Influences of Alloying Element on the Mechanical Properties of Aluminum Alloy- A Review

Abhishek Yadav, Jitender Panchal
Department of Mechanical Engineering, MIET, Mohri Shahbad, Kurukshetra, India

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Abstract

The unique combinations of properties provided by aluminum and its alloys make aluminum one of the most versatile, economical, and attractive metallic materials for a broad range of uses from soft, highly ductile wrapping foil to the most demanding engineering applications. Aluminum alloys are second only to steels in use as structural metals. In last decade there has been a rapid increase in the utilization of aluminum generally designed for low weight and low costs, which yields the use of hydrodynamic journal bearing in a large number alloy in automobile industries due to high specific strength, high wear resistance, low density, and low coefficient of thermal expansion.

1. Introduction

Aluminum is one of the metallic materials most used in metalworking industry and its use has greatly increased in the aeronautics and automotive areas. Low weight/strength ratio, good electric and thermal conductivity, mechanical strength and good machinability are some of the properties that improved their market share. The aluminum due to its excellent qualities has taken important place in engineering applications, making it the most produced non-ferrous metal in the metallurgical industry. To attend the necessary requirements for engineering applications, aluminum is usually combined with other chemicals elements in the alloys form. The objectives of the motor industry to achieve vehicle weight reduction have led to a growing interest in the use of aluminum alloys in body construction. Recent trends and developments indicate that adhesive bonding will figure prominently in car body assembly in the future. While there may be some temptation to extrapolate design data from experiences in the aerospace industry, it is likely that the automotive industry will be constrained by different alloys and different production condition.

2. Effect of alloying element in Aluminum alloy

2.1 Effect of Silicon

Silicon is the main alloying element; it imparts high fluidity and low shrinkage, which result in good cast ability and weld ability. The low thermal expansion coefficient is exploited for pistons, the high hardness of the silicon particles for wear resistance. The maximum amount of silicon in cast alloys is of the order of 22-24% Si, but alloys made by powder metallurgy may go as high as 40-50% Si.

- Improves cast ability of aluminum alloys due to a better fluidity and lower shrinkage of molten aluminum-silicon alloys.
- Increases strength of the alloys.

***Corresponding Author,**
E-mail address: husainmehdi4u@gmail.com

- Improves resistance to abrasive wear.
- Silicon in a combination with magnesium allows strengthening the alloys by precipitation hardening heat treatment (Wrought aluminum-magnesium-silicon alloys (6xxx), Cast aluminum alloy 356.0).

2.2 Effect of copper

Aluminum-copper alloys containing 2 to 10% Cu, generally with other additions, form important families of alloys. Both cast and wrought aluminum-copper alloys respond to solution heat treatment and subsequent aging with an increase in strength and hardness and a decrease in elongation. The strengthening is maximum between 4 and 6% Cu, depending upon the influence of other constituents present.

2.3 Effect of Magnesium

Magnesium is the major alloying element in the 5xxx series of alloys. Its maximum solid solubility in aluminum is 17.4%, but the magnesium content in current wrought alloys does not exceed 5.5%. The addition of magnesium markedly increases the strength of aluminum without unduly decreasing the ductility. Corrosion resistance and weld ability are good.

The main benefit of adding magnesium to aluminum-copper alloys is the increased strength possible following solution heat treatment and quenching. In wrought material of certain alloys of this type, an increase in strength accompanied by high ductility occurs on aging at room temperature. On artificial aging, a further increase in strength, especially in yield strength can be obtained, but at a substantial sacrifice in tensile elongation.

2.4 Effect of Iron

Iron is the most common impurity found in aluminum. It has a high solubility in molten aluminum and is therefore easily dissolved at all molten stages of production. The solubility of iron in the solid state is very low (~0.04%) and therefore, most of the iron present in aluminum over this amount appears as an inter metallic second phase in combination with aluminum and often other elements

2.5 Effect of Nickel

Nickel. The solid solubility of nickel in aluminum does not exceed 0.04%. Over this amount, it is present as an insoluble intermetallic, usually in combination with iron. Nickel (up to 2%) increases the strength of high-purity aluminum but reduces ductility. Binary aluminum-nickel alloys are no longer in use but nickel is added to aluminum-copper and to aluminum-silicon alloys to improve hardness and strength at elevated temperatures and to reduce the coefficient of expansion.

2.6 Effect of Zinc

The aluminum-zinc alloys have been known for many years, but hot cracking of the casting alloys and the susceptibility to stress-corrosion cracking of the wrought alloys curtailed their use. Aluminum-zinc alloys containing other elements offer the highest combination of tensile properties in wrought aluminum alloys.

2.7 Effect of Molybdenum

Molybdenum is a very low level (0.1 to 1.0 ppm) impurity in aluminum. It has been used at a concentration of 0.3% as a grain refiner, because the aluminum end of the equilibrium diagram is peritectic, and also as a modifier for the iron constituents, but it is not in current use for these purposes.

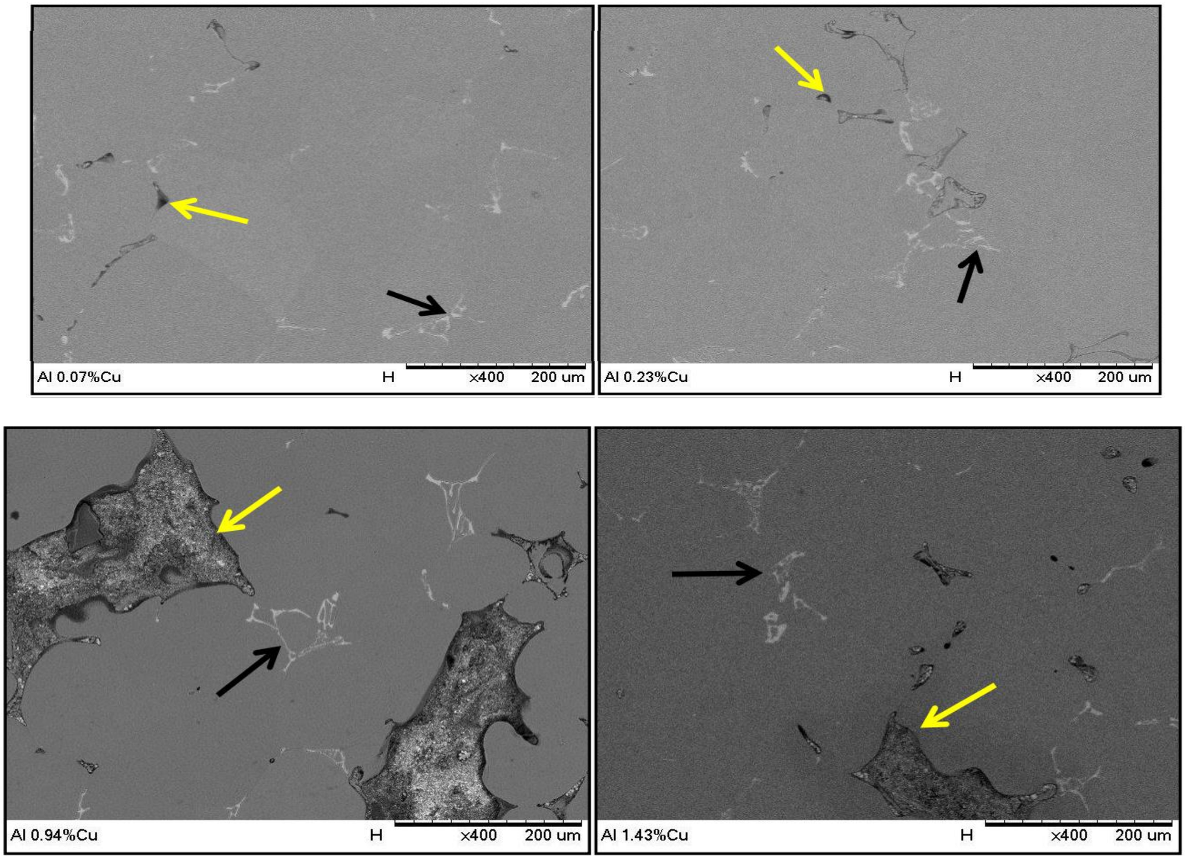
2.8 Effect of Chromium

Chromium occurs as a minor impurity in commercial-purity aluminum (5 to 50 ppm). It has a large effect on electrical resistivity. Chromium is a common addition to many alloys of the aluminum-magnesium, aluminum-magnesium-silicon, and aluminum-magnesium-zinc groups, in which it is added in amounts generally not exceeding 0.35%. In excess of these limits, it tends to form very coarse constituents with other impurities or additions such as manganese, iron, and titanium. Chromium has a slow diffusion rate and forms fine dispersed phases in wrought products. These dispersed phases inhibit nucleation and grain growth. Chromium is used to control grain structure, to prevent grain growth in aluminum-magnesium alloys, and to prevent recrystallization in aluminum-magnesium-silicon or aluminum-magnesium-zinc alloys during hot working or heat treatment.

3 Literature Review

Investigating, the effect of Mg/Si ratio and Cu content on the stretch formability of aluminum alloys of the series 6xxx by using scanning electron microscopy (SEM), hardness tests, forming limit diagram measurements and tensile tests. It was found that the formability of Al–Mg–Si alloys decreases due to a decrease in the work hardening and strain-rate hardening capability, with the increase of Mg/Si ratio. It also has been investigated that with the addition of Cu improved the work hardening capacity, but slightly decreases the strain-rate hardening potential [1]. Aluminum alloys with silicon as a major alloying element are a class of alloys, which are the basis of many manufactured castings. This is mainly due to the outstanding effect of silicon in the improvement of casting characteristics, combined with other physical properties, such as mechanical properties and corrosion resistance [2].The relationship between room temperature (RT) and high temperature fatigue behavior of A354 and C355 alloys and their micro structural features, in particular, secondary dendrite arm spacing (SDAS) and inter metallic compounds. The micro structural analyses and rotating bending fatigue tests emphasized that (i) SDAS influenced room temperature fatigue behavior of the peak-aged A354 and C355 alloys, while its effect on the over aged alloys at high temperature was negligible; (ii) fatigue cracks nucleated mostly from large inter metallic compounds; (iii) at room temperature, C355 alloy was characterized by higher fatigue strength in comparison to A354 alloy [3]. The Silicon is present as a uniformly distributed fine particle in the structure. However, when the primary silicon appears as coarse polyhedral particles, the strength properties decrease with increasing silicon content, but the hardness goes on increasing because of the increase in the number of silicon particles [4].A linear single variable model for precipitation heat treated Al-Zn-Mg-Cu aluminum alloy hardness and yield strength described. Based on the major alloying elements and the strengthening precipitate compositions, a concept model was developed. A Refined composition model was subsequently developed to account for the effect of minor alloying (Mn) and impurity elements (Fe, Si). The model was also valid refined composition for predicting yield strengths of Al-Zn-Mg-Cu-Zraluminum alloys [5].Activation energy for recrystallization on homogenized samples which were cryo rolled up to the maximum possible reduction in area (~75% by is conversion methods using differential scanning calorimetric data, whereas, stored strain energy was determined by X-ray diffraction analysis. It was analyzed that for the same sample the activation energy for recrystallization interrelated well with the stored energy. by optical and transmission electron microscopy, Micro structural evolution was also analyzed. The cry rolled annealed sample showed an improved yield strength with a reasonable ductility. The YS found to be 10 times higher than that of the cast homogenized sample. This is attributed to the recovery of low angle grain boundaries, increasing grain boundary spacing, formation of nano twins and decrease in the dislocation density without any recrystallization [6].Al-Si alloys find wide application in the marine, electrical, and automobile and aircraft industries because of high fluidity, low shrinkage in casting, high corrosion resistance, good weld-ability, easy brazing and low coefficient of thermal expansion [7].The influence of the Si content of the aluminum alloys on their wear resistance has been well documented and eutectic alloys are reported to have better wear resistance than those of hypoeutectic and hypereutectic composition. Manganese is also able to change the morphology of the iron-rich phases from platelets to a more cubic form or to globules. These morphologies improve tensile strength, elongation, and ductility [9]. Investigated the effect of five different heat treatment methods as peak aging (T6), over aging (T74), high temperature and subsequently low temperature aging (HLA), retrogression and raging (RRA) and double retrogression and raging (DRRA) on strength ,fracture toughness and microstructure of 7N01 aluminum alloys by optical microscopy (OM), transmission electron microscopy (TEM), and scanning electron microscopy (SEM). The strength and fracture toughness of the five samples are tested. The results showed that 7N01 Al-alloy treated at T6 condition has high strength but low fracture toughness. Compared with T6 treatment, T74 and HLA treatments increase the fracture toughness by 67% and 90% respectively, while the strength decrease by 9% and 17%. RRA process which improves the fracture toughness without sacrificing strength, was a proper treatment method for 7N01. The fracture toughness of DRRA treated alloy was much lower than that of RRA. Quantitative analysis through TEM images showed that the heat treatment affects the mechanical properties of 7N01 Al-alloy highly through changing the precipitates in grains and on grain boundaries [10].The relation between ageing and retrogression temperatures on Al 6061 alloy on hardness and ultimate tensile strength (UTS) was studied. It was found that higher UTS and hardness were obtained at elevated ageing, retrogression temperatures, and lowest retrogression time. Alloy ultimate tensile strength has been improved by controlling these parameters, showing a reduction in time consumption during the thermal treatment. A relationship has been established between UTS, hardness, and time/temperature for ageing and retrogression regimes by multiple linear regression method. For optimized ageing temperature and retrogression time- temperature, in order to obtain both specific UTS and hardness, this correlation can be used [11].Aluminum and aluminum 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 [12].Several methods for estimating fatigue properties of wrought aluminum alloys from simple tensile data or hardness was discussed. Among them, Park-Song modified Mitchell’s method provided the best estimation results in low fatigue life regime [13].The mechanical properties of aluminum, nylon, GFRP, aluminum-GFRP composite & aluminum-nylon composite were found by using experimental method, The deflection of aluminum composite beams is less than that of pure material beams, the natural frequencies of pure materials (GFRP & Nylon) are larger than those of composite beams made by them if nylon is taken as synthetic fiber with Al, but if GFRP is taken then its deflection is found to be increased when compared to pure GFRP. So, nylon suits good to make composite beam with Al as compared to other synthetic fibers like GFRP [14, 15].The addition of copper as main alloying element (mostly range 3–6 wt. %, but can be much higher), with or without magnesium as alloying constituent (range 0–2 %), allows material strengthening by precipitation hardening, resulting in very strong alloys. Also the fatigue properties are very good for this series. Copper tends to precipitate at grain boundaries, making the metal very susceptible to pitting, inter granular corrosion and stress corrosion [16]. Up to 12 wt. % copper the strength of the alloy can increase through precipitation hardening, with or without the presence of Mg; Hardening is achieved through the precipitation of Al2Cu or Al2CuMg inter metallic phases during ageing which leads to strengths second only to the highest strength 7xxx series alloys [17].

Fig.1 shows the scanning electron microscope (SEM) microstructures of the five samples of 6351 aluminum alloy with different contents of copper with 400 x magnifications. Porosity in aluminum alloys is classified into two kinds: (i) macro porosity (~1–10 mm), which is mainly comprised of massive shrinkage cavities, and occurs in long-freezing range alloys, caused by failure to compensate for solidification shrinkage, and (ii) micro porosity (~1–500 μm), distributed more or less homogeneously, due to the failure to feed inter dendritic regions, and the precipitation of dissolved gases (i.e., gas porosity). In all aluminum alloys samples investigated was observed the two types of porosity like marked in yellow arrows in Fig. 1.



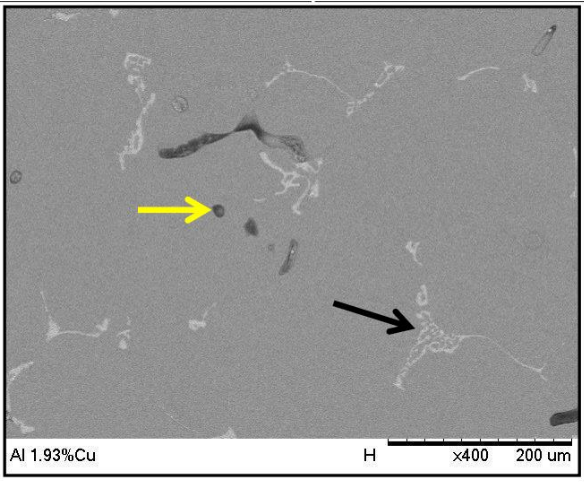


Fig 1: Microstructures of the 6351 aluminum alloy samples with different copper content; porosity (yellow marked); Al (MnCuFe) Si constituent (black marked) [18]

Influence of Ni on the overall properties of thin film, composition of Al–Cu–Ni which was deposited by thermal evaporation. Chemical composition was detected by energy dispersive X-ray spectroscopy and showed a compositional spread of approximately 20 at.% Ni. Decreasing the Ni content in the Al–Cu–Ni thin films resulted in an increased grain size and characteristic surface microstructure evolution. Chemical dissolution experiments have shown that Ni is enhancing the chemical stability of Cu, excepting inside the compositional region between 7 and 13 at.% Ni [19].Ultimate tensile strength of the alloy improved as compared to LM 12 , the solidifications temperature for Al- Alloy reduces and this is an important factor to consider which temperature the heat treatment not should exceed. When increase the silicon content then the melting point of aluminium alloy is decreases whereas fluidity was increases [20, 21].Analysis and hardness measurements to characterize the early stages of precipitation in three Al–Mg–Si alloys with different Cu contents (Al–0.51 at.% Mg–0.94 at. %Si, with 0.01%, 0.06 at.%, or 0.34 at.% Cu) at a range of single and multi- stage heat treatments to evaluate the changes in precipitation processes. Three ageing temperatures were investigated, 298 K (natural ageing), 353 K (pre-ageing) and 453 K (automotive paint-bake conditions). The Cu content had significant effects on the micro structural evolution within the alloy. Formation of clusters which can act as precursors of elongated precipitates during paint-baking was found to be enhanced with increasing Cu content. This improved the paint-bake hardening response and mitigated the deleterious effects of natural ageing [22].The effect of Mg level on the microstructure and mechanical properties for die-cast Al – Si – Cu alloys under the as cast, the solution, and the solution and aged conditions was investigated. It was found that the Mg additions resulted in an effective strengthening to the alloy under both the as-cast condition and the solution and aged condition showed by SEM and TEM analysis. In the die-cast Al–Si–Cu alloys, the lamellar and blocky Al2Cu (Si) were formed overall the experimental alloys, but the irregular Al-Cu-Mg-Si inter metallic were emerged when Mg content was higher than 0.32wt%. The addition of Mg offered extra strengthening after the solution and ageing. Mg content can be controlled at a level up to 0.73wt% for increasing the strength with acceptable ductility under as-cast and heat treatment conditions [25].The deformation behavior of an aluminum–lithium alloy heat treated to different tempering conditions at high strain rate in compression using a direct impact Hopkinson Pressure bar was investigated. Detailed micro structural investigation was carried out using electron back scatter diffraction and bulk crystallographic texture was determined using X-ray diffraction. The naturally aged sample showed less propensity to adiabatic shear band formation and therefore, highest toughness, compared to artificially aged samples. This can be attributed to higher resistance to instability by prolonged strain hardening from dislocation– precipitate interaction in the underage sample compared to peak and over aged samples under dynamic loading conditions. The single stage peak-aged sample provides the best combination of high toughness with stable microstructure amongst the differently aged samples [26].

4. Conclusions

Detailed investigations have been carried out to document the effects of alloying element on the micro structural, mechanical properties and processing parameter on aluminum alloy. The following conclusions can be drawn from this review paper.

- Silicon Improves strength, cast ability of aluminum alloys due to a better fluidity and lower shrinkage of molten aluminum-silicon alloys.
- Copper increases tensile strength, fatigue strength and hardness of the alloys due to the effect of solid solution hardening but it decreases the ductility of alloy.
- Manganese Improves low cycle fatigue resistance, Increases corrosion resistance, Improves ductility of aluminum alloys containing iron and silicon.
- Chromium improves the ductility and toughness of aluminum alloys containing iron and silicon, it Reduces susceptibility of the alloys to Stress corrosion cracking.
- Increases hardness and strength of aluminum alloy and it also reduces the Coefficient of Thermal Expansion.

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