated to effect recrystallization to produce the lowest strength condition, and cast products which are annealed to improve ductility and dimensional stability.
- "H" strain-hardened: Applies to wrought products which are strengthened by strain-hardening through cold-working; the strain-hardening may be followed by supplementary thermal treatment which produces some reduction in strength. The H is always followed by two or more digits (see Table 3).
- "W" solution heat-treated: Applies to an unstable temper applicable only to alloys which spontaneously age at room temperature after solution heat-treatment. This designation is specific only when the period of natural aging is specified; for example, W _ hr. Solution heat treatment involves heating the alloy to approximately 1000°F (~540 °C) to bring the alloying elements into solid solution, followed by rapid quenching to maintain a supersaturated solution to room temperature.
- "T" thermally treated: Applies to products which are heat-treated, sometimes with supplementary strain-hardening, to produce a stable temper other than F or O. The T is always followed by one or more digits (see Table 4).

Subdivisions of the H and T tempers are shown in Tables 3 and 4. There are three basic strain-hardening categories: H1, H2 and H3. The second digit indicates the degree of strain-hardening. The severely cold-worked, or full-hard, condition (H18) is usually obtained with a 75% reduction in cross-sectional area. The H19 temper identifies products with substantially higher strengths and greater reduction in area. For H2X tempers, the products are strain-hardened more than required and then partially annealed to reduce strength to the desired level. The H3X tempers apply to Al-Mg alloys, which tend to age-soften at room temperature and are heated at a relatively low temperature to effect the age-softening and thereby provide stable mechanical properties. This results in a slightly lower strength but improved ductility and working characteristics.

Most heat-treatable aluminum alloys will naturally age at room temperature following quenching and will be strengthened by precipitation-hardening. Natural aging following from a high-temperature forming process, for example casting, is designated T1. More commonly, natural aging follows solution heat-treatment (T4). Artificial aging is accomplished by heating the product to a temperature of roughly 400°F (205°C) for several hours (time and temperature depend on the alloy) to accelerate the precipitation process and to further increase the strengthening effect. Here again, artificial aging may follow a quench from a high temperature forming process (T5) or more commonly, following solution heat-treatment (T6). The T7 temper indicates over-aging from a T6 temper of maximum strength to improve characteristics such as corrosion resistance. The other T tempers indicate that