

# Effects of Mn addition on microstructure and hardness of Al-12.6Si alloy

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**Abstract.** In this work, eutectic Al-12.6Si alloy with and without manganese (Mn) have been developed through gravity casting route. The effect of Mn concentration (0.0 wt.%, 1 wt%, 2 wt% and 3 wt%) on microstructural morphology and hardness property of the alloy has been investigated. The eutectic Al-12.6 Si alloy exhibits the presence of combine plate, needle and rod-like eutectic silicon phase with very sharp corners and coarser primary silicon particles within the  $\alpha$ -Al phase. In addition of 1wt.% of Mn in the eutectic Al-12.6Si alloy, sharp corners of the primary Si and needle-like eutectic Si are became blunt and particles size is reduced. Further, increase in Mn concentration (2.0 wt.%) in the Al-12.6Si alloy, irregular plate shape  $Al_6(Mn,Fe)$  intermetallics are formed inside the  $\alpha$ -Al phase, but the primary and eutectic phase morphology is similar to the eutectic Al-12.6Si alloy. The volume fraction of  $Al_6(Mn,Fe)$  increases and  $Al_6(Mn,Fe)$  particles appear as like chain structure in the alloy with 3 wt.% Mn. An increase in Mn concentration in the Al-12.6Si alloys result in the increase in bulk hardness of the alloy as an effects of microstructure modification as well as the presence of harder  $Al_6(Mn,Fe)$  phase in the developed alloy.

## 1. Introduction

Al-Si alloys are extensively used in various engineering industries such as aerospace, automobile, structural and packaging and industries for their excellent properties like high wear and seizure resistance, improved specific strength and stiffness, low thermal expansion coefficient, improved damping capacity and low weight to strength ratio [1-2]. However, the Al-Si alloys mechanical properties are not adequate due to presence of coarse needle shape and irregular eutectic and primary silicon particles [3] and those sharp corners of Si particles will act as a suitable crack initiation sites during loading [4]. Therefore, modification of Al-Si alloy is essential to enhance the mechanical properties. Several elements such as Na [5], Ba [6], Ca [6], Y [6], Yb [6-7], Eu [7], Sb [8] and Sr [8-9] are generally used to modify the Al-Si alloy. Manganese can be used to modify the Al-Si alloy. The Mn has significant effect to improve the mechanical properties of cast Al and Al-Si alloys without harming the chemical resistance [10-11]. It has role to adjust the iron containing phase in aluminium based alloy [12].

However, limited number of investigations on the effect of Mn addition have been carried out on microstructures modification and mechanical properties enhancement of Al-Si based alloys. A narrow range of Mn concentration in Al-Si alloy has been studied. In this investigation, Al-12.6Si alloy with and without Mn addition has been developed through gravity casting process. The effect of Mn concentration (0.0 wt.%, 1 wt.%, 2 wt.% and 3 wt.%) on microstructure and hardness property of eutectic Al-12.6 alloy has been investigated. Further, a correlation between microstructure morphology and hardness has been established.



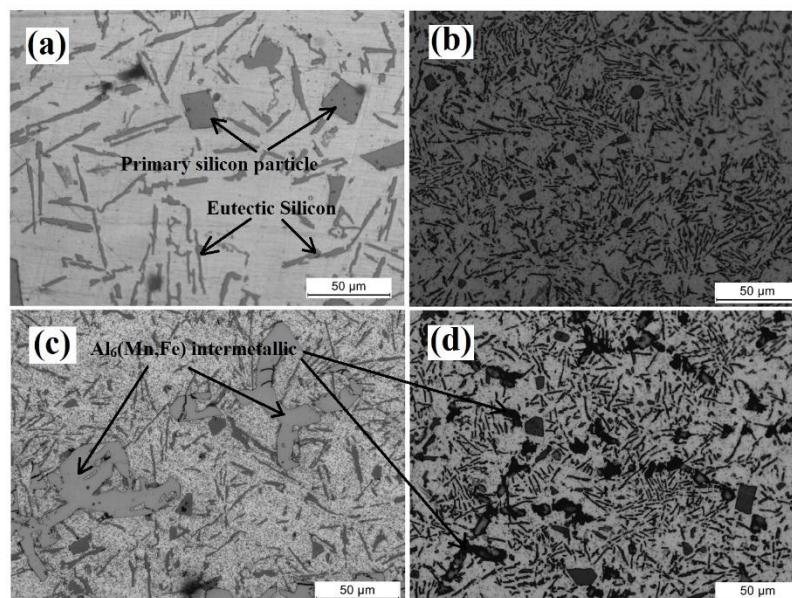
## 2. Experimental procedure

The eutectic Al-12.6Si alloy with (1wt.%, 2wt. % and 3 wt.%) and without Mn addition has been developed through gravity casting process. Commercially pure Al (99.7%), Si (99.8%) and Al-80Mn master alloy were used as starting materials. Initially, small blocks of commercially pure Al were melted at 760°C in a clay graphite crucible of 3kg capacity in an electrical resistance furnace. Then, the pure Si granules were added to the molten Al and hold for 45 to 60 minute for complete dissolution of Si. After that, aluminium foil wrapped small species of Al-80Mn master alloy were added in the melt as per requirement and again hold for 5-10 minute. Afterward, degassing was performed using 0.1 wt.% hexachloroethane and immediately slag was removed and the molten metal was poured into a preheated (160°C for 1hrs) permanent cast iron mould. The metallographic and hardness test samples were collected from the middle portion of the cast billets. All the samples were prepared with standard procedure for aluminium specimen preparation and Keller's reagent (1% HF, 1.5% HCl, 2.5% HNO<sub>3</sub> and distilled water) was used to etch the metallography sample after polishing. The optical microscope (Leica DM 2500M) and scanning electron microscope (JEOL, JSM-5800) equipped with energy dispersive X-ray spectroscopy (EDS) detector (Oxford INCA EDS) were used for metallography and phase identification. The bulk hardness and micro hardness test were carried out using a Vickers hardness testing machine (BV 250 (S)) and a micro-hardness testing machine (MMT-X7B). The different phases present in the modified and unmodified Al-Si alloys were identified by X-ray diffraction (XRD) analysis. The microstructural features such as volume percentage (serologically equated with area percentage) and the Si particle size were measured using the ImageJ image analysis software.

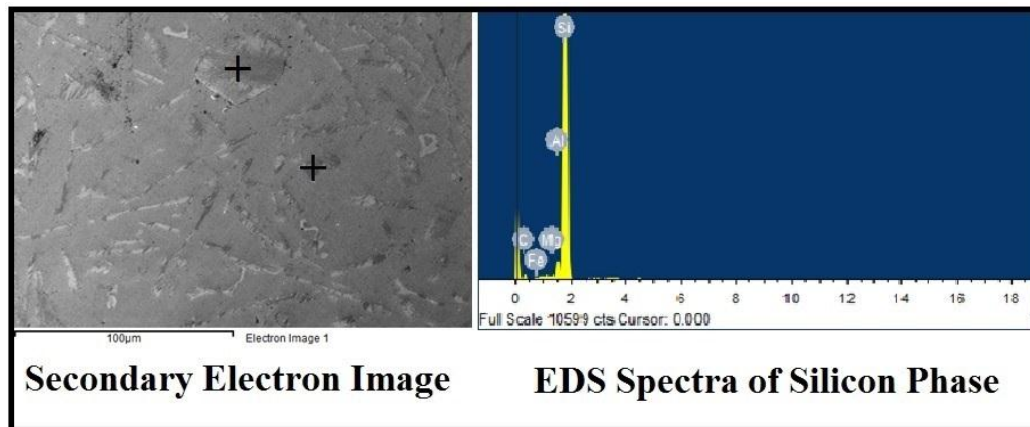
## 3. Results and Discussion

### 3.1 Microstructural Evaluation

The optical microstructure (Fig. 1(a)) of the unmodified Al-12.6Si alloy exhibits the presence of plate, needle and rod like grey colour irregular small eutectic particles with very sharp corners and coarser grey colour primary particles within the  $\alpha$ -Al grains. Further, the EDS spot analysis (Fig. 2) on the grey color particles, identify the particles as primary silicon particles and eutectic Si particles.

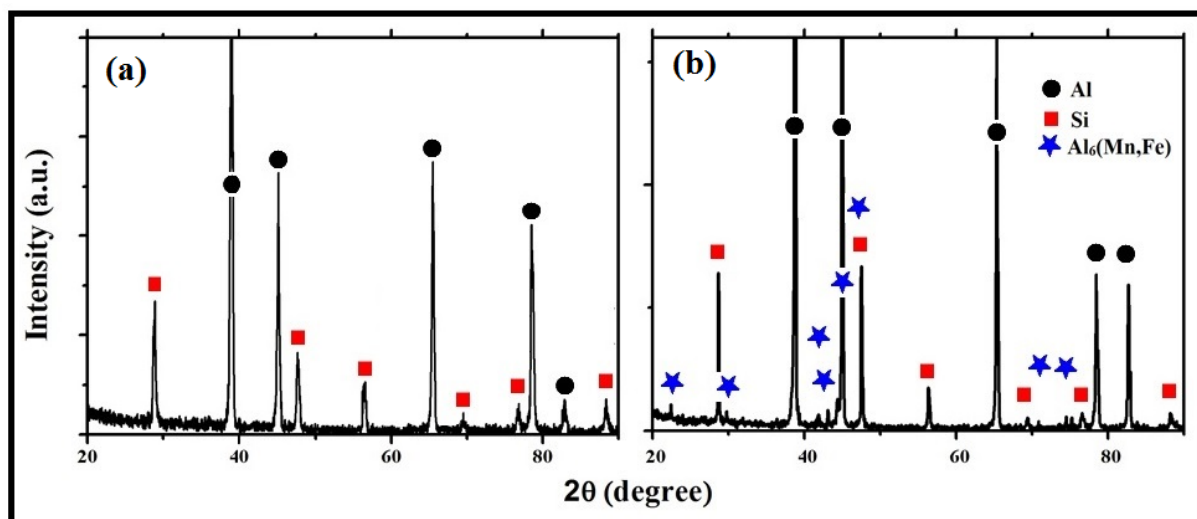


**Figure 1.** Optical microstructures of the gravity cast (a) Al-12.6Si-0 wt.% Mn (b) Al-12.6Si-1.0 wt.% Mn (c) Al-12.6Si-2.0 wt.% Mn and (d) Al-12.6Si-3.0 wt.% Mn alloy.



**Figure 2.** Identification of primary Si particles by SEM based EDS spot analysis in Al-12.6Si-0.0Mn alloy.

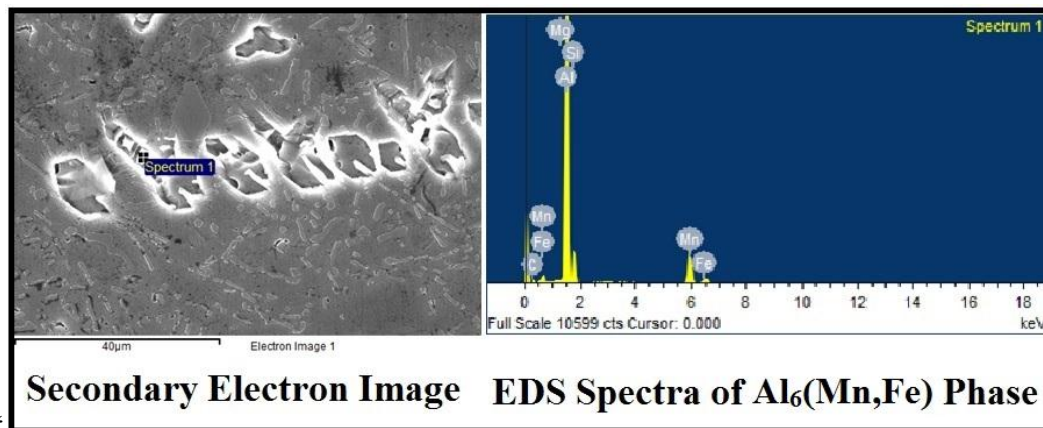
Manganese addition in Al-12.6Si alloy effectively modify the primary Si particles as well as eutectic Si morphology and distribution. In addition of 1wt.% of Mn in Al-12.6Si alloy, sharp corners of the primary Si particles and needle like morphology of eutectic Si become blunt and the primary Si particles as well as eutectic Si particles become finer (Fig. 1(b)). It is also clear from Fig. 1(b) that the eutectic phase volume fraction is increased and the distribution of both the silicon phases becomes uniform and primary silicon particles become compact with addition of 1 wt.% Mn with respect to unmodified alloy. The roundness/sphericity of the primary silicon particles is also increased. It is interesting to report that with the addition of 2.0 wt. % of Mn in the base alloy some irregular intermetallic is formed, but the eutectic silicon phase morphology is like the base Al-12.6Si alloy and the thickness of the eutectic Si phase is found to be reduced (Fig. 1(c)). The primary silicon size is decreased but the sharp corner of the primary silicon particles is remain unchanged. Further, the X-ray diffractogram of the Al-12.6Si and Al-12.6Si-2Mn alloy (Fig. 3) exhibits the presence of Si phase and  $\text{Al}_6(\text{Mn,Fe})$  intermetallic phase apart from the  $\alpha$ -Al and Si phase and those irregular intermetallics are  $\text{Al}_6(\text{Mn,Fe})$  (Fig. 1(c) and (d)).



**Figure 3.** XRD patterns of the (a) Al-12.6Si and (b) Al-12.6Si-2 wt.% Mn alloy.

It is also clear from Fig. 1(c) that the volume fraction of eutectic silicon is decreased. It is notable that when intermetallic of Al and Mn formed in the alloy, there is not sufficient amount of Mn present to

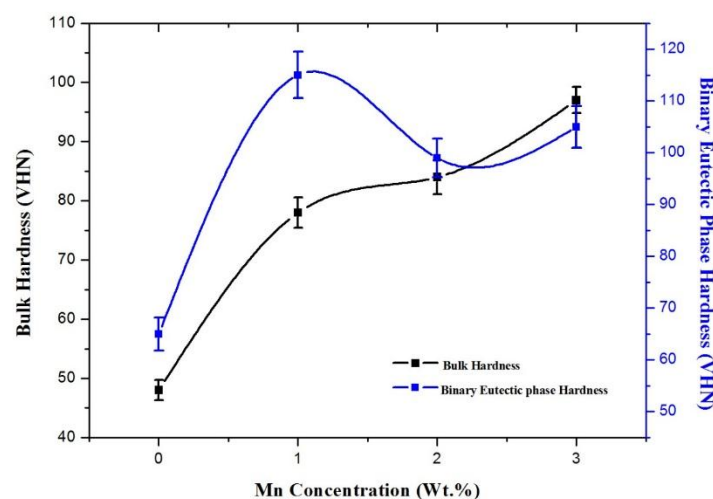
modify the eutectic and primary silicon morphology. Further increase in Mn concentration (3 wt.%) in the alloy increases the volume fraction of  $\text{Al}_6(\text{Mn,Fe})$  intermetallics and  $\text{Al}_6(\text{Mn,Fe})$  intermetallics appear as like a chain, but the shape is changed into compact and small size quadrilateral shape particles (Fig. 1(d)). Further, the EDS spot analysis of this quadrilateral shape phase (Fig. 4) again confirm that those are the  $\text{Al}_6(\text{Mn,Fe})$  intermetallics and it also verify that the Fe is present in the intermetallics ( $\text{Al}_6(\text{Mn,Fe})$ ) as a supplementary of Mn atom.



**Figure 4.** Identification of  $\text{Al}_6(\text{Mn,Fe})$  intermetallic particle by SEM based EDS spot analysis in the Al-12.6Si-3.0 wt.% Mn alloy.

### 3.2 Hardness

The alloying elements and reinforcing phase concentration as well as morphology and volume fraction of phases present in an alloy have strong impact on the bulk hardness of the Al based alloy and composites [13]. Figure 5 shows the bulk hardness of the Al-12.6 Si alloy as a function of Mn concentration. It is found that the hardness is significantly increased with increase in Mn concentration in the alloy.

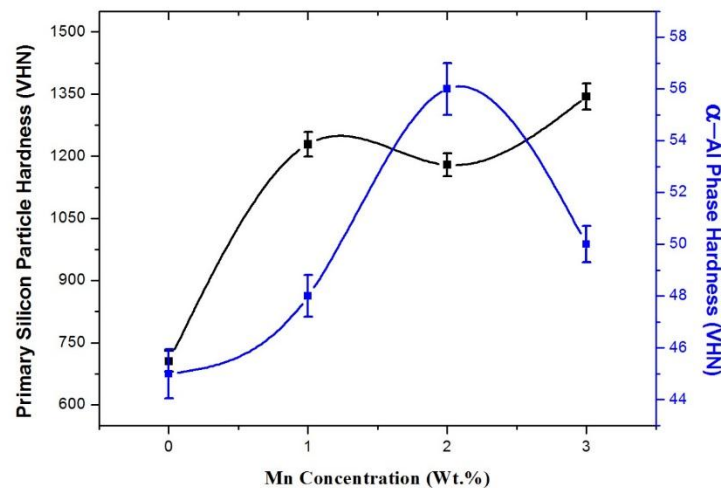


**Figure 5.** Graphical representation of change in the bulk hardness and the binary eutectic phase hardness with increasing Mn concentration.



The hardness of the unmodified alloy is  $48 \pm 1.7$  VHN, but 1 wt.% Mn modified alloy hardness ( $78 \pm 2.6$  VHN) is much higher than the base alloy due to combine modification of primary and eutectic Si particles and uniform distribution of both the phases as well as reduction in sharp corners and increase in compactness of the primary Si particles. Fine and compact primary Si particles without sharp corners are more efficient to protect the plastic deformation during hardness test as the stress concentrated points are reduced due to modification effects of Mn. Furthermore, when the Mn concentration again increased to 2 wt.% and 3 wt.%, again hardness of the alloy increased to  $84 \pm 2.9$  and  $97 \pm 2.2$  respectively because of the presence of harder  $\text{Al}_6(\text{Mn,Fe})$  intermetallics phase. As the Mn concentration increased, the volume fraction of the  $\text{Al}_6(\text{Mn,Fe})$  intermetallics phase increase because of this the alloy with 3 wt.% of Mn has high hardness than the alloy with 2 wt.% of Mn.

The micro hardness of constituent phases is shown in Fig. 5 and Fig.6. It is found that that the micro hardness of Al-Si binary eutectic phase is high in Mn modified alloy. In addition of 1 wt.% of Mn, the Al-Si binary eutectic phase hardness is increased significantly as the eutectic Si become uniform and finer with a higher volume fraction.



**Figure 6.** Graphical representation of change in the primary Al phase hardness and primary Si particles hardness with increasing Mn concentration.

But, 2 wt.% and 3 wt.% Mn modified alloy binary eutectic phase hardness is lower than the 1 wt. % Mn modified alloy because the eutectic phase is not modified significantly and the eutectic Si phase volume fraction is less. The micro hardness of the primary Si particles is increased in modified alloy, because the compactness and roundness are higher in the modified alloy. The  $\alpha$ -Al phase hardness is not significantly changed after Mn addition.

#### 4.0 Conclusion

The microstructure and hardness properties of gravity cast Al-12.6Si alloy with and without Mn addition have been studied and some conclusions are summarised:

- ❖ The Al-12.6Si alloy has coarse irregular primary and eutectic Si particles with very sharp corners.
- ❖ The Mn addition in the alloy effectively modifies the morphology of primary and eutectic Si phase.
- ❖ Addition of Mn on and above 2 wt.% result in formation of  $\text{Al}_6(\text{Mn,Fe})$  intermetallic phase.

- ❖ Increase in Mn concentration in the alloy, the volume fraction of  $Al_6(Mn,Fe)$  intermetallic phase is increased.
- ❖ The bulk hardness and micro harnesses of the alloy increased after Mn addition.

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