# Effect of Structural Changes on Microstructure, Mechanical Properties and Fractographical Analysis of Binary Al-12si Base Alloy

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***Abstract:*** **- Present investigation deals with the influence of grain refinement (Al-1Ti-3B) and modification (Al-10Sr) on the microstructure, mechanical properties such as fracture toughness and fracture behaviour of Al-12Si alloy. The tests like tensile, hardness, impact and fracture toughness are conducted on as cast as well as refined and modified binary Al-12Si alloy. The characterisation of Al-12Si alloy before and after tests are conducted using opticalmicroscope and scanning electron microscope (SEM) techniques. The results showed that improvements in the mechanical properties and fracture toughness with the additions of refiner and modifier when compared to as cast condition. Further, the fractographical analysis shows that brittle fracture with severe damage is observed in case of binary as cast Al-12Si alloy. Whereas grain refined and modified alloys showed less severity in damage due to increase in toughness and strength of the alloys.**

***Keywords:*** **Al-12Si alloy, Al-1Ti-3B, Al-10Sr, Fracture toughness, Fractographyetc.**

## I. INTRODUCTION

The uses of aluminium and its alloys are expanding every day in manufacturing sector to make the machine parts. Among the aluminium group of casting alloys especially Al-Si alloys are the lightest engineering material and most widely recognized because of some extremely appealing properties such as specific strength, outstanding castability, lower co-efficient of thermal expansion, excellent thermal conductivity, high resistance to corrosion and also superior mechanical properties [1-10]. The aluminium silicon alloys are having higher mechanical strength and also wear resistance due to the presence of silicon. The composition of the eutectic point of Aluminium and Silicon ranging from 11.7% - 14.5% Si, the most probable value estimated at 11.7% Si. The Al-Si alloys belongs to the binary eutectic system with the eutectic temperature being $577^0$C [3, 7-8]. Majority of pistons (known as piston alloys) and other components are made up of Al-Si castings which enhance best overall balance of properties are produced by near eutectic (<10%Si) and eutectic (12%Si) [9]. It is well known that mechanical properties of these alloys depends on the micro-structural features that is, eutectic silicon morphology, distance between the secondary dendrites, fine grain size, and also on the chemical composition of alloy. As the cooling rate is faster than the equilibrium cooling rate in eutectic and near eutectic Al-Si alloys, are likely to consist of α-Al dendrites. The addition of strontium (Sr) to this alloy as a modifier has been practiced in the past to produce fine eutectic Si grains to improve properties [3-7]. In order to use aluminium for other applications, it needs to be strengthened by adding other alloying elements. Recently, the addition of Ti and B in the form of grain refiner have been made to change the near eutectic (9-11%Si) and eutectic (12%Si) Al-Si alloys microstructure to columnar α-Al dendrites [4, 7-8]. On the other hand, there is lack of information about the effects of minor additions of Ti, B and Sr in the form of master alloys to near eutectic (10%Si) and eutectic (12%Si) alloys to evaluate its fracture toughness and its fractographical analysis. Hence, in present work an attempt has been made to investigate the effect of minor addition of (Al-1Ti-3B) grain refiner and or (Al-10Sr) modifier on the fracture toughness and fractographical analysis of Al-12Si alloy.

## II. EXPERIMENTAL DETAILS

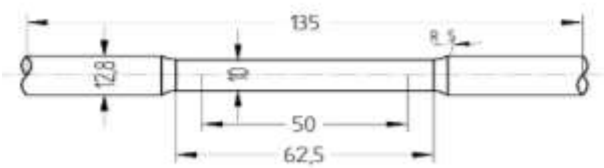
Preparation of the Al-12Si alloy is done using commercial purity Aluminum and Aluminum-20%Silicon master alloy. Melting of the alloy is carried out in an induction furnace under a cover flux and the melt is held at 720°C. After degassing by using solid hexachloroethane ($C_2Cl_6$), the melt is transferred in to a cylindrical graphite mould with its top open for pouring. Also the melt is transferred into split type graphite mould to prepare as-cast (‘0’ minute) tensile, hardness, impact and fracture toughness test specimens. For preparing grain refined and modified samples, master alloy chips (Al-1Ti-3B and or Al-10Sr) are added to binary Al-12Si alloy and the melt was stirred for 30 seconds. After 5min. of holding, the melt was transferred into the graphite moulds. Fig. 1 (a)-(c) shows the dimensions of tensile, charpy impact and fracture toughness test (compact tension) specimens. The chemical composition of the above-prepared Al-12Si alloys are assessed using Atomic Absorption Spectrometer and are shown in table 1. The details of the various alloys for the above studies are given in table 2. Specimens were prepared as per the ASTM standards for conduction of tensile, impact and fracture toughness tests.

Table 1 Chemical composition

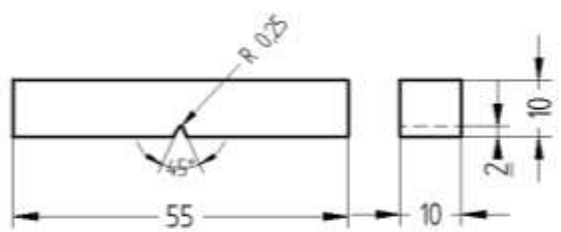
| Cast alloy and Master alloy | Composition wt.% | | | | | |
|---|---|---|---|---|---|---|
| | Si | Fe | Sr | Ti | B | Al |
| Al-12Si | 11.8 | 0.17 | - | - | - | - |
| Al-1Ti-3B | 00.15 | 0.16 | - | 1.00 | 2.60 | Bal |
| Al-10Sr | 00.10 | 0.16 | 10.0 | - | - | Bal |

Table 2 the details of alloys studied

| Alloy No. | Alloy composition |
|---|---|
| 1 | Al-12Si |
| 2 | Al-12Si+1.0wt%(Al-1Ti-3B) |
| 3 | Al-12Si+0.3wt% Al-10Sr |
| 4 | Al-12Si+1.0wt%Al-1Ti-3B +0.3wt%Al-10Sr |




(a)

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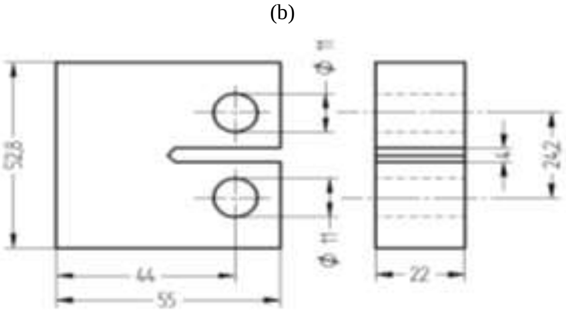


(c)

Figure 1. (a) Tensile specimen (b) Charpy test specimen (c) fracture toughness test specimen prepared as per ASTM standard.

III. RESULTS AND DISCUSSIONS

*A. Macrostructural studies*

Fig. 2 (a) to (c) shows the photomacrographs of Al-12Si alloy without and with addition of 1.0wt% of Al-1Ti-3B grain refiner, (0.3wt% Al-10Sr) grain modifier and with addition of both. It can be seen from Fig. 2(a) in the absence of grain refiner Al-12Si alloy shows coarse-grained structure. With the addition of 1.0wt% of Al-1Ti-3B grain refiner to Al-12Si alloy shows the change in macrostructure from coarse to fine equiaxed (Fig.2b) and similar structure is obtained when the grain refiner and modifier are added together to the alloy (Fig.2c). It is clear from photomacrographs the addition of grain refiner along with modifier to binary Al-12Si alloy resulted in further refinement of structure.

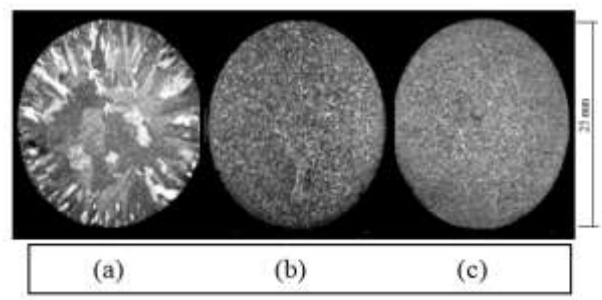


Fig. 2 a-c the photomacrographs of Al-12Si alloy (a) as-cast alloy (b) with 1.0wt% of Al-1Ti-3B and (c) with 1.0wt % of Al-1Ti-3B+0.3wt% of Al-10Sr master alloy.

*B. Studies of the Microstructure*

Fig. 3 (a) to (d) depicts the optical photomicrographs of Al-12Si alloy in as-cast condition, with grain refiner, modifier and collective addition of both. From fig.3 (a) it is clear that in an untreated condition, the microstructure of Al-12Si alloy contains of primarily eutectic combination (α-Al + eutectic Silicon). However, presence of substantial amount of elongated α -Al dendrites as well as primary Si particles are due to skewed coupled zone effect [3, 4]. Adding of 1.0wt% of master alloy Al-1Ti-3B to Al-12Si alloy resulted in fine equiaxed α-Al dendrites, due to the presence of (Al, Ti)$B_2$ particles in the master alloy which acts as heterogeneous nucleating sites during solidification of α-Al dendrites (Fig. 3b),while eutectic Si particles remains more or less same. The amount of microstructural changes due to modification from acicular to fine eutectic Si particles after addition of 0.3%wt of Al-10Sr is shown in Fig. 3(c). However there is no change in α-Al dendritic structure. Similarly Fig.3 (d) shows the influence of adding the 1.0wt% Al-1Ti-3B and 0.3wt%Al-10Sr master alloys together resulted in instantaneous refinement of α-Al dendrites from coarse to fine equiaxed and modification of acicular Si particles to fine rounded particles. The present results suggest that toughness and strength of the alloys increases with the existence of grain refiner and or modifier due to variation in microstructure.

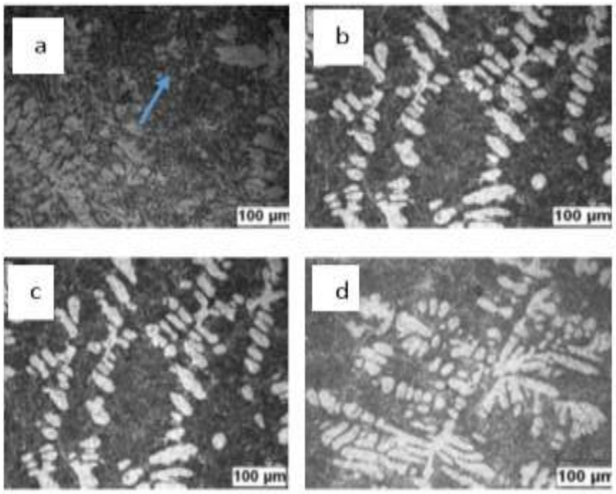


Fig.3. Optical microphotographs of Al-12alloy (a) as cast (b) with 1.0wt% of Al-1Ti-3B (c) with 0.3wt% of Al-10Sr modifier and (d) with combined addition of 1.0wt% Al-1Ti-3B and 0.3wt% Al-10Sr master alloys

### *C. SDAS analysis*

To study the comparison of fractographical analysis of Al-12Si alloy by keeping emphasis on the microstructure, the secondary dendritic arm spacing (SDAS) analysis were performed before and after adding the Al-1Ti-3B grain refiner and or Al-10Sr modifier, using METAVISION automatic image analyser at a magnification of 100X. The SDAS values of the measurement are shown in Fig 4. It is clear from the experimental results the SDAS of Al-12Si alloy in an untreated condition is 98 µm. It is however seen that the addition of 1.0wt% Al-1Ti-3B grain refiner to Al-12Si alloy results in reduction of SDAS to 41.90µm. The extent of reduction in SDAS in case of combined addition of grain refiner and modifier is more or less same as that of individual addition of grain refiner

### *D. Mechanical Properties Of Binary Al-12SiAlloy*

Fig.4 depicts the effect of grain refinement and modification on the mechanical properties of Al-12Si alloy. It is clear from the figure that there is successive improvements in the mechanical properties like Yield Stress(σ), percentage Elongation and Ultimate Tensile Strength of Al-12Si alloy can be achieved with the individual addition of 1.0wt% Al-1Ti-3B grain refiner, 0.3wt% Al-10Sr modifier and collective addition of both when compared to the as-cast alloy. It is also clear from the figures that the collective addition of grain refiner and modifier to Al-12Si alloy resulted in maximum Yield point stress, UTS and %E when compared to the individual addition of grain refiner and modifier in an untreated condition. In as-cast condition, the effects of grain refiner and modifier on mechanical properties of Al-12Si alloys are shown in Fig 4. In the absence of grain refiner and modifier, the Al-12Si alloy shows YS, UTS and % E of 130.37 MPa, 156.47MPa and 2.46% respectively. However, with the individual addition of grain refiner, modifier and combined addition of both, the tensile properties of Al-12Si alloy are enhanced as clearly evident from Fig. 4. The improvements in YS of Al-12Si alloy obtained with the individual addition of 1.0wt% of Al-1Ti-3B grain refiner, 0.3wt% of modifier and combined addition of both are 133.28, 138.58 and 154.74 MPa respectively. Similarly, the improvements in UTS values are 157.87, 162.36 and 179.79 MPa respectively. The corresponding improvements in ductility of Al-12Si alloy after the addition of grain refiner, modifier and combined addition of both are 3.25%, 3.34% and 3.47% respectively. The results clearly suggest that grain refinement or modification alone cannot result in large improvement in mechanical properties and a combination of both leads to excellent improvement in mechanical properties. It is clear from the above discussion that the toughness and strength of Al-12Si alloy depends on microstructure and material related mechanical properties. The overall results of mechanical properties of Al-12Si alloys are correlated with the earlier discussion of SDAS analysis and macroscopy.

### *E. Hardness of Al-12SiAlloy*

The effects of grain refiner and modifier on the hardness of Al-12Si alloy have been studied using automatic micro Vickers hardness tester. The tests are carried out on the polished specimens by applying a 50gms (0.49N) load for 10seconds using a diamond indenter (having an angle of indentation 136°). The measurements were carried out on the matrix of the alloys. Each microhardness value reported in the present work is an average value of five indentations. Fig.4 shows the impact of grain refiner and modifier on the hardness of Al-12Si alloy. It is observed from the figure that improvements in hardness of Al-12Si alloy containing grain refiner and or modifier. Results also suggest that, the combined addition of grain refiner and modifier to Al-12Si alloy resulted in maximum improvement in the hardness of the alloy when compared to the individual addition of grain refiner, modifier and in the untreated conditions. The improvements in the hardness of Al-12Si alloy were due to the structural changes in the microstructure. Thus the overall results of mechanical properties correlated with the earlier discussions of SDAS and microstructural studies.

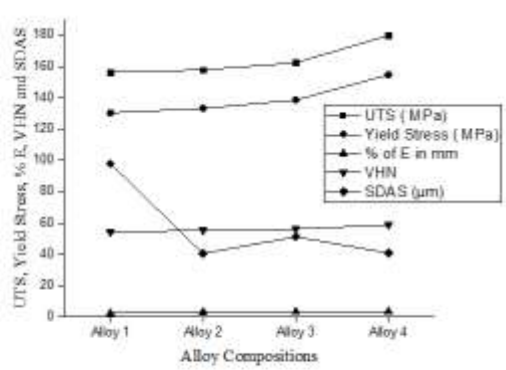


Fig. 4 graph of Alloy compositions versus Yield stress (MPa), UTS (MPa), % Elongation (mm), VHN and SDAS (µm).

### F. *Impact strength and Fracture toughness of Al-12Si alloy*

Average impact strength results of individual alloy are shown in Fig. 5. It clearly indicates that Maximum impact strength was observed in alloy number 4 which is casted with grain refiner and modifier. Minimum impact strength was observed in as cast alloy number 1 similarly the improvements are observed in fracture toughness of various alloys studied by using CT specimens.

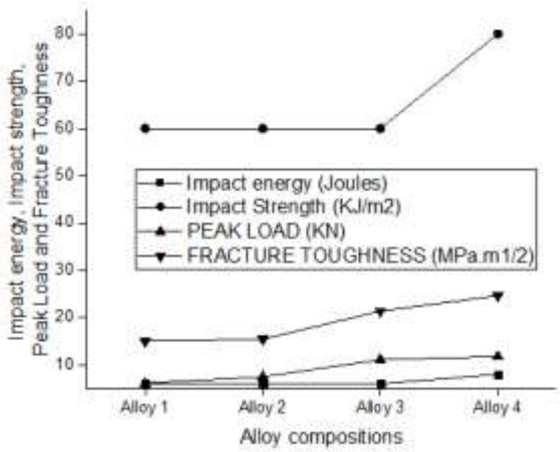


Fig.5 Alloy composition versus impact energy (J), impact strength ($J/m^2$), peak load (KN) and fracture toughness ($MPa.m^{1/2}$).

### G. *Fractographical analysis of Al-12Si alloy*

Figure 6 a-d shows SEM photomicrographs of the fractured surfaces of Al-12Si alloy tensile specimens before and after structural modifications. Fig 6(a) shows the fracture surface of Al-12Si alloy without adding any grain modifier and grain refiner. A close inspection shows that the coarse grain/dendrites of the metal surface because of formation of large brittle facets. Fig 6(b) depicts the details of the fractured surface of Al-12Si alloy with addition of grain-refiner (Al-1Ti-3B). From the figure it is observed that a finer fracture surface, with few couple of dimples present on the fractured surface. The increase in strength is due to the change of coarse equiaxed $\alpha$-Al dendrites into fine equiaxed $\alpha$-Al dendrites, whereas the plate-like eutectic silicon is unaffected. Fig 6(c) exhibits the fractured surface of sample treated with Al-10Sr modifier. From the figure it is observed that a finer fracture surface, including a couple of dimples compared to the as casted alloy. This treatment modifies the plate-like eutectic silicon to fine particles, showing homogeneous allocation of silicon particles throughout the matrix, which enhances the strength of the material. Fig 6(d) shows the fracture surface details of Al-12Si alloy treated with both grain refiner and modifier. Fractured surfaces shows few dimples or tear ridges and the fracture surface is similar to ductile failure. Dimpled fracture surface and fine Si particles contribute to more difficult crack nucleation and delayed propagation during tensile test. This results in the improved ductility of material.

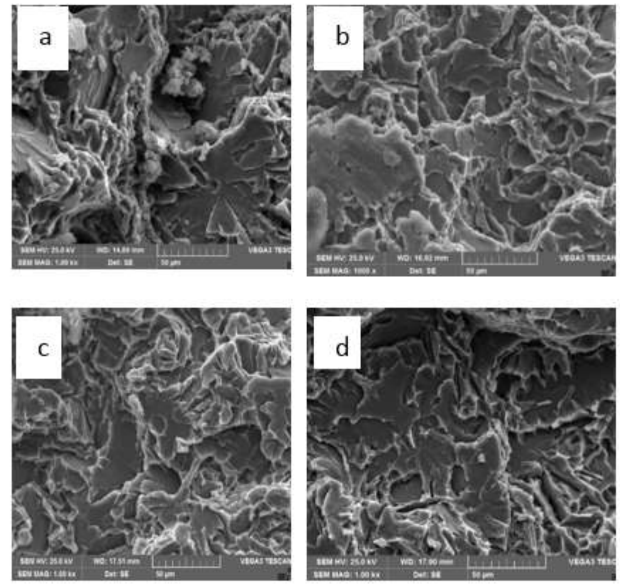


Fig. 6 a-d SEM fractographs of Al-12Si alloy of tensile test (a) as cast condition (b) with Al-1Ti-3B grain refiner (c) with Al-10Sr modifier (d) with combined addition of grain refiner and moodier (Al-1Ti-3B + Al-10Sr) Al-12Si with combined addition ofAl-1Ti-3B + Al-10Sr

## IV. CONCLUSION

1. Enhancement in mechanical properties like tensile strength, percentage elongation and Hardness were observed in grain refined and or modified Al-12Si alloy when compared to as cast conditions
2. There is slight increase in impact strength and fracture toughness were observed in Al-12Si alloy containing grain refiner and modifier when compared to as cast alloy
3. Brittle fracture with severe damage is observed in case of as cast Al-12Si alloy when subjected to tensile, impact and fracture toughness tests. Whereas grain refined and modified alloys shows less severity in damage due to structural modification of Al-12Si alloy.

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