CHAPTER - 1

Introduction

This chapter includes details about 7XXX aluminium alloys and the challenge of cast 7XXX aluminium. It also contains the research purpose and thesis structure.

1.1 Introduction of 7XXX aluminium alloy

The lightweight, easily formable aluminium with alloying elements provides its high applicability in the market [1]. The addition of alloying elements to the aluminium is referred to as the following designations, as illustrated in Figure 1.1.

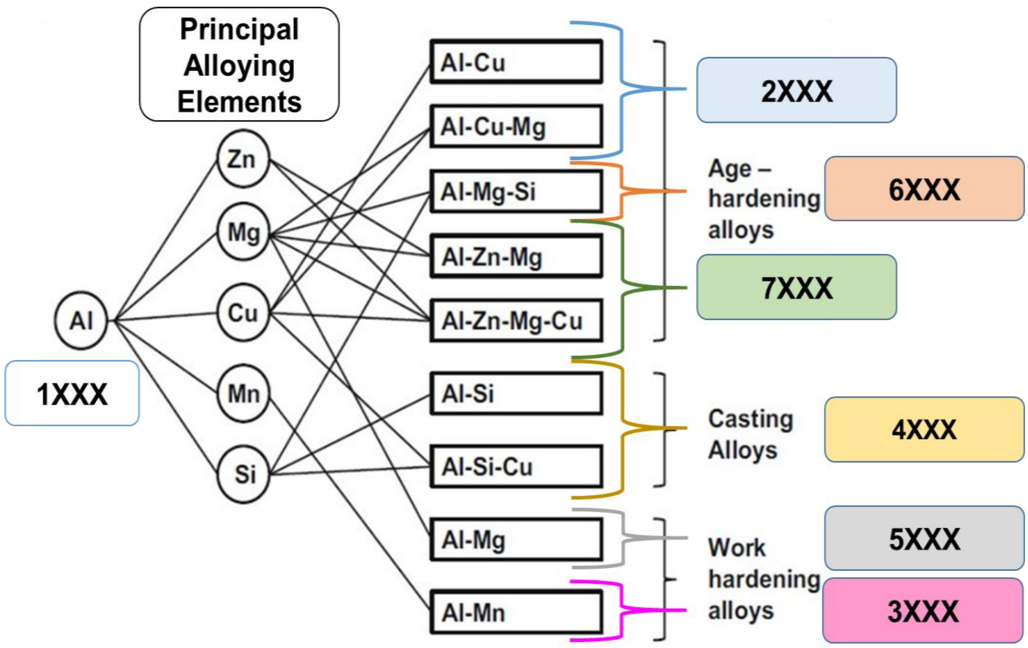

Figure 1.1 Principal alloying element in aluminium alloys and designation [2].

Green energy development demands lightweight alloys like aluminium. The global demand for aluminium increased significantly in the aerospace and automobile industries [3]. The demand for 7XXX aluminium alloys in the aerospace and automobile industries as structural materials is increasing daily because of their high strength-to-weight ratio [4]. This alloy is usually made by a wrought route, which is costlier than the casting route [5]. Figure 1.2 shows the application of aluminium alloys on the Boeing 777.

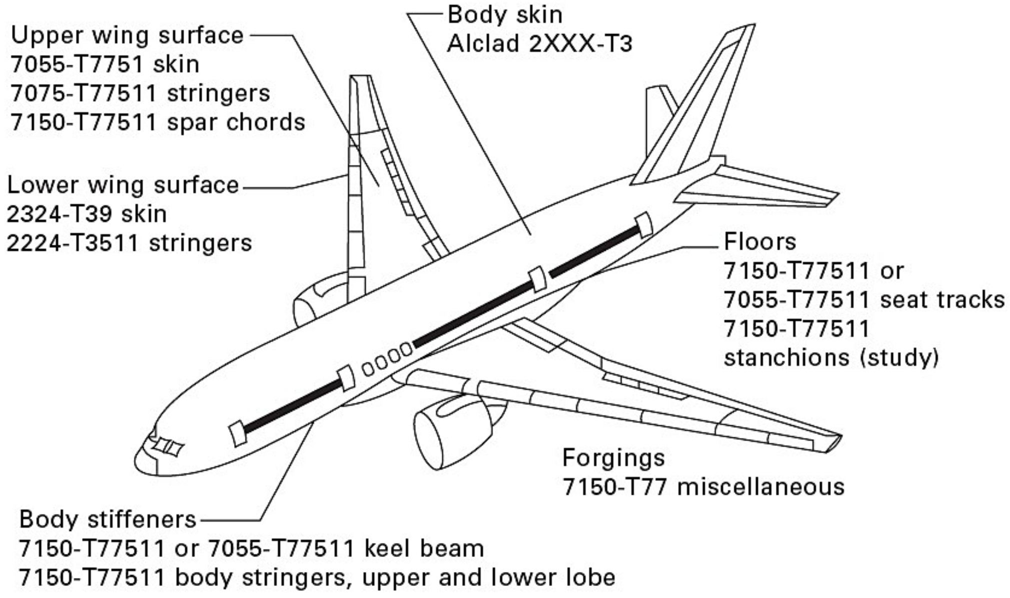

Figure 1.2 Application of aluminium alloys on the Boeing 777 [6].

Based on the strength, the rating of the 7075 aluminium is high compared to the rest. Figure 1.3 shows the major high-strength aluminium alloys ranking.

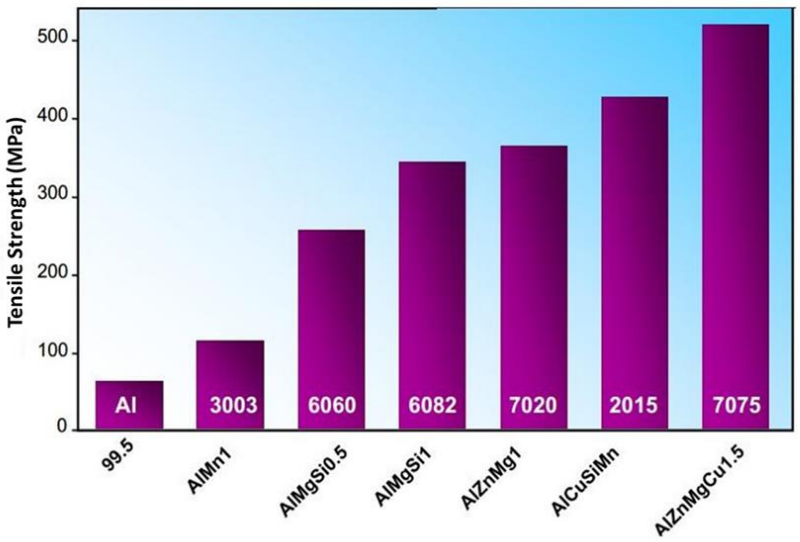

Figure 1.3 Major high-strength aluminium alloy ranking [7].

Aluminium alloys of the 7XXX family are high-strength, heat-treatable alloys with zinc and magnesium as principal alloying elements, and precipitation hardening improves their characteristics [8]. The effect of alloying elements on mechanical properties plays a significant role. The addition of zinc in aluminium increases strength by the eutectic composition containing a solid solution of 83% zinc in aluminium and 1.14% aluminium in zinc, allowing a precipitation hardening response. The addition of magnesium in Al-Zn produces the $MgZn_2$ phase, which provides a heat treatment response. The zinc-to-magnesium ratio also substantially plays a significant role in forming the $MgZn_2$ phase. The addition of copper to Al-Zn-Mg alloy increases the ageing rate by increasing supersaturation, while zinc and magnesium control the ageing process [2]. In aluminium, few elements have higher solubility, while others have very low solubility, as shown in Table 1.1 - certain transition metals, chromium, zirconium, and manganese, with less than 1 at.% solid solubility improves the alloy properties by forming intermetallic.

Table 1.1 Solid solubility of elements in aluminium [9].

Elements	Temperature for maximum solubility (°C)	Maximum Solid Solubility (wt.%)	(at.%)
Cadmium	649	0.4	0.09
Cobalt	657	<0.02	<0.0.1
Copper	548	5.65	2.4
Chromium	661	0.77	0.4
Germanium	424	7.2	2.7
Iron	655	0.05	0.025
Lithium	600	4.2	16.3
Magnesium	450	17.4	18.5
Manganese	658	1.82	0.9
Nickel	640	0.04	0.02
Silicon	577	1.65	1.59
Silver	566	55.6	23.8
Tin	228	~0.06	~0.01
Titanium	665	~1.3	~0.74
Vanadium	661	~0.4	~0.21
Zinc	443	82.8	66.4
Zirconium	660.5	0.28	0.08

The applications of aluminium alloys are shown in Figure 1.4, especially in space applications. It was also reported that the curiosity rover wheels were made of 7075-T7351 aluminium alloy, as shown in Figure 1.5. Other than that, there are many applications of the 7XXX family in automobiles, transportation, the military, and the aviation industry. The application of the 7XXX alloy is limited because of the cost factor. The high cost of processing and machining hinders domestic applications and their overall viability. Some limitations exist in using 7XXX aluminium alloys, like castability, weldability, poor tribology properties, fatigue cracks, and poor resistance to stress corrosion cracking [10].

Segregation of solutes is the primary obstacle when solidifying these alloys, as there is a high concentration of solute and a wide solidification temperature range during the casting [11].

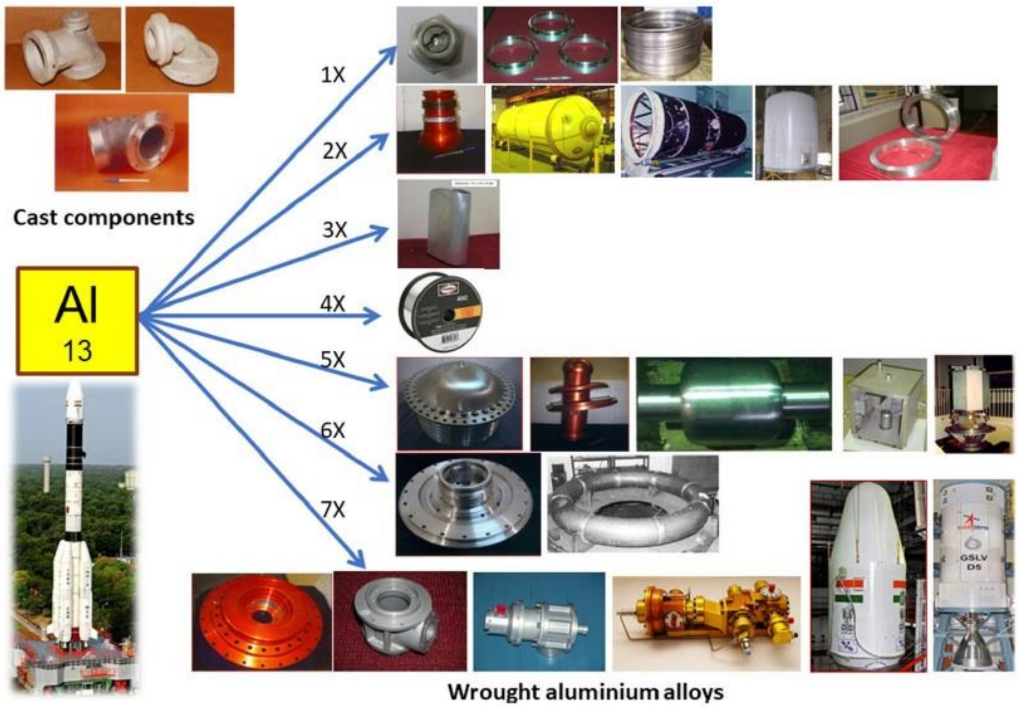

Figure 1.4 Spectrum of aluminium alloys used in space applications. Practically, every grade of wrought aluminium alloy is used for various applications based on its characteristics. The age-hardenable aluminium alloys of 2XXX are used for earth-storable and cryogenic propellant tanks, 6XXX alloys for water tanks of liquid engines, and 7XXX series are used for engine components and heat shields. Aluminium alloy castings are used in liquid engines [12].

Figure 1.5 Curiosity rover wheels of 7075-T7351; a) on the ground, b) under operation conditions on Mars [13].

1.2 Castability of 7XXX aluminium alloys

As discussed in Section 1.1, producing 7XXX aluminium alloys by casting route reduces the cost of the final product and increases the application. The casting of 7XXX aluminium alloys is associated with three major problems.

- Segregation of solute.
- Wide solidification range (freezing range).
- Hot tearing.

The above issues are coupled with the mechanical properties, tribology properties, grain size, fraction and size of the eutectic phases, intermediate phases, and macro and micro-segregation. [11] The quaternary Al-Zn-Mg-Cu, 7075 aluminium alloy, has the problem of solute segregation due to high solute concentration, and the wide solidification range in the mushy zone creates the problem of solidification cracks during the solidification [14–18]. Due to high solute concentration, the microstructure of as-cast Al7075 forms α-Al grains with the formation of intermediate phases like η($MgZn_2$), S($CuMgAl_2$), T($Al_2Mg_2Zn_3$), θ($CuAl_2$), Mg_2Si, and $Al7Cu_2Fe$ [19, 20]. The distribution of the intermediate phases within the α-Al grains and at grain boundaries plays a significant role in the alloy's mechanical, tribological, and corrosion properties. For this reason, it is interesting to note that studying solute segregation in the microstructure during solidification, and its effects on the properties, is essential. The segregation pattern can be changed either chemically, mechanically, thermally or a combination. Post-treatments like heat treatment and thermomechanical processing can also alter as-cast microstructural changes to optimize the mechanical properties [21–26]. Adding grain refiners, modifiers, and micro-alloying elements can act as the heterogeneous nucleation site and help to control the microstructure [26–31]. Mold vibration by mechanical, electromagnetic, and ultrasonic action can also change the segregation pattern [32–34]. Thermally, as-cast can be treated by changing the casting methods or quenching in some media by controlled diffusion solidification [30, 35–41]. Synergistically, the mentioned treatments change the segregation pattern's morphology and refine the grain structure from dendritic to non-dendritic.

1.3 Objective of the present work

The following objectives based on the research gap are discussed below.

1. To study the effect of the addition of high-temperature oxides in the cast Al 7075 to understand the segregation pattern.
2. To study the effect of quenching media on cast Al 7075 to understand the eutectic phase morphology change.
3. To study the effect of double-step ageing treatment on oxide-added Al 7075 to understand the effect of modified heat treatment on microstructure, mechanical, and tribology properties.
4. To study the microstructure and mechanical properties of cast Al 7075 by different casting techniques.
5. To develop cost-effective cast Al 7075 by alloying and compare its properties with wrought Al 7075.

1.4 Structure of the thesis

The present study is structured into different chapters in the thesis, presented in Figure 1.6.

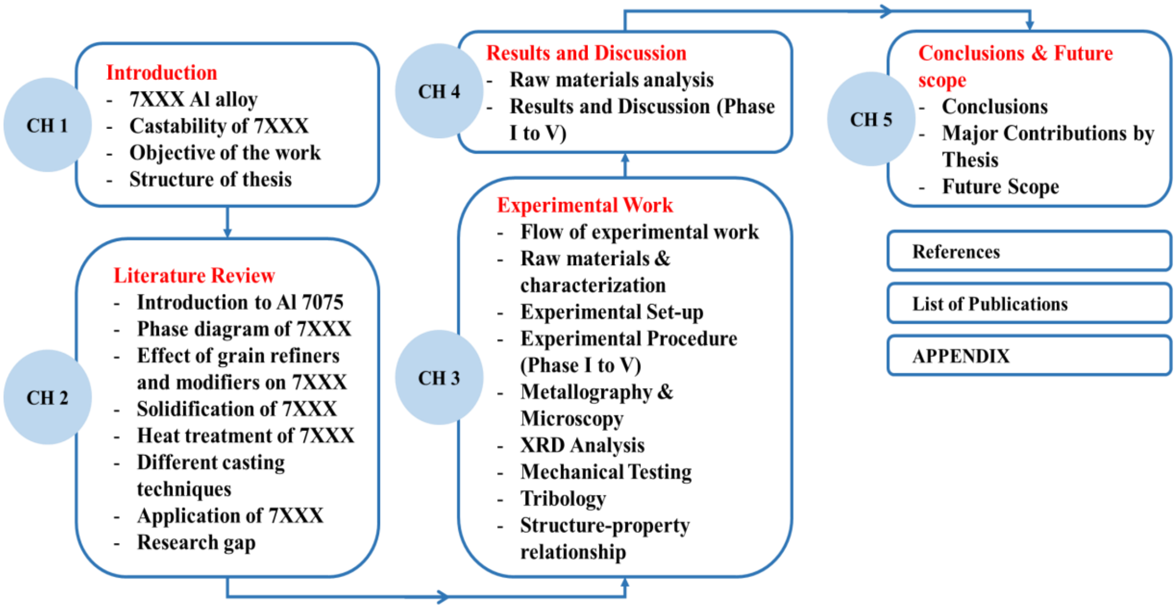

Figure 1.6 Structure of the thesis.