REVIEW ONALUMINIUM AND ITS ALLOYSFOR AUTOMOTIVE APPLICATIONS

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ABSTRACT

Aluminium has a density around one third that of steel or copper. It is one of the lightest commercially available metals in the markets. The resultant high strength to weight ratio makes it an important structural material. This allows an increased payloads or fuel savings for transport industries in particular. In the present scenario, a review of aluminium and its alloys have been made to consolidate some of the aspects of physical, mechanical and wear behavior. The importance of aluminium and its alloys as engineering materials is reflected by the fact that out of over 1600 engineering materials available in the market today more than 300 wrought aluminium alloys with 50 in common use. These materials initially replaced cast iron and bronze alloys but owing to their poor wear and seizure resistance.These materialswere reported by the number of researchers for the past 25 years. In the present study, based on the literature review, the aluminium and its alloys have been discussedin quite detail. Aluminium and its alloys are finding increased applications in aerospace, automobile, space shuttle, underwater, and transportation applications. This is mainly due to light weight, improved physical, mechanical and tribological properties like strong, stiff, abrasion and impact resistant, and is not easily corroded.

Keywords: Aluminium, Aluminium Alloys, Alloy Designations, Aluminium Technical Data

I.INTRODUCTION

The possibility of taking advantage of particular properties of the constituent materials to meet specific demands is the most important motivation for the development of any specific material. Aluminium is a soft material. Generally, it has excellent ductility, formability,corrosion resistant, electrical conductivity and thermal conductivity [1]**.** Aluminium is the world's most abundant metal after iron.This is the third most common element comprising 8% of the earth's crust. The versatility of aluminium makes it the most widely used metal after steel.Aluminium is derived from the mineral bauxite. Bauxite is converted to aluminium oxide (alumina) via the Bayer Process.All the alumina used by the market economy aluminum industry is manufactured by the Bayer process, the basic features of which have remained unchanged since Karl Josef Bayer patented the process in Germany in 1888 [2, 3]. All primary aluminum metal is produced by the Hall-Heroult process whose basic features have not changed since patents were filed in 1886, in France by Paul L.T. Heroult and in the US by Charles M. Hall [2, 3]. The alumina is then converted to aluminium metal using electrolytic cells and the Hall Heroult Process.Worldwide demand for aluminium is around 29 million tons per year [1]. About 22 million tons is new aluminium and 7 million tons is recycled aluminium scrap. The use of recycled aluminium is economically and environmentally compelling. It takes 14,000 kWh to produce 1 tonne of new aluminium. Conversely, it takes only 5% of this to remelt and recycle one tonne of aluminium. There is no difference in quality between virgin and recycled aluminium alloys. Pure aluminium is widely used for foil and conductor cables.But alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the lightest engineering metals, having a strength to weight ratio superior to steel. By utilising various combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever increasing number of applications. This array of products ranges from structural materials through to thin packaging foils [1].The process can be represented [2] by the following equations:

$$Al_20_3.xH_2O + 2NaOH \rightarrow 2NaA1O_2 + (l+x)H_2O \qquad \text{extraction}$$

$$2NaA1O_2 + 4H_2O \rightarrow 2NaOH + A1_2O_3.3H_2O \qquad \text{decomposition}$$

$$A1_2O_3.3H_2O \rightarrow A1_2O_3 + 3H_2O \qquad \text{calcination}$$

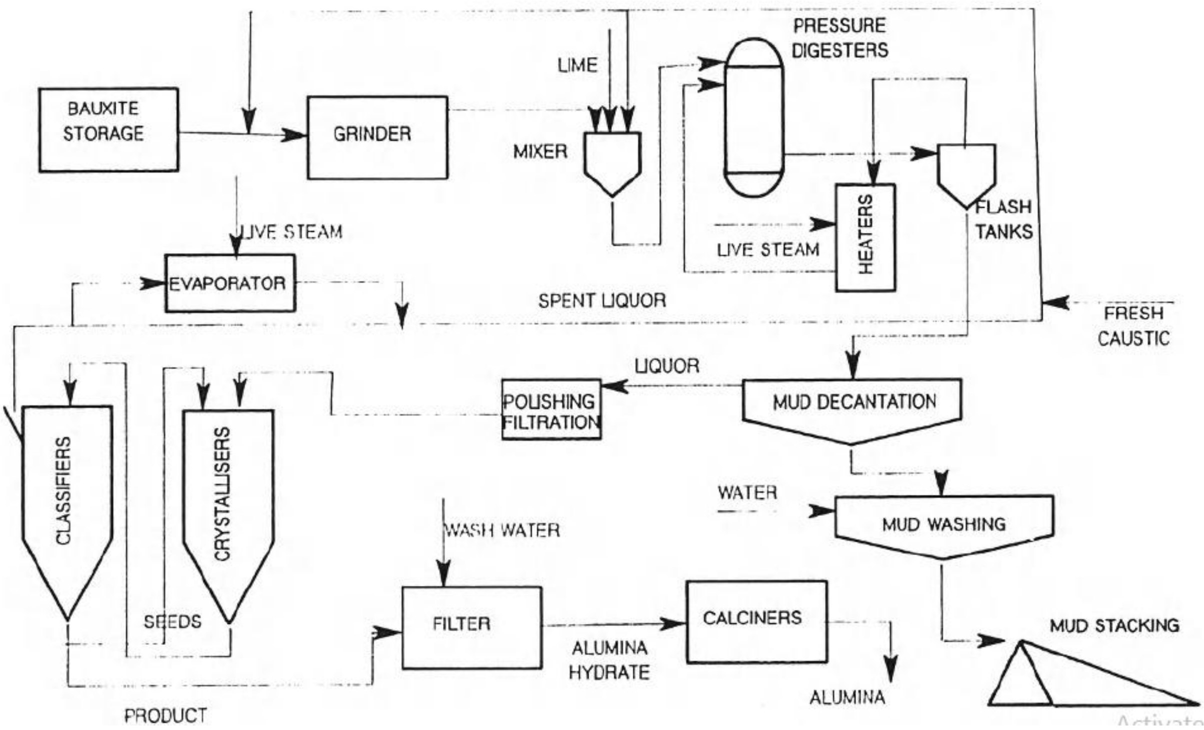

Figure 1 Bayer process flow sheet [2]

II. PROPERTIES OF ALUMINIUM [1, 4]

2.1 Strength of Aluminium:Pure aluminium doesn't have a high tensile strength. However, the addition of alloying elements like manganese, silicon, copper and magnesium can increase the strength properties of aluminium and produce an alloy with properties tailored to particular applications. Aluminium is well suited to cold environments. It has the advantage over steel in that its' tensile strength increases with decreasing temperature while retaining its toughness. Steel on the other hand becomes brittle at low temperatures.

2.2 Corrosion Resistance of Aluminium:When exposed to air, a layer of aluminium oxide forms almost instantaneously on the surface of aluminium. This layer has excellent resistance to corrosion. It is fairly resistant to most acids but less resistant to alkalis.

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2.3 Thermal Conductivity of Aluminium:The thermal conductivity of aluminium is about three times greater than that of steel. This makes aluminium an important material for both cooling and heating applications such as heat exchangers. Combined with it being nontoxic this property means aluminium is used extensively in cooking utensils and kitchenware.

2.4 Electrical Conductivity of Aluminium:Along with copper, aluminium has an electrical conductivity high enough for use as an electrical conductor. Although the conductivity of the commonly used conducting alloy (1350) is only around 62% of annealed copper, it is only one third the weight and can therefore conduct twice as much electricity when compared with copper of the same weight.

2.5 Reflectivity of Aluminium:From UV to infrared, aluminium is an excellent reflector of radiant energy. Visible light reflectivity of around 80% means it is widely used in light fixtures. The same properties of reflectivity makes aluminium ideal as an insulating material to protect against the sun's rays in summer, while insulating against heat loss in winter.

2.6 Mechanical Properties of Aluminium:Aluminium can be severely deformed without failure. This allows aluminium to be formed by rolling, extruding, drawing, machining and other mechanical processes. It can also be cast to a high tolerance.Alloying, cold working and heat treating can all be utilised to tailor the properties of aluminium. The tensile strength of pure aluminium is around 90 MPa but this can be increased to over 690 MPa for some heat treatable alloys.

Table 1 Technical Data for Aluminum [5]

Overview		**Thermal properties**	
Name	Aluminum	Phase	solid
Symbol	Al	Melting point	660.32 ^{o}C
Atomic number	13	Boiling point	2519 ^{o}C
Atomic weight	26.981538	Heat of Fusion	10.7 kJ/mol
Classifications		Heat of Vaporization	293 kJ/mol
Alternate Names	Aluminium	Specific Heat	904 J/(kg K)
Block	P	Thermal Conductivity	235 W/(m K)
Group	13	Thermal Expansion	0.0000231 K^{-1}
Period	3	**Electrical properties**	
Electron Configuration	[Ne] $3s^2 3p^1$	Electrical Type	Conductor
Color	Silver	Electrical Conductivity	3.8×10^{7} S/m
Discovery	1825 in Denmark	Resistivity	2.6×10^{-8} m Ω
Bulk physical properties		Superconducting Point	1.175
Density (solid)	2.7 g/cm3	**Magnetic properties**	
Density (Liquid)	2.375 g/cm3	Magnetic Type	Paramagnetic
Molar Volume	9.99×10^{-6}	**Reactivity**	
Brinell Hardness	245 MPa	Valence	3
Mohs Hardness	2.75 MPa	Electronegativity	1.61
Vickers Hardness	167 MPa	Electron Affinity	42.5 kJ/mol
Bulk Modulus	76 GPa	**Health and Safety**	
Shear Modulus	26 GPa	Auto ignition Point	400 °C
Young Modulus	70 GPa	Flashpoint	645 °C
Poisson Ratio	0.35	**Abundances**	
Refractive Index	1.44	% in Universe	0.005%

Speed of Sound	5100 m/s	% in Sun	0.006%
Atomic dimensions and structure		% in Meteorites	0.91%
Atomic Radius	118 pm	% in Earth's Crust	8.1%
Covalent Radius	118 pm	% in Oceans	5×107%
Crystal Structure	FCC	% in Humans	0.00009%
Lattice Angles	π/2, π/2, π/2	**Nuclear Properties**	
Lattice Constants	404.95, 404.95, 404.95 pm	Half-Life	Stable
		Lifetime	Stable
		Quantum Numbers	^{2}P1/2
		Stable Isotopes	^{27}Al
		Isotopic Abundances	^{27}Al 100%

Table 2 Propertiesof Aluminium [6]

Property	Value	Reference	URL
Young's modulus	70 GPa	Thin Solid Films, 270(1995), p.263	http://www.memsnet.org/material/aluminumalbulk/
Poisson ratio	0.33	Microprobe type measurement of Young's modulus and Poisson coefficient by means of depth sensing indentation and acoustic microscopy, Comte, C. Von, Stebut, J. Surface & Coatings Technology, Vol.154, no. 1, 1 May 2002, p. 428	
Specific heat	898.7 J/kg/K	CRC Materials Science and Engineering Handbook, p.260	http://www.memsnet.org/material/aluminumalbulk/
Thermal conductivity	237 W/m/K	CRC Materials Science and Engineering Handbook, p.270-274	http://www.memsnet.org/material/aluminumalbulk/
Dielectric constant	Aluminum powder 1.6-1.8	Dielectric Constant Reference Guide	http://www.asiinstr.com/dc1.html#List
Index of refraction	1.44	Chemical Properties Handbook Edited by Yaws, C.L. 1999; Mc Graw Hill	
Electrical conductivity	$3.538x10^7$ S/m	Nondestructive Testing Resource Center	http://www.ndted.org/GeneralResources/MaterialProperties/ET/ET_matlprop_Aluminum.htm

III. ALUMINIUM ALLOYS

Aluminium is the most commonly alloyed with copper, zinc, magnesium, silicon, manganese and lithium. Small additions of chromium, titanium, zirconium, lead, bismuth and nickel are also made and iron is invariably present in small quantities. There are over 300 wrought aluminium alloys with 50 in common use [1]. Cast aluminum components are used for many varied functions, from decorative home-owner components, such as lighting fixtures, to highly engineered, safety-critical components for aerospace and automotive applications. There are many different methods and alloys that can be used to produce this wide variety of cast aluminum components. The choice of alloy and casting process will play a major role in the procurement process, affecting both component properties and cost. The procurement process for cast aluminum parts always should begin by the design engineers defining the three major factors that drive the quality and cost on a cast aluminum component—functionality (service requirements), design (shape and size) and production quantity. Each of these factors will have a large bearing on the choice of casting method, alloy selection and cost as well as final component quality [7].

Figure 2 This rear lower control arm for the automotive industry was cast hollow with A356 aluminum alloy through a low-pressure permanent mold casting process [7]

3.1 Aluminum Casting Metallurgy: The specification of an aluminum alloy for a cast component is based upon the mechanical properties it can achieve. Aluminum casting properties result from three primary factors: casting alloy, melting and casting operations, and thermal treatment. The properties obtained from one particular combination of these factors may not be identical to those achieved with the same alloy in a different metalcasting facility or with a different thermal treating source [7].

3.2 Aluminum Processing: Molten aluminum has several characteristics that can be controlled to maximize casting properties. It is prone to picking up hydrogen gas and oxides in the molten state as well as being sensitive to minor trace elements. Although some decorative or commercial castings may have quality requirements that can be met without additional processing, tight melt control and specialized molten metal processing techniques can help provide enhanced mechanical properties when needed [7].

3.3 Alloy Chemistry: During molten aluminum processing, the percentages of alloying elements and impurities must be controlled carefully. If they are not, characteristics, such as soundness, machinability, corrosion resistance, mechanical properties and conductivity, are affected adversely. Molten aluminum alloys are prone to chemistry changes that can be controlled during melting and holding. The most significant of these changes is the potential to lose magnesium and pick up iron, which can alter the mechanical properties significantly. If the service requirements of the cast component demand high material properties, these reactions must be controlled through facility melting and holding practices [7].

3.4 Grain Refining & Modification*:* Molten aluminum is sensitive to trace elements.This sensitivity can be used as an advantage by adding trace amounts of materials to create beneficial changes in the casting microstructure. Both grain refining and silicon modification can improve mechanical properties in the final component. They also can act as useful tools to optimize properties and heat treatment response to meet specific component service requirements and aid the development of certain casting properties. During solidification, aluminum freezes in long columnar grain structures. These grains will grow until they impinge on another grain or the mold wall. Grain refining is a treatment process in which nucleating sites (in the form of titanium and boron master alloys) are added to the molten metal to aid the growth of additional grains. This leads to the creation of more grains, which causes the grains to remain smaller. With modification, a sodium or strontium addition is made to the molten aluminum to change the morphology (shape) of the silicon crystal [7].

3.5 Molten Metal Handling: Molten aluminum is prone to absorb hydrogen from moisture in the atmosphere and other sources.This can lead to defects. Hydrogen gas can form pores in the solid castings.Aluminum oxide and other intermetallic impurities can solidify in the castings as inclusions. Both gas porosity and inclusions have a negative impact on casting quality. It will prevent castings from meeting high service requirements. Melting practices typically include degassing with an inert purge gas to remove hydrogen and fluxing to clean the molten aluminum of oxides and other inclusions prior to pouring [7].

Figure 3 This laser housing for the industrial and scientific industries was cast in A356 aluminum alloy with T51 heat treatment process [7]

IV.ALUMINIUM ALLOYS DESIGNATION SYSTEM

Aluminium alloys are normally identified by a four figure system which originated in the USA and is now universally accepted [1]. For unalloyed wrought aluminium alloys designated 1XXX, the last two digits represent the purity of the metal. They are the equivalent to the last two digits after the decimal point when

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aluminium purity is expressed to the nearest 0.01 percent. The second digit indicates modifications in impurity limits. If the second digit is zero, it indicates unalloyed aluminium having natural impurity limits. And 1 through 9, indicate individual impurities or alloying elements. For the 2XXX to 8XXX groups, the last two digits identify different aluminium alloys in the group. The second digit indicates alloy modifications. A second digit of zero indicates the original alloy and integers 1 to 9 indicate consecutive alloy modifications [1].

In general,the families of aluminium alloys are represented by 1XXX, 2XXX, 3XXX up to 8XXX as shown in the Table 3. The 1xxx series designation concerns unalloyed aluminium materials which are distinguished according to their degree of purity. The 8xxx series designations are for miscellaneous types of alloys (i.e. Fe alloys) which cannot be grouped in the other families. The 2xxx, 6xxx and 7xxx series are heat-treatable alloys, which gain their strength by alloying but make use of precipitation hardening as the main mechanism. The first digit gives basic information about the principal alloying elements. The designation system also says something about the hardening of the alloys belonging to a family [8]. The 1xxx, 3xxx and 5xxx series are so called non-heat-treatable alloys. They gain their strength by alloying (e.g. increasing content of Mg) and work hardening. Among them Al6061 alloy is highly corrosion resistant, extricable in nature and exhibits moderate strength. It finds vast applications in the fields of construction, automotive and marine fields. They have been studied extensively because of their technological importance and their exceptional increase in strength obtained by precipitation hardening [1].

Alloy chart from US Navy Foundry manual has been described that there are two types of aluminum alloy, extrusion and casting [9]. Extruded alloys are made to be pulled and squeezed into their final shape. Examples: door frames, plate, al. ladders, window frames, sheet, pop cans etc. Extrusions are alloys not made for sand casting, but are OK for most home applications. They have a 4 digit number (6061 for example) for identification. Aluminum by itself is too soft for castings, elements are added to the aluminum to give it strength. Casting alloys have a 3 digit number identifying the alloy group. Table 4 describes the general classifications of aluminium alloy series designation of casting alloys. Sometimes, there is a number after the decimal. If the number after the decimal is a "0", it is a casting. If the number is a "1", it refers to ingot. Example: 356.0/casting, 514.1/ingot. The most popular casting alloys are "356" and "319". Anodized alloys are typically 214 or 514 [9].

The U.S. Aluminum Assn. (AA) monitors industry standard specifications for designating aluminum alloys through a numbering system known as the AA “Pink Sheets.” The system designates individual aluminum metalcasting alloys using a three-digit number plus a decimal, which is included on casting blueprints to specify the casting alloy to be used. The standard specifies the chemical composition limits of aluminum alloys and the percentage of each alloying element or an allowable chemistry range. The first digit of the three-digit number system categorizes the casting alloys by groups (or series) according to their major alloying elements as seen in Table 5. The balance of the three-digit number identifies the various individual alloys within each alloy series. For example, the 300 series of alloys includes more than 50 individual alloys (319, 356, 357, 380, etc). Some of these individual alloys have multiple variations, all using the same three-digit number. These alloy designations include a letter before the three-digit alloy designation. For instance, variations of 356 are A356, B356, C356 and F356. This letter distinguishes between alloys that fall within the alloy chemistry ranges, but differ slightly in percentages of alloying elements or impurities—such as F357.0, which has a lower minimum level and

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tighter range for magnesium than 356.0. These variations can determine special casting properties. The Pink Sheet standard designations apply to aluminum alloys in the form of both castings and ingot, and the single digit following the decimal indicates how the alloy will be used [7]. These designations include:

• XXX.0 = casting;

• XXX.1 = ingot used to make the casting;

• XXX.2 = ingot used to make the casting (having typically tighter chemical limits than the XXX.1 ingot designation).

If AA alloys 356.1 or 356.2, for example, are listed as the alloy specification on casting blueprints, they should define the chemistry of the ingot used to make the cast components, not the final castings. The number XXX.0 for castings includes a chemistry different from the ingot specifications. This leaves room for chemistry changes that can occur during remelting. The addition of casting returns, such as scrap castings, to the charge material also can alter the casting chemistry. The primary difference is that the XXX.0 specifications allow for some magnesium loss (due to burn out) and iron or zinc pickup that may be experienced during processing. The alloy chemistry of the final 356 cast component should fall within the limits of the 356.0 specifications but may not meet the chemical specification for the 356.1 ingot. Final cast components also should be properly designated. If a blueprint designates 356.1 as the casting alloy, it would be improper to designate the final castings as 356.1. Components should be shipped designated as 356.0 castings.

Table 3 Standard Terminology and Principle Alloy Elementof Aluminium Alloy [1]

Aluminium Alloy Designation	Principle Alloy Element
1XXX	99% pure
2XXX	Cu
3XXX	Mn
4XXX	Si
5XXX	Mg
6XXX	Mg and Si
7XXX	Zn
8XXX	Others

Table 4 Aluminium Alloy Series Designation of Casting Alloys [9]

Aluminium Series	Principle Alloy Element
100's	Aluminum 99%
200's	Copper
300's	Silicon+ copper and/or magnesium
400's	Silicon
500's	Magnesium
600's	Presently Unused, future alloys
700's	Zinc
800's	Tin
900's	Other

Table 5 Aluminum Assn. Standard Chemical Composition Limits for 356 Aluminum Alloy [7]

AA#	Product	Si	Fe	Cu	Mn	Mg	Zn	Ti	Others		Aluminum
									Each	Total	
356.0	S&P	6.5-7.5	0.60	0.25	0.35	0.20-0.45	0.35	0.25	0.05	0.15	Remainder
356.1	Ingot	6.5-7.5	0.50	0.25	0.35	0.25-0.45	0.35	0.25	0.05	0.15	Remainder
356.2	Ingot	6.5-7.5	0.13-0.25	0.10	0.05	0.30-0.45	0.05	0.20	0.05	0.15	Remainder
A356.0	S&P	6.5-7.5	0.20	0.20	0.10	0.25-0.45	0.10	0.20	0.05	0.15	Remainder
A356.1	Ingot	6.5-7.5	0.15	0.20	0.10	0.30-0.45	0.10	0.20	0.05	0.15	Remainder
A356.2	Ingot	6.5-7.5	0.12	0.10	0.05	0.30-0.45	0.05	0.20	0.05	0.15	Remainder
B356.0	S&P	6.5-7.5	0.09	0.05	0.05	0.25-0.45	0.05	0.04-0.20	0.05	0.15	Remainder
B356.2	Ingot	6.5-7.5	0.06	0.03	0.03	0.30-0.45	0.03	0.04-0.20	0.05	0.15	Remainder
C356.0	S&P	6.5-7.5	0.07	0.05	0.05	0.25-0.45	0.05	0.04-0.20	0.03	0.15	Remainder
C356.2	Ingot	6.5-7.5	0.04	0.03	0.03	0.30-0.45	0.03	0.04-0.20	0.05	0.15	Remainder
F356.0	S&P	6.5-7.5	0.20	0.20	0.10	0.17-0.25	0.10	0.04-0.20	0.03	0.15	Remainder
F356.2	Ingot	6.5-7.5	0.12	0.10	0.05	0.17-0.25	0.05	0.04-0.20	0.05	0.15	Remainder

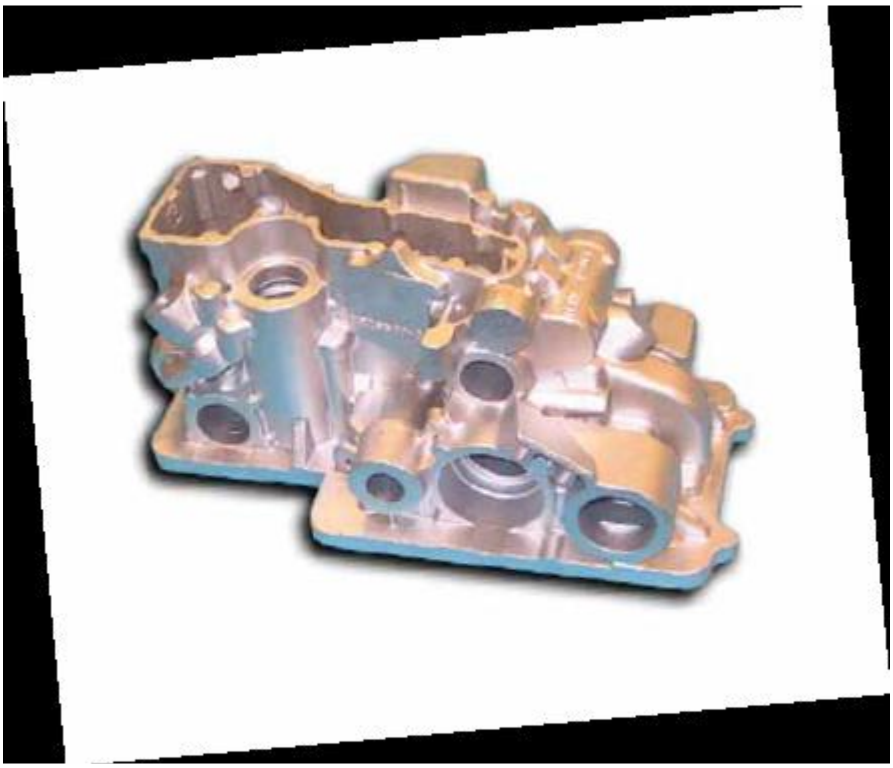

Figure 4 This electric valve housing for Hamilton Sundstrand is cast in C355 aluminum via semi-permanent mold casting [7]

Figure 5 Cast with A356 aluminum alloy using the lost foam process, this verado L6 four-stroke cylinder head for a boat engine coupled an automotive-style cylinder head with a double-water jacketed exhaust manifold [7]

Table 6 Aluminium Alloys and Approximate Equivalents [BS 1490:1988]

UK	ISO	EN AC	France	Germany	Italy UNI	USA AA/ASTM	USA SAE	Japan	End uses
LM0	Al 99.5	–	A5	–	3950	150	–	–	Electrical, food, chemical plant
LM2	Al-Si10Cu2Fe	46 100	A-S9U3-Y4	–	5076	384	383	ADC 12	Pressure diecasting
LM4	Al-Si5Cu3	45 200	A-S5U3	G-AlSi6Cu4 (225)	3052	319	326	AC 2A	Sand, gravity diecasting manifolds, gear boxes etc.
LM5	Al-Mg5Si1	51 300	AG6	G-AlMg5	3058	514	320	AC 7A	Sand, gravity; corrosion resistant, for marine use
	Al-Mg6			(244)					Food plant, chemical plant
LM6	Al-Si12	44 100	AS13	G-AlSi12	4514	A413	–	AC 3A	Sand, gravity; thin sections, manifolds
	Al-Si12Fe			(230)					
LM9	Al-Si10Mg	43 100	A-S10G	G-AlSi10Mg	3049	A360	309	AC 4A	Low pressure etc.; motor housings, cover plates etc.
				(233)					High strength when heat treated
LM12	Al-Cu10Si2Mg	–	A-U10G	–	3041	222	34	–	Gravity, sand cast; machines well, hydraulic

									equipment
LM13	Al-Si12Cu Al-Si12CuFe	48 000	A-S12UN	–	3050	336	321	AC 8A	Sand, chill; used for pistons
LM16	Al-Si5Cu1Mg	45 300	A-S4UG	–	3600	355	322	AC 4D	Sand, chill; cylinder heads valve bodies, good pressure tightness
LM20	Al-Si12Cu Al-Si12CuFe	47 000	A-S12-Y4	G-AlSi12(Cu) (231)	5079	A413	305	–	Pressure diecasting corrosion resistant, marine castings, water pumps, meter cases
LM21	Al-Si6Cu4	45 000	A-S5U2	G-AlSi6Cu4 (225)	7369/4	308	326	AC 2A	Sand, gravity; similar to LM4, crankcases, gear boxes etc.
LM22	Al-Si5Cu3	45 400	A-S5U	G-AlSi6Cu4 (225)	3052	319	326	AC 2A	Chill casting; solution treated, good shock resistance, automotive heavy duty parts
LM24	Al-Si8Cu3Fe	46 500	A-S9U3A-Y4	G-AlSi8Cu3	5075	A380	306	AC 4B	Pressure diecasting; engineering diecasting

Table 7 Maximum Chemical Composition of Aluminium Casting Alloy (A356 or 7Si-0.3Mg)

Element ↓		**Quantity (weight %)**	
Reference →		[ASTM B85 / B85M-14]	[BS 1490:1988 Standard]
Si		6.5-7.5	6.5-7.5
Mg		0.25-0.45	0.2-0.6
Cu		0.2	0.2
Fe		0.2	0.5
Zn		0.1	0.1
Ti		0.2	0.2
Mn		0.1	0.3
Ni			0.1
Pb			0.1
Sn			0.05
Others	**Each**	0.05	
	Total	0.15	
Aluminium		Balance	Balance

Table 8 Properties of aluminium casting alloys (A356) [11]

Property	**Unit**	**Value**
Density at 20ºC	g/cm^3	2.67
Heat capacity	J/gK	0.963
Thermal conductivity	W/mK	151
Melting range	^oC	555-615
Ultimate tensile strength (UTS)	MPa	234
Yield tensile strength (YTS)	MPa	165
Elongation	%	2-3.5
0.2%. Proof Stress	N/mm^2	185
Brinell hardness number	HBN	75
Modulus of Elasticity	GPa	71
Shear strength	MPa	120
Endurance Limit	MPa	56
Specific heat	J/kg	963
Latent heat of fusion	kJ/kg	389

4.1 Applications of Aluminium casting Alloys (A356): Typical uses casting alloys (A356) are 356.0 aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water-cooled cylinder blocks. Other applications where excellent castability and good weldability, pressure tightness, and good resistance to corrosion are required. A356.0: aircraft structures and engine controls, nuclear energy installations, and other applications where high-strength permanent mold or investment castings are required.

V. HEAT TREATMENT OF ALUMINIUM ALLOYS

Many aluminum castings meet property requirements in the as-cast condition and do not require further processing. However, to improve properties and enhance strength and ductility, aluminum castings often are thermally processed by a series of heating and cooling cycles called heat treatment. This thermal processing involves three basic operations: solution, quench and age [7]. Solution treatment involves heating the casting to near the eutectic temperature to dissolve the eutectic constituent and form a solid homogeneous solution. Following this solution treatment, castings can be quenched or rapidly cooled, often in boiling water, which helps retain the homogeneous solution at room temperature. A third step used in heat treatment of aluminum castings is natural or artificial aging. This increases strength and hardness. Age hardening principles also can be used to tailor heat treatments to each application. Combinations of these three heat treatments are called tempers (see Table 9). The principal purpose for heat treating aluminum castings is to develop the best combination of mechanical properties that will meet the critical needs of the component application. The three basic thermal operations often are combined into heat treatment cycles that provide various properties. Although aluminum casting-related books offer “typical” or “recommended” solutions, quench and age times and temperatures for each alloy and temper.These heat treatment cycles often are varied and manipulated to change the mechanical properties of the casting to meet specific component requirements for strength and ductility. Recent research includes the use of fluidized beds to reach solution temperature rapidly and provide for quicker heat treatment cycles [7].

Table 9 Common Aluminum Heat Treatment Tempers [7]

Temper	Thermal Processing
T4	Solution treat and age naturally to a substantially stable condition. Natural aging may continue slowly, particularly at elevated service temperatures, so structural stability may not be satisfactory.
T6	Solution treat and age artificially. In castings, T6 commonly describes optimum strength and ductility.
T61	Solution treat, quench and age artificially for maximum hardness and strength. This variant of T6 yields additional strength and stability but at reduced ductility.
T7	Solution treat, quench and artificially overage or stabilize. This temper improves ductility, thermal stability and resistance to stress corrosion cracking.
T71	Solution treat, quench and artificially overage to a substantially stable condition. This temper further increases thermal stability and resistance to stress corrosion cracking and reduces strength.
T5	Age only. Stress relief or stabilization treatment. Cool from casting temperature and artificially age or stabilize (without prior solution treatment). Frequently, the as-cast condition provides acceptable mechanical properties but is accompanied by microstructural instability or undesirable residual stresses. Perhaps the possibility of in-service growth is the only constraint against using a casting in the as-cast state. In each case, the T5 temper is appropriate.
Annealing	Castings that have low strength requirements but require high dimensional stability are annealed. Annealing also substantially reduces residual stress, a need in die castings. Annealing is a severe stabilization treatment and an elevated temperature variant of the T5 temper. Softening occurs because annealing depletes the matrix of solutes.And the precipitates formed are too large to provide hardening. Use of fluidized beds to reach solution temperature rapidly and provide for quicker heat treatment cycles.

The benefits of heat treatment include [7]:

• Homogenization of alloying elements— this is desirable to distribute elements evenly throughout the matrix, so properties in the casting will be uniform;

• Stress relief—residual stresses are created during cooling from elevated casting and solution temperatures. Heating the casting to an intermediate temperature can relieve these residual stresses;

• Improved dimensional stability and machinability—changes in the microstructure can cause castings to grow over time. To maintain tight dimensional tolerances during and after machining, castings should be heat treated to form stable precipitate phases;

• Mechanical property improvement—the greatest use of heat treatment is to enhance mechanical and corrosion properties through spheroidizing constituent phase particles and by precipitation hardening. Rarely, all of the desired properties are optimized in a single casting. More often, heat treatment is a compromise, maximizing some properties at the expense of others. For example, tensile and yield strengths can be increased, but this results in lower elongation. Contrarily, higher elongations result in lower tensile and yield strengths.

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After heat treatment a suffix is added to the designation numbers [1].The suffix

F means “as fabricated”.

O means “annealed wrought products”.

T means that it has been “heat treated”.

W means the material has been solution heat treated.

H refers to non-heat treatable alloys that are “cold worked” or “strain hardened”.

The non-heattreatable alloys are those in the 3XXX, 4XXX and 5XXX groups.

Table 10 Heat Treatment Designations for Aluminium Alloys [1]

Term	Description
T1	Cooled from an elevated temperature shaping process and naturally aged
T2	Cooled from an elevated temperature shaping process cold worked and naturally aged
T3	Solution heat treated cold worked and naturally aged to a substantially
T4	Solution heat treated and naturally aged to a substantially stable condition
T5	Cooled from an elevated temperature shaping process and then artificially aged
T6	Solution heat treated and then artificially aged
T7	Solution heat treated and overaged/stabilised

VI.ALUMINIUM ALLOY SELECTION

There are a number of available alloys to choose from to satisfy individual requirements. Once the casting method is determined, the alloy choice is limited because not all alloys can be used with all casting methods. Sometimes, the alloy that shows the best properties on paper may have production characteristics that make it less desirable on an overall basis than other eligible alloys. Therefore, it is best to consult with a metalcasting facility, which can advise on such factors as availability and relative cost of ingot, production costs and reproducibility of results. Service requirements also are a key consideration in alloy selection. If high strength is required, heat-treatable alloys must be used. The alloy options can be narrowed further when considering the remaining requirements, such as pressure tightness, corrosion resistance and machinability [7].

Aluminum die casting alloys have a specific gravity of approximately 2.7 g/cc, placing them among the lightweight structural metals. The majority of die castings produced worldwide are made from aluminum alloys.Six major elements constitute the die cast aluminum alloy system: silicon, copper, magnesium, iron, manganese, and zinc. Each element affects the alloy both independently and interactively.This aluminum alloy subsection presents guideline tables for chemical composition, typical properties, and die casting, machining and finishing characteristics for 11 aluminum die casting alloys. This data can be used in combination with design engineering tolerancing guidelines for aluminum die casting and can be compared with the guidelines for other alloys in this section and in the design engineering section [10].

Alloy A380 (ANSI/AA A380.0) is by far the most widely cast of the aluminum die casting alloys. This is offering the best combination of material properties and ease of production. It may be specified for most product applications. Some of the uses of this alloy include electronic and communications equipment, automotive components, engine brackets, transmission and gear cases, appliances, lawn mower housings, furniture components, hand and power tools.

Alloy 383 (ANSI/AA 383.0) and alloy 384 (ANSI/AA 384.0) are alternatives to A380 for intricate components requiring improved die filling characteristics. Alloy 383 offers improved resistance to hot cracking (strength at elevated temperatures).

Alloy A360 (ANSI/AA A360.0) offers higher corrosion resistance, superior strength at elevated temperatures, and somewhat better ductility, but is more difficult to cast.While not in wide use and difficult to cast.

Alloy 43 (ANSI/AA C443.0) offers the highest ductility in the aluminum family. It is moderate in corrosion resistance and often can be used in marine grade applications.

Alloy A13 (ANSI/AA A413.0) offers excellent pressure tightness, making it a good choice for hydraulic cylinders and pressure vessels. Its casting characteristics make it useful for intricate components.

Alloy 390 (ANSI/AA B390.0) was developed for automotive engine blocks. Its resistance to wear is excellent but, its ductility is low. It is used for die cast valve bodies and sleeve-less piston housings.

Alloy 218 (ANSI/AA 518.0) provides the best combination of strength, ductility, corrosion resistance and finishing qualities, but it is more difficult to die cast.

6.1 Machining Characteristics

Machining characteristics vary somewhat among the commercially available aluminum die casting alloys, but the entire group is superior to iron, steel and titanium. The rapid solidification rate associated with the die casting process makes die casting alloys somewhat superior to wrought and gravity cast alloys of similar chemical composition.Alloy A380 has better than average machining characteristics. Alloy 218, with magnesium the major alloying element, exhibits among the best machinability. Alloy 390, with the highest silicon content and free silicon constituent, exhibits the lowest [10].

6.2 Surface Treatment Systems

Surface treatment systems are applied to aluminum die castings to provide a decorative finish, to form a protective barrier against environmental exposure, and to improve resistance to wear.Decorative finishes can be applied to aluminum die castings through painting, powder coat finishing, polishing, epoxy finishing, and plating. Aluminum can be plated by applying an initial immersion zinc coating, followed by conventional copper-nickel-chromium plating procedure similar to that used for plating zinc metal/alloys.Protection against environmental corrosion for aluminum die castings is achieved through painting, anodizing, chromating, and iridite coatings.Improved wear resistance can be achieved with aluminum die castings by hard anodizing.Where a part design does not allow the production of a pressure-tight die casting through control of porosity by gate and overflow die design, the location of ejector pins, and the reconfiguration of hard-to-cast features, impregnation of aluminum die castings can be used. Systems employing anaerobic and methacrylate are employed to produce sealed, pressure-tight castings with smooth surfaces [10].

Die casting alloy selection requires evaluation not only of physical and mechanical properties (Table 10), and chemical composition, but also of inherent alloy characteristics (Table 11) and their effect on die casting production as well as possible machining and final surface finishing.These tables include selected die casting and other special characteristics which are usually considered in selecting an aluminum alloy for a specific application.The characteristics are rated from (1) to (5), (1) being the most desirable and (5) being the least. In applying these ratings, it should be noted that all the alloys have sufficiently good characteristics to be accepted

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by users and producers of die castings. A rating of (5) in one or more categories would not rule out an alloy if other attributes are particularly favorable, but ratings of (5) may present manufacturing difficulties.The benefits of consulting a custom die caster experienced in casting the aluminum alloy being considered are clear.

Table 10Mechanical properties of aluminum casting alloys [ASTM B85 / B85M-14]

AA Number	Tensile Strength, min	Yield Strength, min	Elongation min	Brinell Hardnes, 500 kgf ,10mm	Typical Shear Strength	Endurance limit	Charpy Impact Notched
	ksi (1000 psi)	ksi (1000 psi)	%		ksi (1000 psi)	ksi (1000 psi)	ft lbs
319.0-F	23	13	1.5	70	22	10	1
356.0-F	19	9.5	2.0	55			1 1/ 2
356.0-T51	23	16	not required	60	20	8	
356.0-T6	30	20	3.0	70	26	8	2
A356.0-T6	34	24	3.5	80	26	8.5	
535.0-F	35	18	9.0	70	34	8	10-12
713.0*	32	22	3.0	75	26	9	3

* After 21 days natural aging

F=as cast, T51=cooled from an elevated temperature and artificially aged, T6=solution heat treated and then artificially aged

Table 11 Characteristics of aluminum casting alloys [ASTM B85 / B85M-14]

ANSI Alloy #	Resistance to Hot Cracking	Pressure Tightness	Fluidity	Solidification Shrinkage Tendency	Normally Heat Treated	Corrosion Resistance	Machinability	Polishing	Electroplating	Anodizing Quality	Chemical Oxide Coating	Elevated Temperature Strength	Suitability for Welding
319	2	2	2	2	Yes	3	3	4	2	4	3	3	2
356	1	1	1	1	Yes	2	4	5	2	4	2	3	2
A356	1	1	1	1	Yes	2	4	5	2	4	2	3	2
535	3	5	5	5	No	1	1	1	5	1	1	3	4
713	5	3	4	4	Aged only	2	1	1	2	2	3	5	4

Ratings: 1 =Excellent, 2 = Very Good, 3 = Good, 4 = Fair, 5 = Poor

Table 12Physical properties of aluminum casting alloys [ASTM B85 / B85M-14]

ANSI Alloy #	Pattern Shrinkage Allowance in/ft	Specific Gravity	Density	Approx.Melting Range	Electrical Conductivity	Thermal Conductivity	Coefficient of Thermal Expansion	
			lb/cu in	°F	% of A.I.C.S.	CGS	68-212°F	68-572 °F
319	5/32	2.79	0.101	950-1120	27	0.26	12.0	13.4
356	5/32	2.68	0.097	1035-1135	39	0.36	11.9	13.0
A356	5/32	2.68	0.097	1035-1135	39	0.36	11.9	13.0
535	5/32	2.62	0.095	1020-1150	23	0.24	13.1	14.8
713	3/16	2.81	0.102	1100-1180	35	0.35	13.1	14.2

VII. CONCLUSIONS

The exhaustive literature survey presented above reveals that extensive work has been reported by the researchers in the industries and academiato improve properties of aluminium and its alloys. On the other hand, the studies carried out worldwide on to conduct heat treatment processes after casting has not been adequately addressed so far. A further study in this respect is needed particularly to determine and compare the properties of aluminium lightweightmaterials and its alloys in untreated and heat treated conditions to improve the quality of automotive components. Present research work also includesthe study of aluminium and its alloys and improvement in mechanical and physical properties in heat treatment processes.Moreover, the present review has demonstrated the extensive research effort on understanding the effect of process parameters of casting on aluminium and its alloys. Metal flow in casting processes may have a role to play here, though capturing this aspect of the thermo-mechanical behaviour remains a significant challenge. The selection of aluminum casting alloys for automotive applications are also out lined in the review paper. From an engineering perspective, there is a need to further investigate the suitability of the lightweight materials for automotive and aerospace industries.

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