Reviews on the Influences of Alloying elements on the Microstructure and Mechanical Properties of Aluminum Alloys and Aluminum Alloy Composites

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Abstract- In recent year's aluminum and aluminum alloys are widely used in automotive industries. These are light weight (density of about 2.7g/cc),having good malleability and formability, high corrosion resistance and high electrical and thermal conductivity. High machinability and workability of aluminum alloys are prone to porosity due to gases dissolved during melting processes. However, in the engineering application pure aluminum and its alloys still have some problems such as relatively low strength, unstable mechanical properties. The microstructure can be modified and mechanical properties can be improved by alloying, cold working and heat treatment in this regards, this paper reports the influences of some alloying elements on the microstructures and mechanical properties of Aluminum alloys and aluminum alloy composites.

Keywords- Aluminum alloy, aluminum alloy composites, Machinability, alloying, Heat treatment, Cold working

I. Introduction

Aluminium and aluminium alloy are gaining huge industrial significance because of their outstanding combination of mechanical, physical and tribological properties over the base alloys. These properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity.[1]. These properties obtained through addition of alloy elements, cold working and heat treatment. Alloying elements are selected based on their effects and suitability. The alloying elements may be classified as major and minor elements, microstructure modifiers or impurities, however the impurity elements in some alloys could be major elements in others[2]. In this paper the influences of alloying Such as Major elements (Si ,Cu ,Mg), Minor elements(Ni, Sn) ,Microstructure modifier elements(Ti, B, Sr ,Be ,Mn ,Cr) and Impurity elements(Fe, Zn) on microstructures and mechanical properties of aluminium alloys are reviewed.

II. Effects of Major alloying Elements in aluminium

It's the foremost preliminary step for proceeding with any research work writing. While doing this go through a complete thought process of your Journal subject and research for it's viability by following means:

The major alloying elements in Aluminum and aluminium alloys typically include Silicon (Si), copper (Cu) and magnesium (Mg).

2.1 Silicon(Si): Silicon is the most important single alloying element used in majority of aluminum casting alloys.[2] It is primarily responsible for so –called good castability (high fluidity,low shrinkage),low density(2.34g/cm3)which may be advantage in reducing total weight of cast component and has very low solubility in Aluminum therefore precipitates as virtually pure Si which is hard and improve the abrasion resistance. Si reduces thermal expansion coefficient of Al-Si alloys. Machinability is poor with addition of silicon in Aluminum. [3].Depending on the Si concentration in weight percentage, the Al-Si alloy systems are divided into three major categories: Hypoeutectic (<12 wt % Si), Eutectic (12-13 wt % Si), Hypereutectic (14-25 wt % Si). G.T. Abdel-Jaberet al [4] Investigate solidification and mechanical behaviour of Al-Si alloy against both the molding conditions and silicon content(3%-15%si).It was found that with increasing Si content, the solidification time increased as also a decrease liquidus temperature was observed upto 12% and then increased with Si% .ultimate tensile strength slightly increase with increase of silicon contents from 3% to 8%, whenever a liner increase in UTS was found with the increase of silicon content from 8% to 15% .It may related to change of eutectic composition and the creative of primary silicon at the hypereutectic. With increase of silicon content % elongation increase gradually and reach its maximum value at 12% Si .The minimum elongation% produced at 10mm mold thickness while 30mm mold thickness mold produce maximum elongation %. It may related to the effect of solidification rate.It was reported that hardness increase with increase the silicon content and reach maximum value70MPa at 12%Si content and then decrease down to 60 MPa related to 15% Si content. It may related to change of eutectic composition with the increase of silicon content and due to creative of primary silicon at the hypereutectic. It also reported that there is no pronounced effect of the mold thickness on the hardness and completely eutectic composition only has been perfectly modified and uniformly distributed. Wear rate and coefficient of friction of Al-Si casting alloys was also studied and it was observed that weight loss decreased down with increasing silicon contents up10% and then slightly increase. Higher weight loss was produced in case of 10mm mold thickness while lower weight loss in 30mm thickness mold .due cooling effect and present of hard Al2Si particles.

2.2 Effect of Cu addition: copper effect the strength and hardness of aluminum casting alloys, both heat treated and not heat treated and at both ambient and elevated service temperature. It also improve the machinability of alloys by increasing matrix hardness,.[2] On the down side, copper generally it reduces the corrosion resistance of aluminum and in certain alloys and tempers, it increase stress corrosion susceptibility[2].S.G. Shabestari et al [5] Investigate the effect of copper and solidification condition on the microstructure and mechanical properties of Al-Si-Mg alloys . copper in the range of 0.2-2.5wt% has been used in A356 aluminum alloy and cast at different solidification condition(sand, graphite, copper and cast iron molds). It has been found that Ultimate tensile strength of the alloys increased with heat treatment(T6), mold cooling rate(graphite) and copper content upto 1.5% . UTS increase because of precipitation of copper bearing phase in the interdendritc space cause by increasing copper. It has been found that the best mechanical properties with about 1.5% Cu in Al si-Mg alloy solidified in the graphite moulds.

2.3 Effect of Mg addition: Magnesium (Mg). Provides substantial strengthening and improvement of the work-hardening characteristics of aluminium. It can impart good corrosion resistance and weldability or extremely high Strength [6, 7]. . Silicon combine with magnesium to form the hardening phase Mg2Si that provides the strengthening [2]..Zhengang Liu at el[8] investigate the influence of Mg addition on graphite particle distribution in the Aluminum alloy matrix composites.in this studied Mg as surface active agent was added into commercial alumimum to prevent the graghite particles from clustering and improve the physical and mechanical properties of aluminum matrix. The results show that contents of graphite increase with increasing Mg contents. The graphite particle distribute uniformly in the particle reinforced PMMC with 0.6Wt%Mg. however, the agglomeration of graphite particles is observed in matrix when Mg contents is more than 1Wt% Mg. the proper Mg addition amount is beneficial to enhance the mechanical properties of the graphite particles reinforced aluminum alloy matrix composites and the abrasion resistance of the materials due to uniformaly distribution of hard particles and reduction of friction coefficient.

2.4 Effect of Mg and Si addition: Shubin Ren et.al[9] Investigate the effect of Mg and Si alloy element in the aluminum on the thermo-mechanical properties of pressureless infiltrated SiCp/Al composites. Si and Mg addition to the aluminum can improve the wettability of SiC by the aluminum The results showed that, when the Si content was lower than 6 wt% or the Mg content was lower than 4 wt%, the composites showed poor thermo-physical properties because of higher porosity due to relative density of infiltrating SiCp/Al composites is very low in the composites resulting from the poor wettability between Al and Si. Increasing the Si content to the aluminum can enhance the elastic modulus, thermal dimensional stability and thermal conductivity of the composites and reduce the coefficient of thermal expansion (CTE) of the composites. However, excessive Si beyond 12 wt% can reduce the thermal conductivity and bending strength of the composites. An optimum content of Mg addition to aluminum was found to be 4–8 wt%, at which the composites exhibited good thermo-mechanical properties. However, as the Mg content was increased beyond 8 wt%, the higher porosity in the composites resulting from the lower pressure of the magnesium led to lower thermo-mechanical properties.

III. Effect of Minor Elements:

3.1 Effect of Ni addition: JE Hanafee et al[10] Investigate the effect of nickel on hot hardness of aluminum alloys It is shown that nickel can be utilized to improve the hot hardness (up to 600 F) of aluminum-silicon (10 to 16 per cent silicon) casting and forging alloys. The maximum benefits are realized by developing a large volume and favourable distribution of nickel aluminide. The addition of more than the eutectic amount of silicon was not particularly helpful in improving hot hardness. While the addition of more than the eutectic amount of nickel did improve hot hardness.

F. Hernández-Méndez, A. Altamira no-Torres et al[11] Investigate the Effect of Nickel Addition on Microstructure and Mechanical Properties of Aluminum-Based Alloys. Alloys were produced by powders metallurgy. Characterization results indicate that the microstructure of the aluminum-nickel alloys present a thin and homogeneous distribution of an intermetallic compound in the aluminum's matrix, identified as Al_3Ni. Furthermore, it was find out that the amount of intermetallic Al_3Ni increase as the nickel content in the alloy rises. Regarding the mechanical properties evaluated; it was establishes that the hardness, compression and flexion resistances also were improved due to the presence of the intermetallic compound.

3.2 Effect of tin addition: Tin (Sn) used in aluminum casting alloys for reducing friction in bearing and bushing applications. Alloying element Tin in emergency conditions can provide short-term liquid lubrication to rubbing surfaces if such bearings/bushings severely overheat in service..[2]

IV. MICROSTRUCTURE MODIFYING ELEMENTS

Include titanium (Ti), boron (B), strontium (Sr),phosphorus (P), beryllium (Be), manganese (Mn) and chromium (Cr)[2]

4. 1 Effect of Ti addition:
Majed Jaradeh, et al[12] investigate the Effect of titanium additions on the microstructure of DC-cast AA 3003 aluminium alloys. Some improved corrosion properties can be obtained from increasing the Ti contents in aluminium alloys to a level above the normal practice for grain refinement. However, increasing the Ti content above the peritectic point, 0.15%, can influence the grain refinement and cause casting difficulties. It was found that with normal Ti contents in the range of 0.015%, the grain refinement is effective. However, upon larger Ti additions to levels around 0.15% the grain structure becomes coarser .N. Saheb , T. Laoui et al[13] Investigate the effect of Ti addition(up to 4Wt%) to Al–Si eutectic alloy. The addition of Ti to Al–Si eutectic alloy resulted in the precipitation of the intermetallic compound Al3Ti phase, which induced an increase in the micro hardness of the binary alloy. Among the Ti-containing alloys, the increase in Ti content improved their wear resistance as a result of increase in the microhardness due to the presence of relatively hard-phase Al3Ti. However, these alloys showed higher wear rates (thus lower wear resistance) compared with the binary alloy due to the tendency for embrittlement and microcracking brought about by Al3Ti particles. Heat treatment of the Ti-containing alloys at 200◦C for 6 h improved further their wear resistance.

4.2 Effect of Titanium & Boron:
Titanium (Ti) and boron (B) are used to refine primary aluminum grains. Titanium, added in aluminum alloy, forms TiAl3, which serves to nucleate primary aluminum dendrites. More frequent nucleation of dendrites means a large number of smaller grains. Grain refinement is illustrated in Figure 1

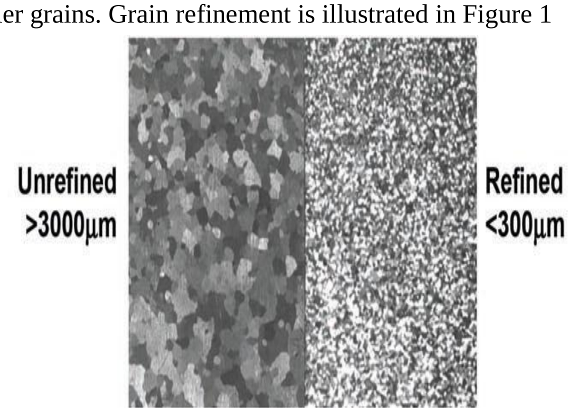

Figure 1: Illustration of grain-refined aluminium

Grain refining is better when titanium and boron are used in combination. Master alloys of aluminum with 5% titanium and 1% boron are commonly used additives for this purpose. Titanium with boron form TiB2 and TiAl3, which together are more effective grain refiners than TiAl3 alone..[2]

4.3 Effect of strontium addition: *Strontium, Sodium, Calcium and Antimony* These elements are added to eutectic or hypoeutectic aluminum silicon casting alloys to modify the morphology and microstructure of the eutectic silicon phase, eutectic silicon solidifies in a relatively coarse continuous network of thin platelets, shown in Figure 2. That morphology provides abundant stress risers and thus limits to achieve maximum strength and ductility. Modification with one of the above elements can changes the eutectic silicon into a fine fibrous or lamellar structure (Figures 2b and 2c).[2]

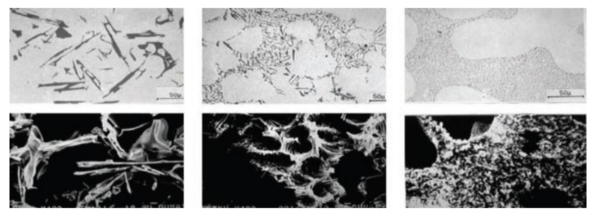

Figure 2a:Unmodified Figure 2 b: Modified Figure 2c: Super-modified

A. Razaghia, M. Emamy et al[14] Investigate the effect of strontium as a modifier on the microstructures and tensile properties of two castable particulate metal matrix composites The particulate metal matrix composites had similar matrix alloy (A357) but different reinforcing fine particles (silicon carbide and alumina). Results showed that the addition of 0.03% strontium makes a modest improvement to the yield strength, ultimate tensile strength and elongation percentage values, and the scatter of these properties, but makes a significant improvement to minimum strength and elongation results. Microstructural examinations by scanning electron microscope and energy dispersive spectroscopy analysis of metal matrix composites showed segregation of strontium on both the silicon carbide and alumina particles. Further results showed that the addition of higher strontium levels contributes to the over-modification of the eutectic silicon and promotes the formation of an Al–Si–Sr intermetallic compound on the particle/matrix interface.

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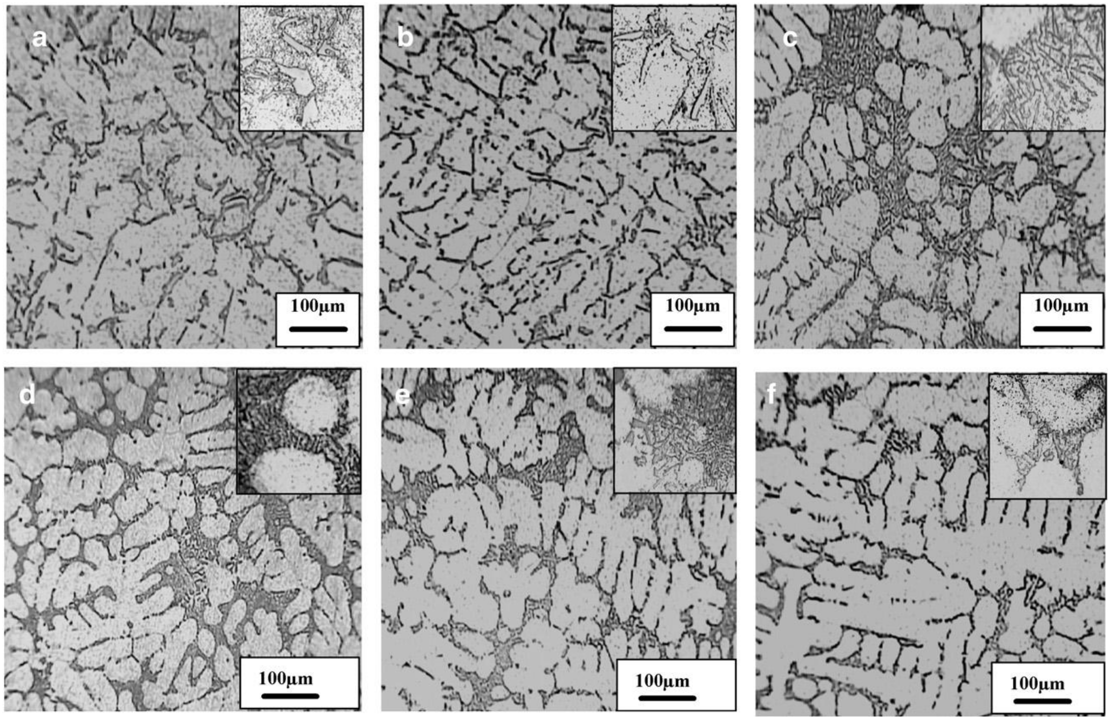

Fig. 3: Optical micrograph of A357: (a) non-modified, (b) modified with 0.01%Sr, (c) modified with 0.02%Sr, (d) Modified with 0.03%Sr, (e) modified with 0.05%Sr, and (f) modified with 0.1%S

4.4 Effect of Manganese & Chromium: Manganese or in combination,with manganese (Mn) and chromium (Cr) change the morphology of the iron-rich Al5FeSi phase (Figure 4a) from its typical platelet/acicular form to a more cubic Al15(MnFe)3Si2 form (Figure 4b) that is improve the ductility. [2]''.

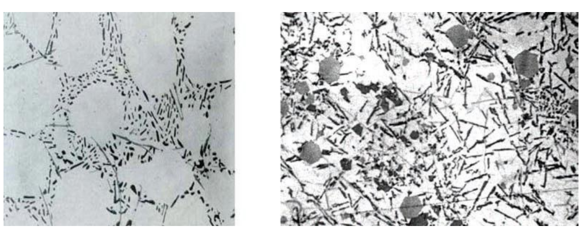

Figure 4a: Fe-richAl5FeSi Figure4b: Cubic Al15(MnFe)3Si2 form.phase in platelet form

4.5 Effect of Mn addition: Soo Woo Nam and Duck Hee Lee[15] Investigate the effect of Mn on the Mechanical Behavior of Al Alloys.. Recently, it was found that as the manganese content increases over 0.5 wt.% in aluminum alloys, both yield and ultimate tensile strength increase significantly without decreasing ductility. Adding manganese to aluminum alloys enhances the tensile strength as well as significantly improves low-cycle fatigue resistance. Corrosion resistance is also improved by the addition of manganese.

V. Effect of Impurity Elements :

5.1 Effect of zinc addition: Zinc is only present in aluminum casting alloys of 7XX series,. Otherwise, zinc is present merely as an acceptable impurity element in many secondary (scrap-based) die casting alloys. As such, zinc is quite neutral; it neither enhances nor detracts from an alloy's properties. [2]. ZHU Mei-jun, DING Dong-yan et al[16] Investigate the effect of Zn content on tensile and electrochemical properties of 3003 Al alloy. The effect of Zn addition on the microstructure, tensile properties and electrochemical properties of as-annealed 3003 Al alloy was investigated. It was found that High density precipitates are observed in the Zn-containing alloys and the alloy with 1.8% Zn addition also has rod-like precipitates.. The alloy with 1.5% Zn addition has the highest ultimate tensile strength. M.C. Carroll, P.I. Gouma et al [17]. Studied effect of Zn addition on the grain boundry precipitation and corrosion of Al. Stress corrosion cracking (SCC) concerns in aluminum alloys containing Mg levels greater than 3.5%have been largely attributed to the formation of the beta-phase (Al3Mg2) at grain boundaries. It has been demonstrated that the beta-phase need not be continuous in order to provide a path for crack propagation, but aging treatments, exposure to intermediate to high temperatures, and excessively corrosive environments can all contribute to early failure of Al-Mg alloys due to SCC. Proof of the presence of a corrosion-prone secondary phase can be demonstrated easily through exfoliation testing and the associated lining of grain boundaries, which can be confirmed optically. Additions of Zn to these Al-Mg alloys in levels of 1–2wt% have been shown to be more SCC resistant due to the formation of a stable ternary Al-Mg-Zn phase , the pie phase. Recent studies have shown that Al-5083 variants which contain even minor levels of Zn (0.68–0.70wt%) perform much better during exfoliation testing. Zinc additions of 0.68–0.70wt% to sensitized 5083-based Al-Mg-Mn alloys precludes the formation of b-phase precipitates, resulting instead in the formation of a chemically and structurally distinct Al-Mg-Zn t-phase at grain and subgrain boundaries. The t-phase appears to be more resistant to corrosion than the b-phase**.**

5.2 Effect of iron addition: John A. Taylor [18] Investigate the effect of Iron in Al-Si Casting Alloys This paper discusses the various sources of iron and how it enters aluminum alloys, the way that iron leads to the formation of complex inter-metallic phases during solidification, and how these phases can adversely affect mechanical properties, especially ductility, and also lead to the formation of excessive shrinkage porosity defects in castings. The paper offers guidelines to the levels of iron that can be tolerated, how to maintain these levels and how to minimize the negative effects of iron. Author suggested some Practical guidelines for addition of iron in Al-Si casting alloys*:*

- Wherever possible, iron levels in Al-Si alloys should be kept as low as practical in order to avoid the detrimental effects on mechanical properties, particularly ductility and fracture toughness. This means minimizing iron contamination through careful selection of raw materials (i.e. ingots, silicon, etc.) and the maintenance of good refractory coatings on all steel tools used to prepare and handle melts.
- Iron levels above the critical level for the silicon content of the alloy should be avoided as these can cause serious loss of ductility in the final cast product and decreased casting productivity through increased rejects due to shrinkage porosity, and particularly "leakers".
- The critical iron content (in wt%) for an alloy can be calculated using $Fe_{crit} \approx 0.075 \times [\%Si] - 0.05$.
- If solidification/cooling rates are very high (e.g. high pressure die casting), super critical iron contents may not be detrimental, but as the cooling rate decreases (gravity die casting → sand casting, etc.) the probability of super critical iron levels causing problems dramatically increases
- Traditional heat treatment regimes for Al-Si alloys, e.g. T6, do not alter the nature of the offending Fe-containing phases. As-cast inter-metallic is retained and although the overall performance of an alloy may be improved by heat treatment, it would be better still with low iron levels initially.
- Additions of Mn to neutralize the effects of iron are common, at Mn:Fe ratios of ~ 0.5, however, the benefits of this treatment are not always apparent. Excess Mn may reduce β-phase and promote α-phase formation, and this may improve ductility but it can lead to hard spots and difficulties in machining. Mn additions do not always improve castability and reduce porosity in high Fe alloys. Its affect is sensitive to alloy composition.
- The addition of Mn to melts with high iron levels can also promote the formation of sludge, if the sludge factor (derived by [%Fe] + 2[%Mn] + 3[%Cr]) exceeds a particular value for a given alloy and melt holding temperature. This is a serious problem for die-casters who use low melt temperatures and high impurity secondary alloys

5.3 Effects of beryllium addition: Y. Wang, Y. Xiong [19] Investigate effects of beryllium (Be) in Al–7Si–0.4Mg–0.2Ti–*x*Fe–*x*Be cast alloy. The results show that beryllium addition changes the shape of iron-rich compound from needle or plate shapes to Chinese scripts or polygons. And the iron-rich compound (named Be–Fe) is aggregated when the composition of Fe is high. The aggregation of Be–Fe phase is the main crack nucleus in the alloy. It is also found that Be–Fe is formed during peritectic reaction on titanium-rich particle and located inside the a-Al. These lead to the higher mechanical properties of the alloy with Be addition.& findings are-

(1) The Fe phase is one of the main deterioration to the mechanical properties of cast aluminium alloy, especially the b-phase in the alloy leads to poor mechanical properties.
(2) Beryllium addition changes the morphology of iron-rich compounds to Chinese scripts and polygons And aggregative Be–Fe phases are found in high Fe contained alloy. Be–Fe phases are local inside the a-Al.
(3) The fracture always takes place on iron-rich compounds. In the Be-containing alloy with iron, the crack propagation on Fe-phase was deterred during fracture, and this is considered to be beneficial to the fracture toughness of the alloy.
(4) The mechanical properties of Be-containing alloy improve significantly. This is contributed to the alternation of Fe phase shape.
(5) It is expected to exceed the permissible exposure limit in the low beryllium content alloy(B0.5%) industry.

5.4 Effect of iron and beryallium addition: Murali, S and Trivedi, A and Shamanna et[20] al investigate the effect of iron and combined iron and beryllium additions on the fracture toughness and microstructures of squeeze-cast Al-7Si-0.3Mg alloy. An increase in iron content significantly decreases fracture toughness. Trace additions of beryllium completely neutralize the detrimental effect of iron.

5.5 Effect of rare earth elements: It is well known that trace element additions to aluminum alloys can strongly influence the precipitation process, including modifying the dispersion, morphology and crystal structure of the resulting precipitations[21-23].Studies on rare-earths as micro-alloying elements showed that they had beneficial effects on the mechanical properties of aluminum alloys. It was reported that addition of Ce to Al-Cu-Mg-Ag alloy improved the thermal stability of the *Ω* phase thus raised the service temperature of this alloy[24]. LI et al[25]demonstrated that adding 0.1%−0.2% (mass fraction) Y improved the tensile properties of 2519 alloy at room and elevated temperatures for Y changed the size and density of θ' phase. It was indicated that Nd was mainly distributed in form of intermediate compound AlCuNd, which exerted a restraining force on the grain boundaries and enhanced the mechanical properties of 2519 alloy at high temperature [26].Some recent researches showed that Yb was considered as an effective micro-alloying element in aluminum alloys. It was reported that Yb addition improved the mechanical properties of Al-Cu-Mg-Ag alloy and Al-Zn-Mg-Cu-Zr alloy [27-28]. Furthermore, complex additions of Yb, Cr and Zr to Al-Zn-Mg-Cu alloy significantly enhanced the resistance to recrystallization [29].

VI. CONCLUSION

Alloying elements are selected based on their effect and Suitability. Silicon lowers the melting point and increase the fluidity(improve casting characteristics) of Aluminum. A moderate increase in strength is also provided by Silicon addition. Magnesium provides substantial strengthening and improvement of work harding characteristic of aluminium alloy. It can impart good corrosion resistance and weldability or extremely high strength. Copper has a greatest impact on the strength and hardness of aluminum casting alloys, both heat treated and not heat treated and at both ambient and elevated service temperature. It improve the machinability of alloys by increasing matrix hardness. Nickel (Ni) enhances the elevated temperature strength and hardness. Tin(Sn) improves antifriction characteristic and fluidity of aluminum casting alloys. it decrease electrolytic potential which is desirable in sacrificial anodes..It is concluded that selection of alloying element depends on use of materials requirement.

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