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Studies on the Effect of Al-1Ti-3B and Al-10Sr Master Alloys on Fracture Toughness and Fractographical Analysis of Binary Al-10Si Alloy

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***Abstract*:- In the present study an experimental investigation was carried out to determine the effect of grain refiner (Al-1Ti-3B) and or modifier (Al-10Sr) on the microstructure, hardness, tensile properties, impact strength and fracture toughness of near eutectic (Al-10Si) Al-Si alloy. The microstructures and fractured surfaces of tensile test specimens of Al-10Si alloy before and after melt treatment are characterized by optical metallurgical microscope /SEM analysis. The results suggest that, improvement in mechanical properties, fracture toughness and strength of Al-10Si alloy was observed with the addition of (Al-1Ti-3B) grain refiner and or (Al-10Sr) modifier when compared to the as cast condition.However, maximum improvement in mechanical properties and fracture toughness were observed with the combined addition of grain refiner and modifier to Al-10Si alloy.**

***Keywords*: Al-10Si, Al-1Ti-3B, Al-10Sr, Grain refiner, Modifier. Fracture toughness etc.**

I. INTRODUCTION

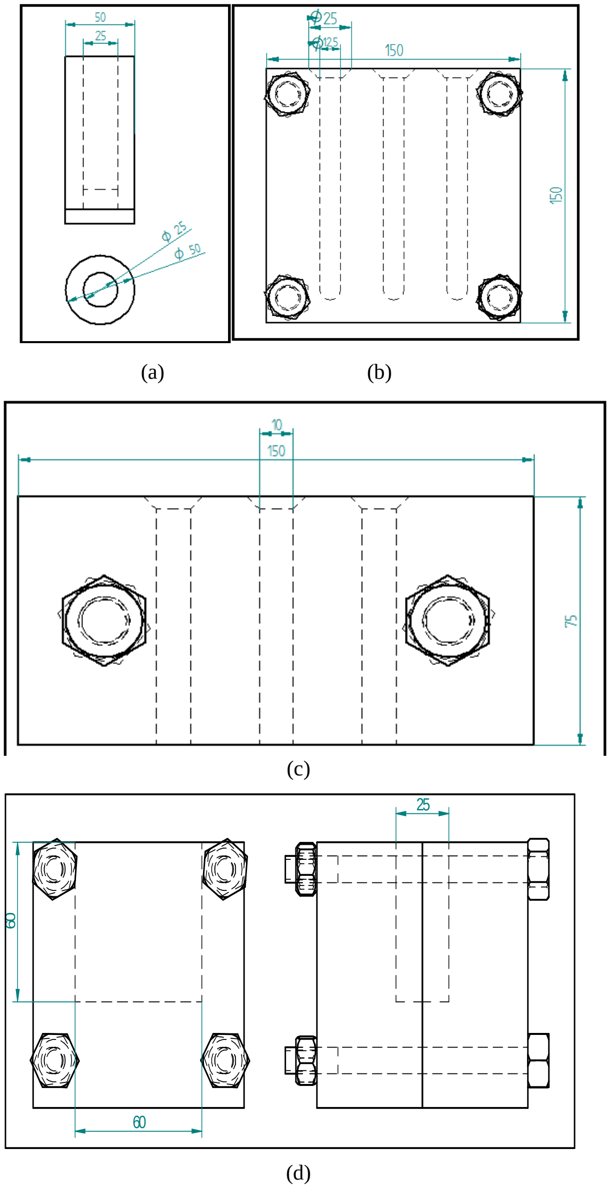
The applications of aluminium and its alloys for the machine parts are increasing day to day. Among the commercial aluminium casting alloys perhaps Al-Si alloys are the most common particularly due to some very attractive characteristics such as high strength to weight ratio, excellent castability, and pressure tightness, low co-efficient of thermal expansion, good thermal conductivity, good mechanical properties and corrosion resistance [1-5].

Al-Si alloys find wide applications in marine castings, motor car and lorry fittings (pistons), engine parts (casing etc), cylinder blocks and heads, cylinder liners, axles and wheels, rocker arms, automotive transmission casings, water cooled manifolds jackets, piston for internal combustion engines, pump parts, high speed rotating parts and impellers etc. [1-5]. The binary Al-Si alloys belong to the simple eutectic system, the eutectic temperature being 577°C. But the composition of the eutectic point has been reported ranging from 11.7% - 14.5%Si with the most probable value at 11.7%Si [3]. The eutectic composition in binary Al-Si system is known to shift depending on the alloying elements and cooling conditions or casting processes involved. Eutectic (12%Si) and near eutectic (10%Si) Al-Si alloys are cast to produce majority of pistons and are known as piston alloys which provide the best overall balance of properties [6-8].

It is well known that the mechanical property (toughness, ductility, hardness and UTS) of these alloys depends on the microstructural features such as eutectic silicon morphology, secondary dendrite arm spacing, grain size, chemical composition. In as cast condition, eutectic and near eutectic Al-Si alloys are likely to consist of α-Al dendrites and irregular eutectic as the rate of cooling is faster than the equilibrium cooling. In order to improve the properties of such alloys modification treatments (by the addition of Sr) have been practiced in the fast to produce fine eutectic Si [4-6]. Recently some effort has been made to refine the columnar α-Al dendrites (by the addition of Ti and B) present in the near eutectic (9-11%Si) and eutectic (12%Si) Al-Si alloys [8-10]. However, there is a lack of information regarding the effect of minor addition of Ti, B and Sr in the form of master alloys on the fracture toughness and fractographical analysis of near eutectic (10%Si) and eutectic (12%Si) alloys. Hence, 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 near eutectic (Al-10Si) alloy.

II. EXPERIMENTAL DETAILS

Binary Al-10wt%Si alloy was prepared using commercial purity Al and Al-20wt%Si master alloy. Melting of the alloy was carried out in a resistance furnace (Silicon Carbide heating element, M/s Industrial furnace and Control, Karnataka, India) under a cover flux (45%NaCl+45%KCl+10%NaF) and the melt was held at 720°C. After degassing with solid hexachloroethane (C_2Cl_6), the melt was poured in to a cylindrical graphite mould with its top open for pouring (for macrostructural studies, microstructural studies and hardness test). Also the melt was poured into split type graphite moulds to prepare as cast ('0' min.) tensile, impact and CT test specimens. Similarly, for preparing grain refined or modified samples, master alloy chips [1.0wt % of (Al-1Ti-3B) and or 0.2wt% of (Al-10Sr)] were added to Al-10wt%Sialloy after degassing. The melt was stirred for 30 seconds with zirconia coated steel rod after the addition of master alloy, after which no further stirring was carried out. After 5min. of holding, the melt was poured into the graphite moulds. The '0' min. refers to the melt without the addition of grain refiner and or modifier. Figure.1a-d shows the graphite moulds for the preparation of test specimens. The chemical compositions of the above-prepared Al-Si alloys were assessed using Atomic Absorption Spectrometer (Model AA 240: VARIAN, The Netherlands) and also by gravimetric method. Table 1 shows chemical composition of cast alloys and master alloys. Table 2 shows the details of the alloys studied.



(a) (b)

(c)

(d)

Fig.1a-d shows the graphite moulds for preparation of specimen for characterization (a) cylindrical graphite mould for formacrostructural, microstructural studies and hardness test (b) Split type graphite mould for tensile specimen (c) Split type graphite mould for impact test specimen (d) split type graphite mould for Compact Tension (CT) specimens.

Table 1. Chemical composition

Cast alloy and Master alloy	Composition wt%					
	Si	**Fe**	**Sr**	**Ti**	**B**	**Al**
Al-10Si	9.98	0.17	-	-	-	-
Al-1Ti-3B	0.15	0.16	-	1.00	2.60	Bal
Al-10Sr	0.10	0.16	10.0	-	-	Bal

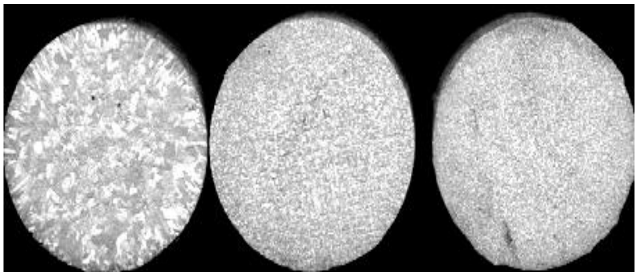
Table 2.The details of alloys studied

Alloy No.	Alloy composition
1	Al-10Si
2	Al-10Si+1.0wt% of (Al-1Ti-3B)
3	Al-10Si+0.2wt% of Al-10Sr
4	Al-10Si+1.0wt% of Al-1Ti-3B +0.2wt% of Al-10Sr

III. RESULTS AND DISCUSSIONS

A. *Macrostructural studies*

Fig. 2a-c shows the photomacrographs of Al-10Si alloy without and with addition of 1.0wt% of Al-1Ti-3B grain refiner and with combined addition of 1.0wt% of Al-1Ti-3B grain refiner and 0.2wt% of Al-10Sr modifier. It can be seen from Figure. 2a that, in the absence of grain refiner Al-10Si alloy shows coarse-grained structure. With the addition of 1.0% of Al-1Ti-3B grain refiner to Al-10Si alloy shows the change in macrostructure from coarse to fine equiaxed (Figure.2b) and similar structure obtained when the combined addition of grain refiner and modifier are added to the alloy (Figure.2c). It is clear from photomicrographs that addition of grain refiner along with modifier to Al-10Si alloy resulted in further refinement of structure.



(a) (b) (c)

Fig. 2 a-c shows the photomacrographs of Al-10Si alloy (a) as-cast alloy (b) with 1.0wt% of Al-1Ti-3B and (c) with 1.0wt% of Al-1Ti-3B+0.2wt% of Al-10Sr master alloy

B. *Microstructural studies*

Fig. 3a-d shows the optical microphotographs of Al-10Si alloy before and after grain refinement and or modification. From Fig. 3a, it is clear that in the absence of grain refiner, Al-10Si alloy shows coarse columnar α-Al dendrite structure and unmodified needle/plate like eutectic silicon with different magnifications. With the addition of 1.0wt % of Al-1Ti-3B master alloy, the structure changes from coarse columnar to coarse equiaxedα-Al dendrites (Fig. 3b), while eutectic silicon remains unmodified as expected. The Al-1Ti-3B master alloy contains $(Al,Ti)B_2$ particles, which acts as better nucleating agents than Al_3Ti/TiB_2 particles. Further, addition of 0.2wt% of Al-10Sr to Al-10Si alloy, the plate like eutectic Si is converted in to fine particles and α-Al dendrites remain as columnar dendritic structure as clearly observed from Figure. 3c. The Al-10%Sr modifier contains Al_4Sr intermetallics and these atoms are absorbed on to the growth steps of the solid-liquid interface. The atomic radius of the Al_4Sr modifier being almost equal to that of silicon and hence, growth twins will be caused at the interface. The mechanism of modification of eutectic Si by the addition of Sr is termed as impurity induced twinning. Figure. 3d shows the simultaneous refinement (of α-Al dendrites) and modification (of eutectic Si) of Al-10Si alloy due to the combined addition of 1.0wt% of Al-1Ti-3B grain refiner and 0.2wt% of Al-10Sr modifier containing $(Al, Ti)B_2$ and Al_4Sr particles, which are responsible for changing the microstructure.

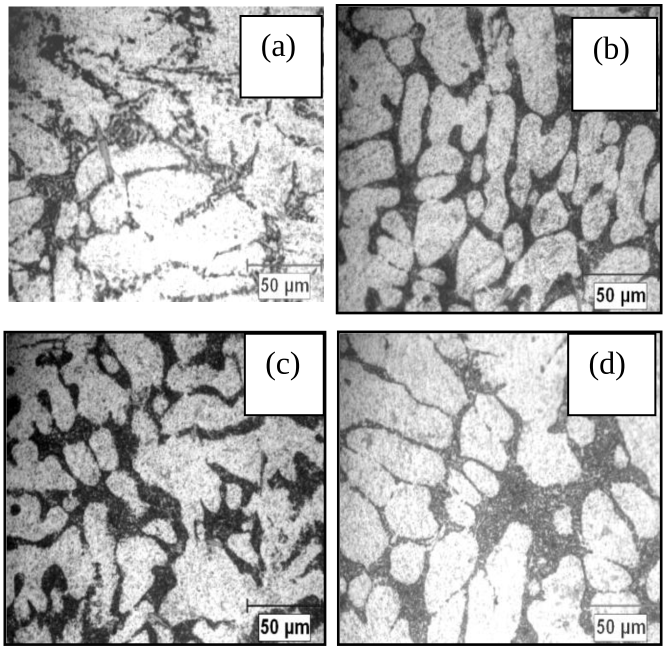


Fig.3a-d Shows the photomicrographs of Al-10Si alloy (at 200x). (a) Without grain refiner (b) with 1.0% of Al-1Ti-3B (c) with 0.2% of Al-10Sr modifier and (d) with combined addition of 1.0% Al-1Ti-3B and 0.2% Al-10Sr master alloys

C. *SDAS analysis*

The secondary dendrite arm spacing (SDAS) analysis of Al-10Si alloy was performed before and after the addition of Al-1Ti-3B grain refiner and or Al-10Sr modifier, using METAVISION Automatic Image Analyzer at a magnification of 200x. The SDAS values of the measurement are shown in the Table 3The result suggests that, addition of 1.0wt% of Al-1Ti-3B grain refiner to Al-10Si alloy changes the coarse columnar α-Al dendrites with SDAS of 98.6µm into coarse equiaxedα-Al dendrites with 42.68µm. But α-Al dendrites remains elongated while the eutectic Si modification takes place when 0.2% of Al-10Sr modifier was added to Al-10Si alloy. Modification of Al-1Si alloy reduces the size of the secondary dendrite arm spacing with 63.63µm and however, the shape of the α-Al dendrites as columnar and it clearly observed in the Figure. 3c. Similarly, the combined addition of 1.0wt% of Al-1Ti-3B grain refiner and 0.2wt% of Al-10Sr modifier to Al-10Si alloy changes the morphology of both α-Al dendrites and eutectic Si with SDAS of 42.50µm.

Table 3. SDAS (µm) of Al-10Si alloy before and after refinement and modification

Nominal composition	Addition level of Grain refiner	SDAS µm	
		'0' min	'5' min
Al-10Si	-	98.6	-
Al-10Si	1.0wt%of (Al-1Ti-3B)	-	42.68
Al-10Si+0.2wt% of Al-10Sr	-	-	63.63
Al-10Si+0.2wt% of Al-10Sr	1.0wt%of (Al-1Ti-3B)	-	42.50

D. *Tensile properties*

Tensile properties mainly depend on the shape and size of the eutectic silicon morphology in case of near eutectic (Al-10Si) Al-Si alloy. The coarse Si plates of the unmodified plate/rod like silicon structure act as internal stress raiser in the microstructure and provide easy paths for fracture. The addition of 1.0wt% of Al-1Ti-3B grain refiner to Al-10Si alloy converts the predominantly elongated α-Al dendritic structure to fine equiaxedα-Al dendritic structure, thereby enhances the mechanical properties as clearly observed from the Fig. 4 Similarly, by the addition of grain refiner and with modification the structure becomes finer, large elongated α-Al dendrites gets converted in to fine equiaxedα-Al dendrites and the elongated eutectic silicon needles become more rounded fine particles. As a result ultimate tensile stress and ductility increases greatly in Al-10Si alloy. The improvements which are observed in the present studies depend on the structural differences between the grain refined, modified and combined effect of grain refiner and modifier in case of Al-10Si alloy.

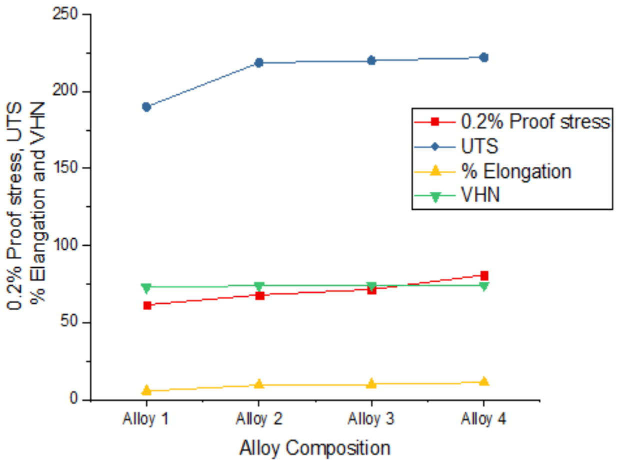


Fig. 4 Alloy compositions versus 0.2% proof stress (MPa), UTS (MPa), % Elongation (mm) and VHN.

IV. EFFECT OF MICROSTRUCTURE ON HARDNESS OF AL-10SI ALLOY

The hardness of the materials surface is an important parameter in predicting the fracture toughness and fractrographical behavior of Al-10Si alloy. The influences of grain refinement and or modification on the hardness of Al-10Si alloy have been studied using automatic micro Vickers hardness tester. The tests were carried out on the polished specimens by applying a 50g (0.49N) load for 10s using a diamond indenter (having an angle of 136°). The measurements were carried out on the matrix of the alloy. Each microhardness value reported in the present work is an average value of five readings and the average values of the measured data (Fig. 4). From the results it is clear that marginal improvements in hardness of Al-10Si alloys are achieved with the addition grain refiner and or modifier. Results also suggest that, the combined addition of grain refiner and modifier to Al-10Si 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 improvement in the hardness of Al-10Si alloys was due to the structural changes in the microstructure due to the addition of grain refiner and modifier. Thus the overall results of mechanical properties correlates the earlier discussions of SDAS, macroscopy and microscopic studies.

V. EFFECT OF MICROSTRUCTURE ON IMPACT STRENGTH AND FRACTURE TOUGHNESS OF AL-10SI ALLOY

Fig. 5 shows the average impact strength result of individual alloy. Maximum impact strength was observed in alloy number 2, 3 and 4 which are casted with grain refiner and or modifier. Minimum impact strength was observed in as cast alloy number 1 Similar the improvements are observed in fracture toughness of various alloys studied by using CT specimen.

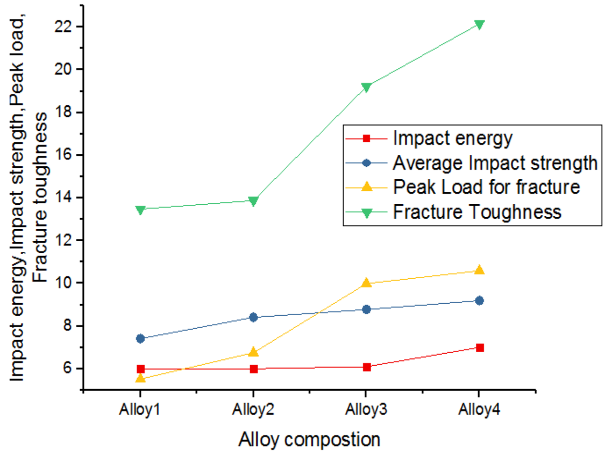


Fig.5 Alloy composition versus impact energy (J), impact strength (J/m^2), peak load (KN) and fracture toughness (MPa.m$^{1/2}$).

VI. FRACTOGRAPHICAL ANALYSIS OF AL-10SI ALLOY

Fractography is the study of fractured surface of materials. It is used to determine the nature and cause of failure. In the present work the fractography is utilized to assist the effectiveness of melt treatment of Al-10Si alloy. The fracture mechanisms of Al-10Si alloy were mainly determined by the shape, size and distribution of the silicon crystal particles, the cohesion between the silicon particles and the matrix and the ease with which the silicon particles crack.Fig.6a-d shows the fractured surfaces of Al-10Si alloy under different melt treated conditions (as cast, grain refined, modified and combined addition condition). Modification of microstructure structure is evident from optical micrographs explained in section 3.2 (Fig.3a-d). From the SEM images of fractured surfaces of Al-10Si alloy, it is observed that ductile mode of failure in case of melt treated alloys (Fig.4.b-d) when compared to brittle mode failure in as cast condition (Fig. 6a). It is very much clear that the eutectic silicon particles are much coarser in as cast Al-10Si alloy. During tensile test due to increase in tensile force, stresses increased in the matrix and lead to stress transfer to eutectic silicon particles as they are the stress risers and crack gets initiated at the sites of irregular eutectic. Due to which brittle fracture was observed in as cast condition. However, ductile fracture was observed in case of Al-10Si alloy treated with grain refiner and or modifier resulted in conversion from coarse silicon particles to fine particles and coarse α-Al dendrites to coarse equiaxedα-Al dendrites. The fractured surfaces are clearly observed from SEM micrographs (Fig. 6a-d).

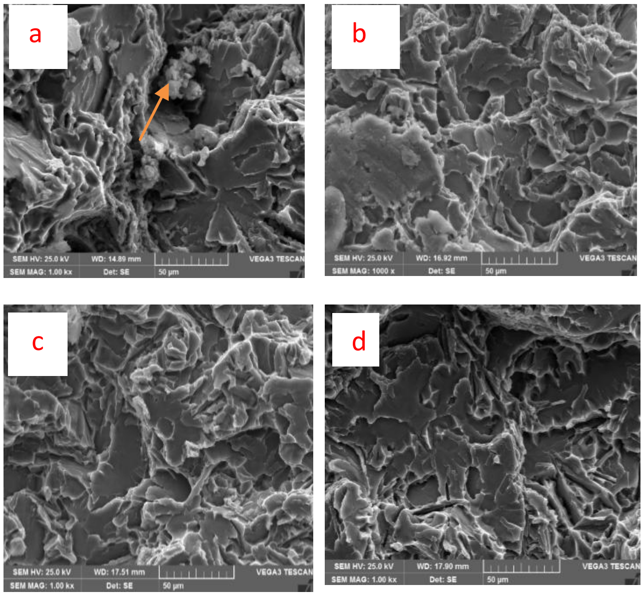


Fig. 6a-d SEM fractographs of Al-10Si alloy of tensile test (a) as cast condition (b) with Al-1Ti-3B grain refiner (c) with Al-10Sr modifier (d) with combined addition of grain refiner and moodier (Al-1Ti-3B + Al-10Sr) Al-10Si with combined addition ofAl-1Ti-3B + Al-10Sr

VII. CONCLUSION

1. Improvement in mechanical properties such as tensile strength, percentage elongation and Hardness were observed in grain refined and modified Al-10Si alloys when compared to as cast conditions
2. Improvements in impact strength and fracture toughness were observed in Al-10Si alloys 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-10Si alloys 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-10Si alloy.

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