Reviews on effect of Additions the alloying element on the Microstructure and Mechanical Properties of Aluminum Alloys

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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. In this paper, the effect of addition of the alloying element on Aluminum Alloys and to study the modification of the iron intermetallic and the microstructural refinement through the formation of secondary phases. 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, Aluminum alloy composites, Hardness of Al, alloying Element, mechanical properties.

Introduction:

Aluminum (Al) alloys have many applications, especially in the automotive and the aeronautical industry [1–2]. In recent years, AlSiFe based alloys have been of interest of the scientific community due to their ability to replace cast iron parts in several manufacturing industries. The properties of these alloys are greatly dependent on the morphology, size, and distribution of primary silicon (Si) particles [3–4]. Properties include high specific strength, high wear and seizure resistance, high stiffness, better high temperature strength, controlled thermal expansion coefficient and improved damping capacity.[5]. 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[6]. 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.

EFFECTS OF MAJOR ALLOYING ELEMENTS IN ALUMINUM ALLOYS:

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). Manganese (Mn) is the most common alloying addition; this has been used to modify the morphology and type of intermetallic phases, in Al cast alloys. It has been reported that additions of Cr can have a similar effect, but the microstructural details are not that clear [2,7]. This element (Cr) occupies the same crystal site in the body center cubic (BCC), Al15X3Si2 structure (where X = Fe, Mn, Cr). The morphology of this intermetallic phase has been reported as Chinese script, star-like, or polygonal. These complex intermetallic compounds have high density and tend to segregate at the bottom of Al melts [8].

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-Jaber et 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 value 70MPa 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. Figure 1. (a) Backscattered electron image of AlSiFe with 1 wt. % Mn alloy. Elemental mapping of (b) aluminum, (c) silicon, (d) iron, and (e) manganese. \((\alpha+\text{Si})_\text{E} = \text{Eutectic}\).

Figure 1. (a) Backscattered electron image of AlSiFe with 1 wt. % Mn alloy. Elemental mapping of (b) aluminum, (c) silicon, (d) iron, and (e) manganese. \((\alpha+\text{Si})_\text{E} = \text{Eutectic}\).

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 up 10% 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.

Figure 2 shows that by increasing the amount of alloying element, the hardness of the material tends to increase, reaching a value of about 220 ± 18 HVN.

Figure 2. Microhardness of the Al–20Si–5Fe alloy with several Cr additions.
Effect of Chromium and Cobalt:

There was a general increase of corrosion resistance with increase of Co and Cr in the aged-hardened condition than as-cast condition. Addition of Cr and Co separately and CrCo simultaneously to Al-Si-Fe alloy improved the corrosion resistance in both as-cast and aged-hardened conditions subject to a maximum of 0.5% (Cr and Co) addition. The Al–Si–Fe master alloy showed a needle shaped iron intermetallic, with a hardness of 106 _ 7 HVN. The addition of 3 wt. % Cr considerably modified the morphology of the ternary Al3FeSi2 intermetallic, as shown in Figure 3. The amount of such intermetallic compound dropped and the formation of the _-CrFe phase was promoted. In terms of crystal growth, it can be noted that the original needle Al3FeSi2 compound gave way to a dendritic _-CrFe phase. Presumably, most of the Si atoms ejected from the Al3FeSi2 intermetallic compound were segregated as primary Si.

This morphology is due to the low solubility of Cr in Al alloys, which leads to the formation of the _-CrFe phase.

Effect of Titanium:

In general terms, the changes in the microstructure with the additions of Cr, Ti, and Mn were gradual, observing a completely different microstructure at 5 wt. % for all alloying additions.

The additions of Cr increased the hardness, with values higher than 200 HVN. This was associated to the microstructural modification, as with the addition of Cr, the original Al3FeSi2 phase changed to a harder dendritic shaped _-CrFe compound. The Ti additions increased around 37 points HVN. With Ti the microstructural modification was significant, as the acicular phase Ti5Si3 was observed even at 1 wt. % Ti. However, the addition of 5 wt. % Ti caused the segregation of eutectic Si around this binary intermetallic. With 5 wt. % Mn the microstructure of the master alloy changed drastically. In this composition, only primary silicon, (_+Si)E and the binary intermetallic Mn0.2Fe0.8 phases were observed. The compound formed (_-CrFe, Ti5Si3, Mn0.2Fe0.8) by the Cr, Ti, and Mn additions showed higher hardness than that of the master alloy Al3FeSi2 intermetallic. Titanium (Ti) is 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 4.

Figure 4: Illustration of grain-refined aluminium
**Effect of iron addition:** John A. Taylor [9,10,11] 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 Fecrit = 0.075 x [%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.

**Effect of zinc:**

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. [10]. ZHU Mei-jun, DING Dong-yan et al[11] 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 [12]. 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.

**Effect of Ni:**

JE Hanafee et al[13,14] 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 aluminate. 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.
CONCLUSION

Alloying elements are selected based on their effect and suitability. Silicon lowers the melting point and increases 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 hardening characteristic of aluminum 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. It decrease electrolytic potential which is desirable in sacrificial anodes. It is concluded that selection of alloying element depends on use of materials requirement.

References

[1] Shah, S.K.; Czerwinski, F.; Kasprzak, W.; Friedman, J.; Chen, D.L. Effect of Cr, Ti, V and Zr Micro-additions on Microstructure and Mechanical Properties of the Al–Si–Cu–Mg cast alloy. Metall. Mater. Trans. A 2016, 47, 2396–2409.
[2] Gustafsson, G.; Thorvaldsson, T.; Dunlop, G.L. The Influence of Fe and Cr on the Microstructure of Cast Al–Si–Mg Alloys. Metall. Mater. Trans. A 1986, 17, 45–52.
[3] Dám, K.; Prus, F.; Vojtech, D. Structural and mechanical characteristics of the Al–23Si–8Fe–5Mn alloy prepared by combination of centrifugal spraying and hot die forging. Mat. Sci. Eng. A-Struct. 2014, 610, 197–202.
[4] Khalif, W.; Samuel, F.H.; Gruzleski, J.E.; Doty, H.W.; Valtierr, S. Nucleation of Fe-Intermetallic Phases in then Al–Si–Fe Alloys. Metall. Mater. Trans. A 2005, 36, 1017–1032.
[5] Khalif, W.; Samuel, F.H.; Gruzleski, J.E. Iron Intermetallic Phases in the Al Corner of the Al–Si–Fe. Metall. Mater. Trans. A 2003, 34, 807–825.
[6] Pontevichi, S.; Bosslet, F.; Barbeau, F.; Peronnet, M.; Vial, J.C. Solid-Liquid Phase Equilibria in the Al–Fe–Si System at 727 °C. J. Phase Equilib. Diffus. 2004, 25, 528–537.
[7] Lu, L.; Dahle, A.K. Iron-Rich Intermetallic Phases and Their Role in Casting Defect Formation in Hypoeutectic Al–Si Alloys. Metall. Mater. Trans. A 2005, 36, 819–835.
[8] Narayanan, L.A.; Samuel, F.H.; Gruzleski, J.E. Dissolution of Iron Intermetallics in Al-Si Alloys through Nonequilibrium Heat Treatment. Metall. Mater. Trans. A 1995, 26, 2161–2174.
[9] Ferraro, S.; Bjurenstedt, A.; Seifeddine, S. On the Formation of Sludge Intermetallic PARTICLES in Secondy Aluminum Alloys. Metall. Mater. Trans. A 2015, 46, 3713–3722.
[10] Wang, B.; Xue, S.; Wang, J.; Lin, Z. Effect of combinative addition of mischmetal and Titanium on the microstructure and mechanical properties of hypoeutectic Al–Si alloys used for brazing and/or welding consumables. J Rare Earths 2017, 35, 193–202.
[11] Guan, K.S.; Xu, X.D.; Zhang, Y.Y.; Wang, Z.W. Cracks and precipitate phases in 321 stainless steel weld of flue gas pipe. Eng. Fail. Anal. 2005, 12, 623–633.
[12] Chen, M.; Lan, L.; Shi, X.; Yang, H.; Zhang, M.; Qiao, J. The tribological properties of Al0.6CoCrFeNi high-entropy alloy with the _ phase precipitation at elevated temperature. J. Alloy. Compd. 2019, 777, 180–189.
[13] Tang, Z.; Williams, J.J.; Tho, A.J.; Akine, M. High temperature oxidation behavior of Ti5Si3-based intermetallics. Intermetallics 2008, 16, 1118–1124.
[14] Swanson, T. Standard X-ray Diffraction Powder Patterns; Dept. of Commerce, National Bureau of Standards: Washington, DC, USA, 1953; Volume I, p. 11.
[15] Bond, W.L.; Kaiser, W. Calculated from ICSD using POWD-12++ (1997). J. Phys. Chem. Solids 1960, 16, 44.
[16] Zeng, L. ICDD Grant-in-Aid (1997). Schubert, K., Burkhart, K., Gold, W., Panday, P., Naturwissenschaften, Eds.; Guangxi Univ., Inst. of Materials Science; Nanning, Guangxi, China, 1965; Volume 52, p. 301.
[17] Yakel, H.L. Atom Distributions in Sigma Phases: I. Fe and Cr Atom Distributions in a Binary Sigma Phase Equilibrated at 1063, 1013 and 923 K. Acta Crystallogr. Sec. B Struct. Sci. 1983, 39, 20.
[18] Kajitani, T.; Kawase, T.; Yamad, K.; Hirabayashi, M. Site Occupation and Local Vibration of Hydrogen Isotopes in Hexagonal Ti5Si3 H(D)1-x. Trans. Jpn. Inst. Met. 1986, 27, 639.
[19] Takeuchi, A.; Inoue, A. Classification of Bulk Metallic Glasses by Atomic Size Difference, Heat of Mixing and Period of Constituent Elements and Its Application to Characterization of the Main Alloying Element. Mater. Trans. 2005, 46, 2817–2829.
[20] Sumiyam, K.; Ohshim, N.; Nakamura, Y. Magnetic Properties of Metastable _Mn Type Mn1-3Fe Alloys Produced by Vapor Quenching. Phys. Status Solidi A 1986, 98, 229.