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Effect of Composition on the Microstructure, Tensile and Hardness Properties of Al–*x*Si Alloys

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Abstract

Aluminum alloys have extensive application in industries. The range of physical properties that can be imparted to them is remarkable. Mixing of silicon to aluminum tends to increase its strength to weight ratio and wear resistance, and tends to decrease its density and coefficient of thermal expansion. Using Al–Si cast alloys in automotive industry also for manufacturing purposes is profitable in many aspects. These alloys are important, because reduce vehicle weight also because their good fluidity and corrosion resistance. Density test is done by measuring the mass & the volume of the alloy samples. Controlling the microstructure is very important, because intermetallic phases affecting mechanical and fatigue properties. Study of microstructure has showed the presence of primary silicon. The mechanical properties of Al–Si alloys are strongly influenced by the size, shape and distribution of Si phase present in the microstructure. Yield strength, ultimate tensile strength and harness have increased with the increase of silicon content. But, percent elongation decreases with the increase of silicon content. The hardness of the samples increases with the increase in silicon content.

Introduction

At the original equipment level, the use of aluminum in main and rod bearings is growing for a variety of reasons. One among them is, aluminum bearings are less expensive to manufacturer and it also gets rid of lead which is an environmental concern for manufacturers. Aluminum alloys and other lightweight materials have growing applications in the automotive industry, with respect to reducing the fuel utilization and shielding the environment, where they can successfully reinstate steel and cast iron parts. These alloys are extensively used in buildings and constructions, containers and packaging, marine, aviation, aerospace and electrical industries because of their lightweight, corrosion resistance in most environments, or combination of these properties. Aluminum based alloy provides good combination of strength, corrosion resistance, along with fluidity and freedom from hot shortness. Aluminum alloys are distinguished according to their major alloying elements. Most of the Al casting alloys contains Si as a major alloying element. Si is eutectic former to control the shrinkage that occurs in casting. Silicon is good in metallic alloys. This is because it increases the fluidity of the melt, reduces the melting temperature, decreases the shrinkage during solidification and is very inexpensive as a raw material. Silicon also has a low density, which may be an advantage in reducing the total weight of the cast component. Silicon has a very low solubility in aluminum; it therefore precipitates as virtually pure silicon, which is hard and hence improves the abrasion resistance [1–7]. Aluminum–Silicon (Al–Si) alloys are the most important of the Al alloys, these are classified in three groups: hypoeutectic (<11 wt. % Si), eutectic (11–13 wt. % Si), and hypereutectic (>13 wt. % Si) [8–11]. The hypereutectic alloys are attractive to the automotive industry and desirable for wear resistant applications, where high strength and low weight ratio are required [12−15]. Their good mechanical properties and high resistance to wear are essentially attributed to the presence of hard primary silicon particles distributed in the matrix. Therefore, the size and morphology of primary silicon in hypereutectic Al–Si alloys influence the mechanical properties of the alloys [2, 16]. The presence of coarse primary Si particles in the microstructure of the Al–Si hypereutectic alloys has been identified as the main limitation for their industrial use. Even with the use of silicon modifiers and high cooling rates, the primary Si particles can only be reduced in size. Although the primary Si particles are very hard and certainly increase locally the wear resistance of the alloy, they are brittle and easy to crack exposing the soft Al matrix to extreme wear resulting in catastrophic failure automotive or aerospace components [11, 14]**.** To improve the strength and the formability of lightweight aluminum alloys for further industrial applications, semi–solid forming technique is used as an alternative to traditional casting and forging processes. Semi–solid forming technique is a method that can produce complex shape products. The process has advantages of productions of high quality and performance, and low cost. Semi–solid forming technique is now a commercially manufacturing route producing millions of near net-shape parts per annum for the automotive industry. Mechanical properties are principally controlled by the cast structure. Microstructure evolution of hypoeutectic Al–Si alloys during solidification is in two stages: primary dendrite Al–phase formation (α–matrix), and the subsequent eutectic transformation (eutectic Si particles in α–matrix). The mechanical properties of Al–Si alloys depend, more on the distribution and the shape of the silicon particles [12, 15]. It is only known that increasing the Si content results in an increase of the strength of hypoeutectic alloys and a decrease of the strength of hypereutectic alloys [11, 17]. The tribological properties of Al–Si alloys are affected by shape and

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distribution of silicon particles, and addition of alloying elements such as copper, magnesium, nickel, and zinc often combined with a suitable heat treatment [18–20]. The excellent tribological properties Al–Si alloys have led to their extensive uses in engineering application, particularly in plain bearings, internal combustion engine pistons, and cylinder liners [21–23].

Experimental

Al–Si based alloys with varying Si–contents (Al–2%, Al–4%, Al–6%, Al–8%, Al–11.6%, Al–12.5%, Al–15%, Al–17% and Al–20% Si) were prepared by melting commercially pure aluminum (99.7%) and commercially pure silicon (99.5%) in a graphite crucible in a high frequency induction furnace and the melt was held at 720 °C in order to attain homogeneous composition. After melting of the mixture of Al and Si at 850 ^{o}C and holding for 20 min, the melt was then poured into a metal mould preheated at 200 ^{o}C. The cast samples were of 100 mm length, 30 mm wide and 20 mm height. For microstructural analysis the sample were sectioned transversally and prepared by standard polishing procedures. The microstructure of the specimen was observed using Optical microscope. Under mechanical test, hardness and tensile tests carried out. Tensile properties of samples were determined from tensile testing machine. The average of three readings was taken as tensile strength value. The hardness tests of all the samples were conducted using a Vicker's hardness testing machine. The applied load during the testing was 5 kgf, with a dwell time of 15 s. For each composition, five indentations were taken and average value is reported.

Results and Discussion

Different tests like tensile test and hardness test on Al–*x*Si alloys were carried out. The results obtained from these tests are analyzed and discussed. Mechanical properties of Al–*x*Si casting alloys depend not only on their chemical composition but, more importantly, on microstructural features such as the morphologies of the Al–rich α–phase, the eutectic Si particles and other intermetallic that are present in the microstructure. The effects of silicon on the tensile and hardness properties of Al–Si alloys are well studied. These properties of the Al–Si alloys are dependent on the size, shape and distribution of eutectic and primary silicon particles. Small, spherical, uniformly distributed silicon particles enhance the strength properties of Al–Si alloys.

Density

Mass and volume for each sample of nine alloys are measured with the help of digital balance and Vernier Caliper respectively, which are being used to calculate the density of the same.

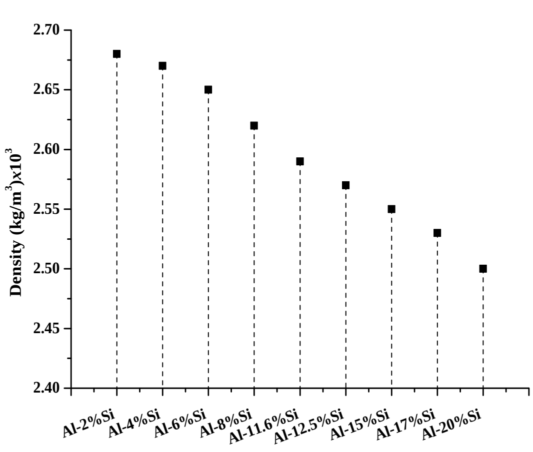

Figure 1: Influence of Si content on the density of Al–Si alloys.

The densities for alloys Al–2%, Al–4%, Al–6%, Al–8%, Al–11.6%, Al–12.5%, Al–15%, Al–17% and Al–20% Si are found to be 2.68 g/cm^3, 2.67 g/cm^3, 2.65 g/cm^3, 2.62 g/cm^3, 2.59 g/cm^3, 2.57 g/cm^3, 2.55 g/cm^3, 2.53 g/cm^3 and 2.50 g/cm^3 respectively as shown in Fig. 1. It is observed from the above data that the density of samples is decreasing with the increase in silicon content. It is due to silicon content, the density of alloy decreases with increase in silicon content as it has lower density (i.e. 2.34 g/cm^3) than that of Aluminum (i.e. 2.70 g/cm^3).

Microstructure

The goal of microstructural analysis is to develop a quantitative description of microstructure that can be used to establish its relationship to properties. Microstructural factors that have an important influence on the properties include: grain size, defects like porosity and oxides, size, shape and distribution of silicon and intermetallic particles, volume fraction of eutectic and precipitates. Efforts are always made to improve the performance of these materials by controlling the microstructure. The Al–Si casting alloys contain two principal phases: aluminum based α–Al as the phase with the largest volume fraction, acts as the matrix for the alloy, and the silicon phase, which is found largely in two forms: primary 'blocky' silicon and 'plate like' eutectic silicon. The microstructure of the alloys depends on the composition of the two primary elements, aluminum and silicon.

Figure 2 to Fig. 7 shows microstructures of the Al–Si binary alloys. The hypoeutectic alloy shows a mixture structure of α–phase and fine eutectic phase of α+Si, though the hypereutectic alloys show a mixture of fine eutectic phase of α+Si and Si particle phase in which the size of particles increases with increasing silicon concentration of the alloy. Fig. 6 and Fig. 7 show that, the degree of refinement of the eutectic silicon increased as the silicon content of the alloy increased beyond the eutectic composition. Here the primary silicon appears as coarse polyhedral particles.

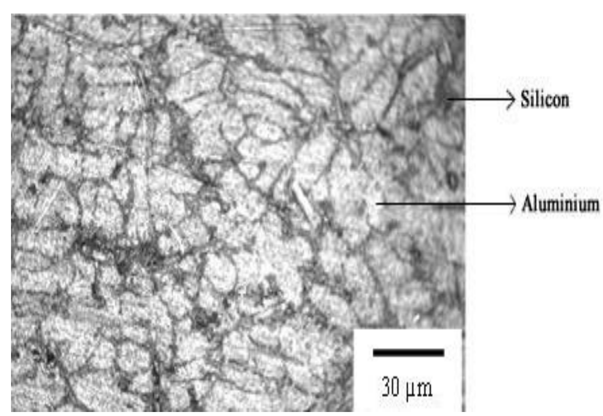

Figure 2: Microstructure of Al–6% Si sample

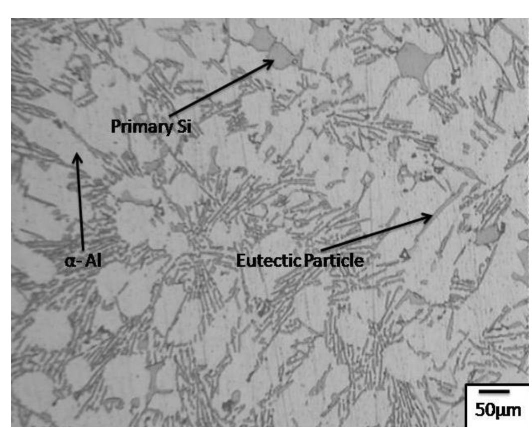

Figure 3: Microstructure of Al–11.6% Si sample

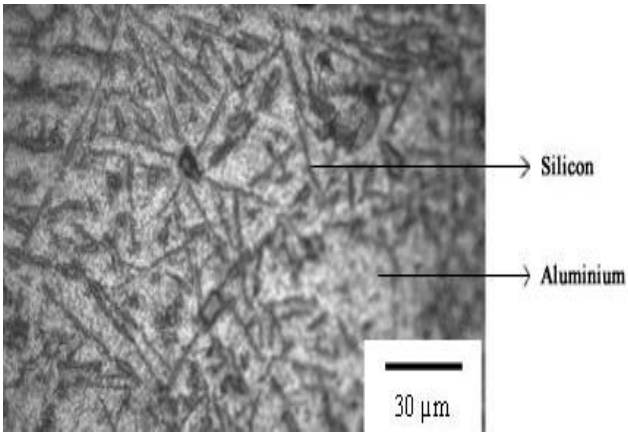

Figure 4: Microstructure of Al–12.5% Si sample

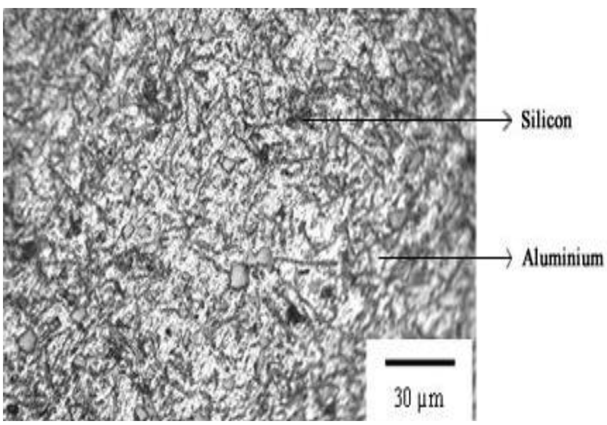

Figure 5: Microstructure of Al–15% Si sample

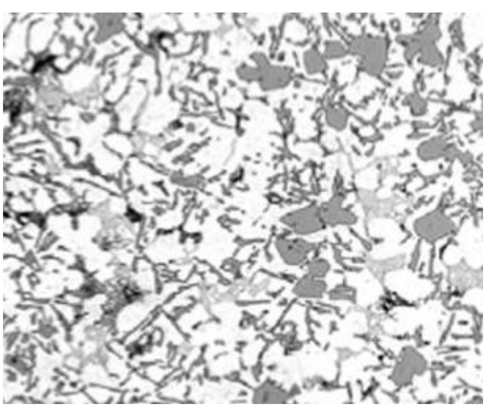

Figure 6: Microstructure of Al–17% Si sample

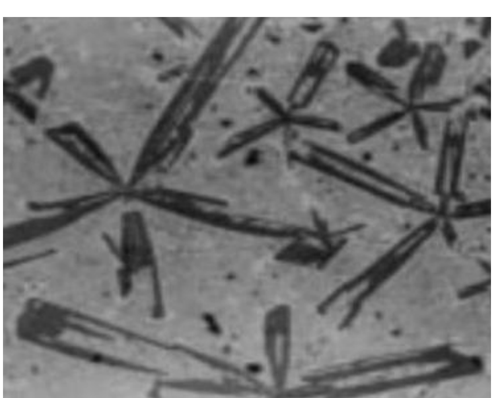

Figure 7: Microstructure of Al – 20% Si sample

Vickers hardness

The Vickers hardness numbers for alloys Al–2%, Al–4%, Al–6%, Al–8%, Al–11.6%, Al–12.5%, Al–15%, Al–17% and Al–20% Si are found to be 39.5, 47.3, 55.6, 61.6, 67.0, 70.0, 72.5, 76.6 and 81.0 respectively. Figure 8 showed that Al–20%Si alloy has more strong effect on hardness the others. The amount of primary silicon increased with the increase in silicon amount in the cast. The net result showed that hardness of the Al–Si alloy increased with increasing weight percentage of silicon and this may be due to the harder nature of silicon.

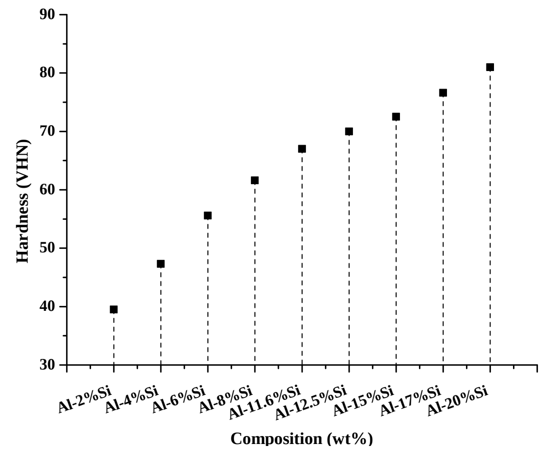

Figure 8: Influence of Si content on the hardness of Al–Si alloys.

Tensile properties

Tensile test is the most common procedure; hence it is an easy way to get information about the materials strength and deformation properties in single tests. Some of the results from the tensile test are ultimate tensile strength, yield strength and percent elongation. From Fig. 9 to Fig. 11, it may be revealed that as the silicon content in the alloy increases, the strength properties (ultimate tensile strength and 0.2% tensile stress) of Al–Si alloys also increase to maximum value 189 MPa at 12.5 wt% of silicon, after which they show a decline with further increase in the silicon content. However, the percent elongation decreases continuously with increasing silicon content. This may be largely attributed to the size, shape and distribution of silicon particles in the cast structures up to the eutectic composition. Silicon is present as fine particles and is uniformly distributed in the structure, and hence the strength properties increase. However when the primary silicon appears as coarse polyhedral particles, the strength properties decrease with increasing silicon content.

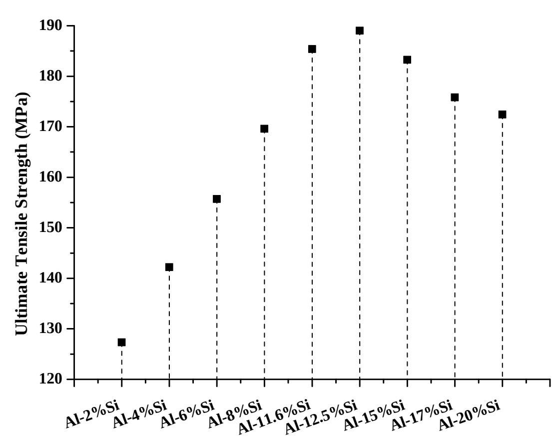

Figure 9: Influence of Si content on the ultimate tensile strength of Al–Si alloys.

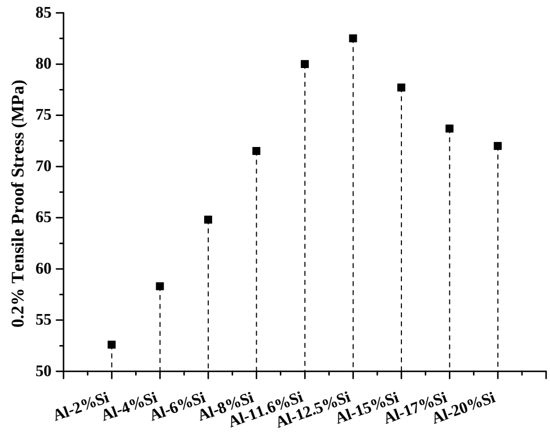

Figure 10: Influence of Si content on the 0.2% tensile stress of Al–Si alloys.

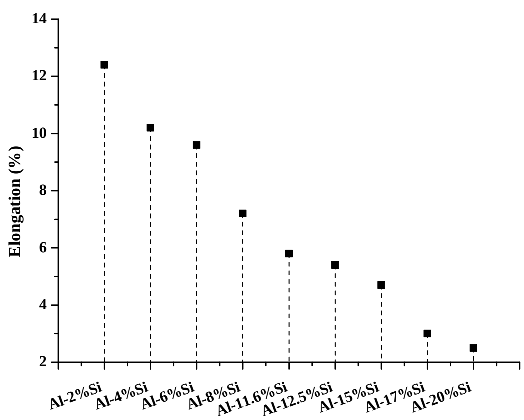

Figure 11: Influence of Si content on the percent elongation of Al–Si alloys.

Conclusions

1. The prepared Al–*x*Si alloys have homogenous distribution of silicon throughout the cast.
2. The amount of primary silicon increases with the increase in silicon content in the cast.
3. The density of the Al–*x*Si alloy is lower than that of the base alloy.
4. Yield strength and ultimate tensile strength increases with the increase in silicon content.
5. Total elongation decreases with the increase in silicon content.
6. Hardness of the Al–*x*Si alloys increases with the increase in silicon content.

References

1. M. Elmadagli, T. Perry, AT. Alpas, A parametric study of the relationship between microstructure and wear resistance of Al-Si alloys, Wear, 262 (2007) 79–92.
2. M. Dash, M. Makhlouf, Effect of key alloying elements on the feeding characteristics of aluminum-silicon casting alloys, Journal of Light Metals, 1 (2001) 251–265.
3. Chang J., Moon I., Choi C., Refinement of cast microstructure of hypereutectic Al–Si alloys through the addition of rare earth metals, J. Mater. Sci., 33 (1998) 5015–5023.
4. Kori S., Murty B., Chakraborty M.; Development of an efficient grain refiner for Al-7% Si alloy, Mater. Sci. Eng. A, 280 (1) (2000) 58–61.
5. Wislei R. Osório, Noé Cheung, Leandro C. Peixoto and Amauri Garcia, Corrosion Resistance and Mechanical Properties of an Al–9wt%Si Alloy Treated by Laser Surface Remelting, Int. J. Electrochem. Sci., 4 (2009) 820–831.
6. Basavakumar K.G., Mukunda P.G., Chakraborty M., Dry sliding wear behaviour of Al–12Si and Al–12Si–3Cu cast alloys, Mater. Des., 30 (2009) 1258–1267.
7. YE, H., An overview of the development of Al–Si alloy based materials for engine applications, Journal of Materials Engineering and Performance, 12 (2003) 288–297.
8. Prashanth, K.G., Scudino, S., Klauss, H.J., Surreddi, K.B., Loeber, L., Wang, Z., Chaubey, A.K., Kühn, U., Eckert, J., Microstructure and mechanical properties of Al–12Si produced by selective laser melting: Effect of heat treatment. Mater. Sci. Eng. A, 590 (2013) 153–160.
9. Chirita, G., Stefanescu, I., Soares, D., Silva, F.S., Influence of vibration on the solidification behaviour and tensile properties of an Al–18 wt% Si alloy, Mater. Des., 30 (2009) 1575–1580.
10. Patel V.P., Prajapati H.R., Microstructural and mechanical properties of eutectic Al-Si alloy with grain refined and modified using gravity die casting and sand casting, International journal of engineering research and application (IJERA), 2 (3) (2012) 147–150.
11. M. Gupta, S. Ling., Microstructure and mechanical properties of hypo/ hyper-eutectic Al–Si alloys synthesized using a near–net shape forming technique, Journal of Alloys and Compounds, 287 (1999) 284–294
12. LIAO H, SUN Y, SUN G, Correlation between mechanical properties and amount of dendritic α–Al phase in as–cast near–eutectic Al–11.6% Si alloys modified with strontium, J. Materials Science and Engineering A, 335 (1–2) (2002) 62−66.
13. LASA L., RODRIGUES-IBADE J. M. Wear behaviour of eutectic and hypereutectic Al–Si–Cu–Mg casting alloys tested against a composite brake pad, J. Materials Science and Engineering A, 363 (1–2) (2003) 193−202.
14. TOMIDA S., NAKATA K., SHIBATA S., ZENKOUJI I., SAJI S., Improvement in wear resistance of hyper–eutectic Al–Si cast alloy by laser surface remelting, J. Surface and Coatings Technology, 169−170(1) (2003) 468−471.
15. Dr. Vandana J. Rao, Chintan Joshi, Anuradha Bapat and Manan Kosambia, Modification of Die Cast Hypoetectic Al–Si Alloy With Different Sources of Nickel and Its Effect on Mechanical Properties, International Journal of Science, Environment and Technology, 3 (2) (2014) 492–496.
16. A. Hekmat-Ardakan, F. Ajersch, Thermodynamic evaluation of hypereutectic Al–Si (A390) alloy with addition of Mg, Acta Materialia, 58 (2010) 3422–3428.
17. G.B. Stroganov, V.A. Rotenberg, G.B. Gershman, Aluminum–Silicon Alloys, Metallurgiya, Moscow, 1977 (in Russian).
18. Yang C.Y., Lee S.L., Lee G.K., Lin J.G., Effect of Sr and Sb modifiers on the sliding behaviour of A357 alloy under varying pressure and speed conditions, Wear, 261 (2006) 1348–1358.
19. Harun M., Talib I.A., Daud A.R., Effect of element additions on wear property of eutectic aluminium–Silicon alloys, Wear, 194 (1996) 54–59.
20. Dwivedi D.K., Wear behaviour of cast hypereutectic aluminium silicon alloys, Mater Des., 27(7) (2006) 610–616.
21. Davis F.A., Eyre T.S., The effect of silicon content and morphology on the wear of aluminium–silicon alloys under dry and lubricated sliding conditions, Tribology International, 27 (1) (1994) 171–181.
22. Yasmin T., Khalid A.A, Haque M.M., Tribological (wear) properties of aluminium–silicon eutectic base alloy under dry sliding condition, Journal of Materials Processing Technology, 153–154 (2004) 833–838.
23. Kori S.A., Chandrashekharaiah T.M., Studies on the dry sliding wear behaviour of hypoeutectic and eutectic Al–Si alloys, Wear, 263 (2007) 745–755.