ASSESSMENT OF THE EFFECT OF GRAIN REFINEMENT ON THE SOLIDIFICATION CHARACTERISTICS OF Al-Si-Cu EUTECTIC CAST ALLOY USING THERMAL ANALYSIS TICHNICAL (CA-CCTA)

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This thesis dedicated to the memory of my grandfather, Mabrouk Elaswad. His words of inspiration and encouragement in pursuit of excellence, still linger on, and my dear mother and my father dear and my dear wife's …

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All praise for Allah S.W.T, blessings to Prophet Muhammad S.A.W along with his family and friends. Thanks to Allah because gave this permission to me prepared and accomplished this MASTER PROJECT in title " ASSESSMENT OF THE EFFECT OF GRAIN REFINEMENT ON THE SOLIDIFICATION CHARACTERISTICS OF Al-Si-Cu EUTECTIC CAST ALLOY USING THERMAL ANALYSIS TECHNICAL (CA-CCTA).” in its time.

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ABSTRACT

Aluminium (Al-Si-Cu) alloys are widely used in automotive, aerospace, and general engineering industries due to their excellent combination of properties, such as good castability, low coefficient of thermal expansion, and high strength-to-weight ratio. Recently, sustainability and recycling of resources are of paramount importance with increasing public awareness on environmental issues and energy, and depleting natural resources. In the case of Al-11.7 Si-Cu-alloys, this would involve the fineness of the primary α-Al dendrites (as determined by (SDAS) value), the Al-Si eutectic structure (Si morphology), as well as the $CuAl_2$ and other copper intermetallic, depending upon the alloying and the trace elements present in the alloy. In addition, there has been no clear explanation of the present form of TiB5 additions via experimental observation on Al-Si-Cu- eutectic cast alloy. The objective of this research are to obtain the probable refiner concentrations of TiB5 additions in the base alloys and to evaluate the effects of these additions on solidification, microstructure and mechanical properties,. Moreover, the main objective of this research is to evaluate the the grain refinement treatments with the additions of (1.6-9.7) wt.% of TiB5, using Cooling Curve Thermal Analysis. Furthermore, the study also investigated the roles of TiB5 on microstructural constituents and formation of intermetallic, Furthermore, the study focuses on the effects of variable amount level of TiB5on mechanical properties, and microstructural. The results obtained were correlated with the earlier microstructural characterization, and thermal analysis. The additives investigated here were TiB5 (1.6-9.7) wt. % . Good agreement was observed between the results obtained for CA-CCTA, Si structure morphology, and SDAS. The microstructure shows that the smaller and the refiner structure of Si particles with 4.8 wt.% TiB5 additions reduced the size by 67-70% . The mechanical properties, such as hardness and impact toughness of base alloy, were improved with the additions of TiB5 by not more than 4.8 wt.%., where by lower strength and impact

toughness were observed due to the intermetallic accompaniment with pore porosity defects, which increased by 6.8% with the increased level of additions. On the other hand, the value of hardness for Al-Si-Cu increased by 7-8% with the increase of TiB5 additions.

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LIST OF SYMBOLS

A - Surface area
C_P - Specific heat
f_{DCP} - Solid fraction at dendrite coherency point
f_{α} - Solid fraction
h - Heat transfer coefficient
Q - Latent heat
s - Second
T - Temperature
T_o - Ambient temperature
T_G - Growth temperature (or maximum temperature)
T_G^E - Eutectic growth temperature
T_{Min} - Minimum temperature
T_N - Nucleation temperature
t_N - Nucleation time
V - Volume
α-Al - Primary aluminium dendrite
λ - Silicon inter spacing
ρ - Density
ΔT_G^E - Depression of eutectic growth temperature
ΔT_R - Recalescence ($\Delta T_R = T_G - T_{Min}$)
ΔT_R^{Al} - Recalescence of primary aluminium
Δt_R^E - Recalescence time
ΔT_N - Undercooling ($\Delta T_N = T_N - T_{Min}$)
°C - Centigrade degree

CHAPTER 1

INTRODUCTION

1.1 Backgrounds

Aluminum, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. It was to become a metal for its time. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of Aluminum and its alloys, greatly benefit growth in the production and use of the new metal.

The properties of aluminium that make this metal and its alloys the most economical and attractive for a wide variety of uses are appearance, light weight, fabricability, physical properties, mechanical properties, and corrosion resistance.

Aluminum has a density of only 2.7 g/cm^3, aluminium typically displays excellent electrical and thermal conductivity, but specific alloys have been developed with high degrees of electrical resistivity. These alloys are useful, for example, in high-torque electric motors. Aluminum is often selected for its electrical conductivity, which is nearly twice that of copper on an equivalent weight basis. The requirements of high conductivity and mechanical strength can be met by use of long-line, high voltage, aluminium steel cord reinforced transmission cable. The thermal conductivity of aluminium alloys, about 50 to 60% that of copper, is advantageous some aluminium alloys exceed structural steel in strength. However, pure aluminium and certain aluminium alloys are noted for extremely low strength and hardness.

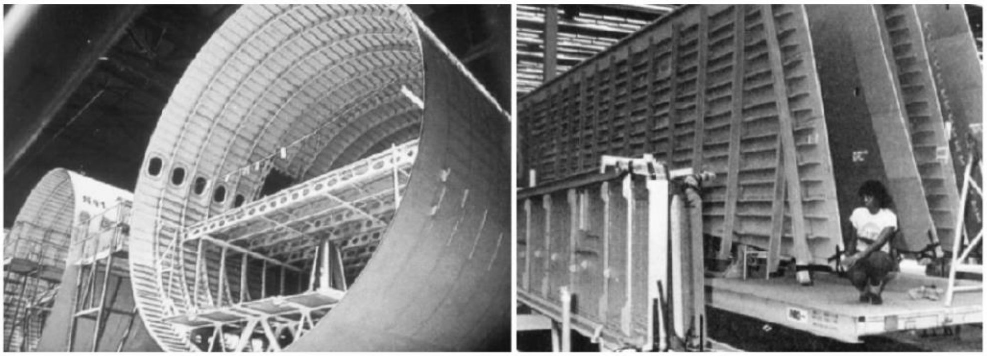


Figure (1.1) Aircraft wing and fuselage structure includes extrusions and plate of 2xxx alloys like 2024, 2124 and 2618 and 7xxx alloys like 7050 and 7475. External sheet skin may be Alclad 2024, 2524, 2618or 7475; the higher purity cladding provides corrosion protection to the AI–Cu and Al–Zn–Mg alloys that may darken with age otherwise.

It is convenient to divide Aluminum alloys into two major categories: casting compositions and wrought compositions. A further differentiation for each category is based on the primary mechanism of property development. Many alloys respond to thermal treatment based on phase solubilities. These treatments include a solution heat treatment, quenching, and precipitation, or age, hardening. For either casting or wrought alloys, such alloys are described as heat treatable. A large number of other wrought compositions rely instead on work hardening through mechanical reduction, usually in combination with various annealing procedures for property development. These alloys are referred to as work hardening.

Some casting alloys are essentially not heat treatable and are used only in as-cast or in thermally modified conditions unrelated to solution or precipitation effects.

Aluminum is used extensively in buildings of all kinds, bridges, towers, and storage tanks. Because structural steel shapes and plate are usually lower in initial cost, Aluminum is used when engineering advantages, construction features, unique architectural designs, light weight, and/or corrosion resistance are considerations.

Corrugated or otherwise stiffened sheet products are used in roofing and siding for industrial and agricultural building construction. Ventilators, drainage slots, storage bins, window and door frames, and other components are additional applications for sheet, plate, castings, and extrusions.

Aluminum products such as roofing, flashing, gutters, and downspouts are used in homes, hospitals, schools, and commercial and office buildings. Exterior walls, curtain walls, and interior applications such as wiring, conduit, piping, ductwork, hardware, and railings utilize Aluminum in many forms and finishes.

Aluminum is used in bridges and highway accessories such as bridge railings, highway guardrails, lighting standards, traffic control towers, traffic signs, and chain-link fences. Aluminium is also commonly used in bridge structures, especially in long-span or movable bascule and vertical-lift construction. Construction of portable military bridges and superhighway overpass bridges has increasingly relied on aluminium elements.

Aluminum alloys are economical in many applications. They are used in the automotive industry, aerospace industry, in construction of machines, appliances, and structures, as cooking utensils, as covers for housings for electronic equipment, as pressure vessels for cryogenic applications, and in innumerable other areas [1].

The predominant reason for alloying is to increase strength, hardness, and resistance to wear, creep, stress relaxation or fatigue. The effects on these properties are specific to the different alloying elements and combinations of them, and are related to their alloy phase diagrams and to the microstructures and substructures that they form as a result of solidification, thermomechanical history, heat treatment and/or cold working.

The tensile yield strength of super-purity aluminium in its annealed (softest) state is approximately 10 MPa, whereas those of some heat treated commercial high-strength alloys exceed 550 MPa. When the magnitude of this difference (an increase of over 5000%) is considered, this practical, everyday accomplishment, which is just one aspect of the physical metallurgy of aluminium, is truly remarkable. Higher strengths, up to yield strength of 690 MPa and over, may be readily produced, but the fracture toughness of such alloys does not meet levels considered essential for aircraft or other critical-structural applications.

The elements that are most commonly present in commercial alloys to provide increased strength—particularly when coupled with strain hardening by cold working or with heat treatment, or both—are copper, magnesium, manganese, silicon, and zinc (Figure1.1).

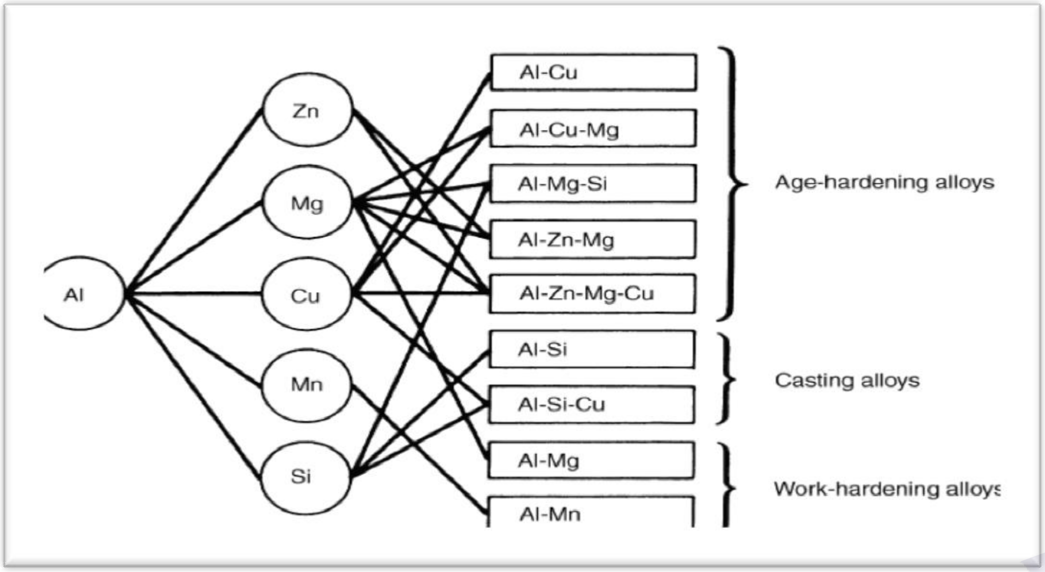


Figure (1.2)

the principal aluminium alloys

These elements all have significant solid solubility in aluminium, and in all cases the solubility increases with increasing temperature [2].

The mechanical, physical, and chemical properties of aluminium alloys depend upon the composition and microstructure. The addition of selected elements to pure aluminium greatly enhances its properties and usefulness.

Because of this, most applications for aluminium utilize alloys having one or more elemental additions. The major alloying additions used with aluminium or copper, manganese, silicon, magnesium, and zinc. The total amount of these elements can constitute up to 10% of the alloy composition (all percentages given in weight percent unless otherwise noted). Impurity elements are also present, but their total percentage is usually less than 0.15% in aluminium alloys.

Aluminum–silicon alloys have the potential for excellent cast ability, good weld ability, good thermal conductivity, high strength at elevated temperatures and excellent corrosion resistance. They are therefore well suited for aerospace structural applications, the automobile industry and military applications.

The eutectic aluminium, silicon alloy - or LM-6 alloy - is a member of this group. Just like all piston alloys, LM-6 alloy is difficult to machine. Therefore, LM-6 and the rest of the piston alloys are generally cast into shape; however, with more and more automotive technology advances, and complicated component shapes, lean manufacturing, and constant changes in design, the need for machining LM-6 alloy has increased. The near-artistic group of aluminium, silicon alloys enjoys common features; low thermal expansion, excellent cast ability, high corrosion resistance, and high abrasive wear resistance, this has led to their use in automotive piston components. This group of alloys is sometimes referred to as “piston alloys [3].

The microstructure is characterized by various parameters such as the grain size, the Secondary dendrite arm spacing (SDAS), the size, shape and distribution of the eutectic silicon particles, as well as the morphologies and the amounts of intermetallic phases present. Some of these parameters are changed after heat treatment, which consequently affects the resultant mechanical properties. Some elements often added as alloying elements to increase the strength and hardenability such as copper (Cu) and magnesium (Mg), while iron (Fe), manganese (Mn), nickel (Ni) and chromium (Cr) are usually present as impurity elements. The Al-Si-Cu-Mg alloys have excellent Castability and mechanical properties while making them popular foundry alloys for industrial applications [4].

In addition, grain refinement of aluminium alloys has the main feature in the control of quality products manufacturing of wrought aluminium alloys. The grain refinement improved the mechanical properties by increasing in resistance to hot cracking, homogeneity of microstructure feature. Master alloys commonly contain titanium (2-10 wt. %) or boron (up to 5 wt. %) or combination of both elements in aluminium [5].

The thermal analysis technique estimates the nucleation potential of the melt during solidification but only for a specific cooling rate, and the characteristic cooling curve parameters must be correlated with the actual state of nucleation of the melt."" The advantage of the thermal analysis technique is that it can be used as an online control tool. Faster results can be obtained with the certainty that the results reflect the nucleation potential of the melt [6].

The main contribution of this research, monitor the effect of grain refiner additive for asset the optimum refiner value during metallurgical phase transformations in solidification.

1.2 Problem statement:

As known, Grain refinement is one the effective treatment used widely to improve the quality of the castings. The control of grain size, prior to casting, is a matter of great interest. Without doubt, optical microscopy is the best technique to evaluate changes induced by grain refining. However, the main drawbacks of this technique are the time required to prepare a sample and the fact that the casting must be destroyed. Chemical analysis to determine the levels of grain refiner in the melt is an attractive method. Grain size depends not only on chemical analysis, but also on the cooling rate. Also grain refiner, added in the form of a master alloy, has been found to have an incubation time of 1–2h, with the degree of grain refining improving with time. In addition, the mechanisms responsible for grain refinement of conventional Al–Ti and Al–Ti–B methods have been extensively studied. However, the exact mechanisms by which grain refinement occurs using the Al–Ti–B have not yet been fully understood, especially for Al-Si-Cu eutectic ternary phase cast alloy.

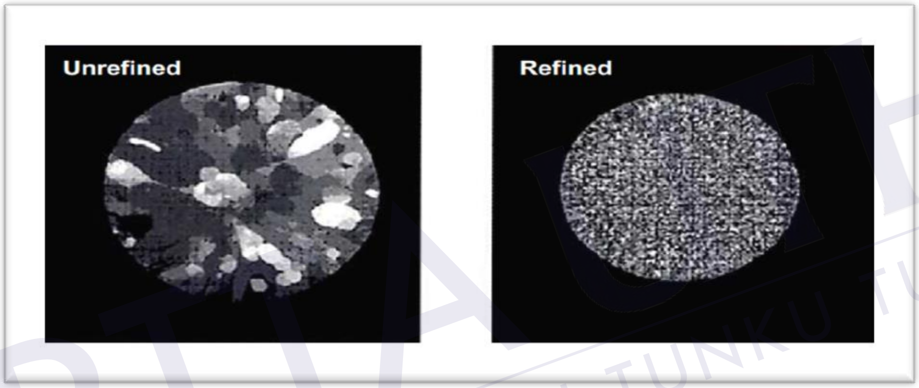


Figure 1.3 Grain structure of aluminium alloy without and with grain refinement during solidification.

1.3 Objectives of research:

1. Evaluate the effect of TiB5 grain refiner addition to solidification parameters of α- Al primary phase.
2. To investigate the effect of additions on Al-Si phase parameters during solidification.
3. To study the effect of refiner additions on mechanical property and microstructure (intermetallic forming and Si particles) with Correlating with thermal analysis.

1.4 Scope of study:

1- The Al-Si-Cu eutectic cast alloy will be used as the base alloy. Different concentrations Of TiB5 (1.6 to 9.7 wt. %) additions will be used to assess the degree of addition for grain refinement.

2- Cooling curve characteristics by thermal analysis (CA-CCTA).

3- Microstructure analysis (qualitative and quantitative) Quantitative microscopy will focus on measuring the Si particle size, grain size and aluminium secondary dendrite arm spacing (SDAS. Qualitative analysis will focus on rich intermetallic formation by SEM/EDS.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The unique combinations of properties provided by aluminium and its alloys make Aluminum one of the most versatile, economical, and attractive metallic materials for a broad range of uses—from soft, highly ductile wrapping foil to the most demanding engineering applications, Aluminum alloys are second only to steels in use as structural metals [2].

Aluminum, the second most plentiful metallic element on earth, became an economic competitor in engineering applications as recently as the end of the 19th century. It was to become a metal for its time. The emergence of three important industrial developments would, by demanding material characteristics consistent with the unique qualities of aluminium and its alloys, greatly benefit growth in the production and use of the new metal [1].

Aluminum alloys are broadly used in products and applications that touch us regularly in our daily lives, from aluminium foil for food packaging and easy-open aluminium cans for your beverages to the structural members of the aircraft in which we travel. The broad use of aluminium alloys is dictated by a very desirable combination of properties, combined with the ease with which they may be produced in a great variety of forms and shapes [7].

Aside from steel and cast iron, aluminium is one of the most widely used metals owing to its characteristics of lightweight, good thermal and electrical conductivities.

Despite these characteristics, however, pure aluminium is rarely used because it lacks strength. Thus, in industrial applications, most aluminium is used in the form of alloys. There are a number of elements that are added to aluminium in order to produce alloys with increased strength and improved foundry or working properties. In addition to alloying aluminium with other elements, the mechanical properties can also be enhanced by heat treatment. Generally, aluminium alloys can be classified into two main categories: cast alloys and wrought alloys [8].

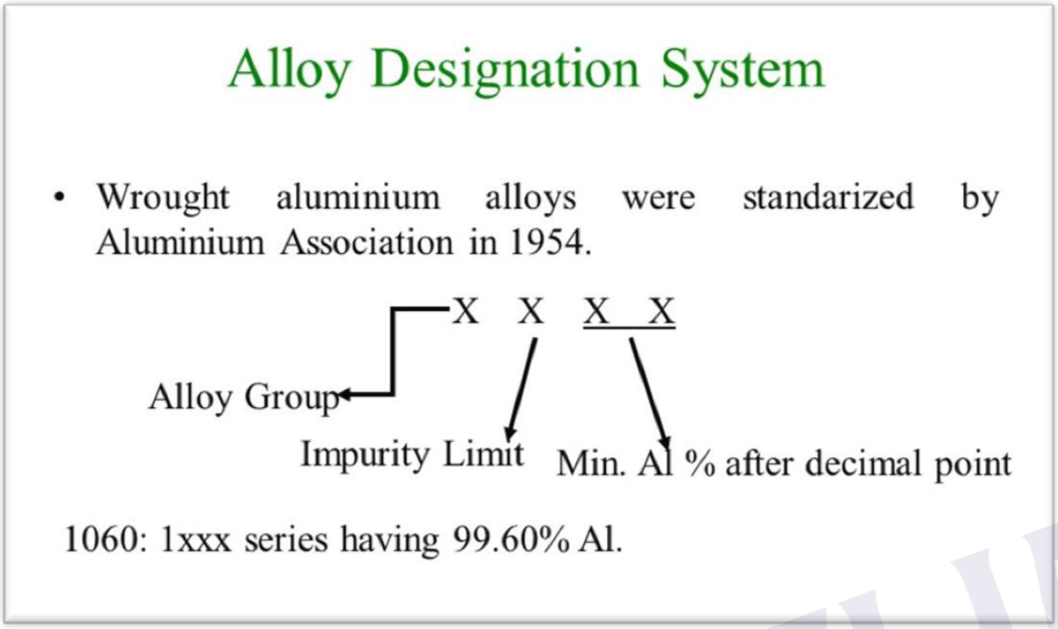
2.2 Aluminum Alloy Designation Systems

It is convenient to divide aluminium alloys into two major Designations: wrought compositions and cast compositions. A further differentiation for each designation is based on the primary mechanism of property development. Many alloys respond to thermal treatment based on phase solubilities. These treatments include a solution heat treatment, quenching, and precipitation, or age, hardening. For either casting or wrought alloys, such alloys are described as heat treatable. A large number of other wrought compositions rely instead on work hardening through mechanical reduction, usually in combination with various annealing procedures for property development. These alloys are referred to as work hardening. Some casting alloys are essentially not heat treatable and are used only in as-cast or in thermally modified conditions unrelated to solution or precipitation effects. Cast and wrought alloy nomenclatures have been developed. The Aluminum Association system is most widely recognized in the United States. Their alloy identification system employs different nomenclatures for wrought and cast alloys, but divides alloys into families for simplification [2].

2.2.1 Wrought Aluminum Alloy

Most aluminium alloys used for wrought products contain less than 7 % of alloying elements. By the regulation of the amount and type of elements added, the properties of the aluminium can be enhanced and its working characteristics improved. Special compositions have been developed for particular fabrication processes such as forging and extrusion.

Four-digit numerical designation system is used to identify wrought aluminium alloys. As shown below, the first digit of the four-digit designation indicates the group:


Alloy Designation System

- Wrought aluminium alloys were standarized by Aluminium Association in 1954.

1060: 1xxx series having 99.60% Al.

Figure (2.1) Wrought Aluminum Alloy

For the 2*xxx* through 7*xxx* series, the alloy group is determined by the alloying element present in the greatest mean percentage. An exception is the 6*xxx* series alloys in which the proportions of magnesium and silicon available to form magnesium silicide (Mg2Si) are predominant. Another exception is made in those cases in which the alloy qualifies as a modification of a previously registered alloy. If the greatest mean percentage is the same for more than one element, the choice of group is in order of group sequence:
Copper, manganese, silicon, magnesium, magnesium silicide, zinc, or others.

2.2.2 Cast Aluminum Alloys

The aluminium alloys specified for casting purposes contain one or more alloying elements, the maximum of any one element not exceeding 12 percent. Some alloys are designed for use in the as-cast condition; others are designed to be heat treated to improve their mechanical properties and dimensional stability. High strength, together with good ductility, can be obtained by selection of suitable composition and heat treatment.

A system of four-digit numerical designations incorporating a decimal point are used to identify aluminium alloys in the form of castings and foundry ingot. The first digit indicates the alloy group:

For 2*xx. x* though 8*xx. x* alloys, the alloy group is determined by the alloying element present in the greatest mean percentage, except in cases in which the composition being registered qualifies as a modification of a previously registered alloy. If the greatest mean percentage is common to more than one alloying element, the alloy group is determined by the element that comes first in the sequence.

The second two digits identify the specific aluminium alloy or, for the aluminium (1*xx. x*) Series, indicates purity. The last digit, which is separated from the others by a decimal point, indicates the product form, whether casting or ingot. A modification of an original alloy, or of the impurity limits for unalloyed aluminium, is indicated by a serial letter preceding the numerical designation. The serial letters are assigned in alphabetical sequence starting with A but omitting I, O, Q, and X, the X being reserved for experimental alloys. Explicit rules have been established for determining whether a proposed composition is a modification of an existing alloy or if it is a new alloy [1].

Table 2.1: Aluminum alloy designation system

Wrought Alloys		**Cast Alloys**	
Alloying element	**Designation**	**Alloying element**	**Designation**
None(99% Al)	1XXX	None(99% Al)	1XX.X
Cu	2XXX	Cu	2XX.X
Mn	3XXX	Si + Cu and/or Mg	3XX.X
Si	4XXX	Si	4XX.X
Mg	5XXX	Mg	5XX.X
Mg + Si	6XXX	Unused series	6XX.X
Zn	7XXX	Zn	7XX.X
Others	8XXX	Sn	8XX.X
Unused series	9XXX	Others	9XX.X

2.3 Advantages of aluminium alloys

The first step in becoming familiar with the opportunities to utilize aluminium alloys advantageously is to briefly note some of the basic characteristics of wrought and cast aluminium alloys that make them desirable candidates for such a wide range of applications as well as their limitations. Wrought alloys (those mechanically formed by rolling, forging, and extrusion into useful products) are addressed first, then cast alloys (those cast directly to the nearest final finished shape).

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