SEMI-SOLID HEAT TREATMENT OF HYPEREUTECTIC Al-18% Si ALLOY CONTAINING IRON-RICH INTERMETALLICS

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Abstract

In this research the effect of semi-solid heat treatment on matrix structure and iron-rich intermetallics of hyper-eutectic Al-18% Si containing 0.95%Fe is studied. Semi-solid heat treatment at heating temperature of 585 °C shows a significant refinement of iron-rich intermetallic phase. In as cast samples ,needle-like iron-rich intermetallics phases was observed, otherwise, plate-like and fine plate-like iron-rich intermetallics phases was observed for all samples heat treated in semi-solid state. Hardness values for semi-solid heat treated Al-18% Si Alloy for all heating time range (10-40 min) are relatively higher compared with the as cast one. Hardness value of 72.5 HRB is achieved by heating Al-18% Si alloy at heating temperature of 585 °C for 20 min. At the early stages of heating time (up to 20 min), a significant decreases of weight loss is observed in Al-18% Si alloy when semi-solid isothermal heat treatment was applied at 585 ° C heating temperature. However, semi-solid isothermal heat treatment performed above heating time of 25 min might result in increases of weight. The optimum semi-solid heating treatment condition was achieved at the temperature of 565 °C for the range of 15 to 25 mins.

Keywords: *Al-18% Si, Intermetallics, Heat treatment, Microstructure, Semi-solid.*

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1. INTRODUCTION

It is well established that hypereutectic Al–Si cast alloys have the good potential for tribological applications. Silicon as a hard material increases the wear resistance of Al–Si hypereutectic alloys. The presence of Fe and its compounds can be a problem in hypereutectic Al–Si alloys. Iron as an impurity in Al–Si alloys or as necessaryelement in the die-cast process can leave some serious detrimental effects on the mechanical properties of the casting parts. This is due mainly to the precipitation of brittle β-Al5FeSi intermetallics that appear as needles or plate-like morphologies in the microstructure. However,in Al–Si piston alloys, iron is a desirable element that helps to enhance high temperature properties and thermal stability of the alloy. Attempts have to be made to modify the negative effects of iron intermetallics, e.g., by refining their size and by modifying them to the lessdeleterious morphologies [1].

Hypereutectic Al–Si alloys such as A390 (Al–17% Si–4.5% Cu–0.5% Mg) are used in applications that require high resistance to wear and corrosion, good mechanical properties, low thermal expansion and reduced density. These properties are of particular interest to the automobile industry for the production of fuel-efficient vehicles using light-weight components produced from these alloys such as connecting rods, pistons, air conditioner compressors, cylinder liners and engine blocks [2]. 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 [3].

Taghiabadi et al. [4] have shown that addition of about 0.7 wt.% Fe increased the hardness and improved the wear resistance of the F332 Al–Si alloy. Addition of iron up to 2.5 wt.% increased the hardness, but decreased the wear resistance.

This investigation has been focused on the effect semi-solid heat treatment on iron-rich intermetallics and to study their effects on hardness and wear loss of hypereutectic Al–Si piston alloy containing 0.95% Fe.

2. EXPERIMENTAL

The alloy was melted in 30 kg capacity medium frequency induction furnace. The chemical composition of alloy samples is shown in **Table 1**. After flux treated, the melt was held at 750 °C for 5 min and then poured into a permanent mould whose size of mould cavity is ø50 mm×200mm.

The differential scanning calorimetric analysis (DSC) for the studied Al-Si alloy was conducted showing that solidus temperature of 575.5 °C, as shown in **Fig.1**. Specimens of approximate dimensions 15x15x15 mm were cut for isothermal heat treatment as well as microstructure examination and hardness measurements. All specimens were heated to 585 ^{0}C hold for 10, 20, 30 and 40 mins, respectively in an electrically heated resistance furnace with heating rate of 10 °C.min^{-1}. After the semi-solid heat treatment, the samples were taken out immediately for air cooling.

Table 1 Chemical analysis of Al-Si samples, wt.-%

Si	17.95	Mn	0.02
Cu	4.20	Sn	0.07
Mg	0.55	Ti	0.06
Fe	0.95	V	0.03
S	0.01	$T_L(^{0}C)^{a}$	690
Ni	0.33	$T_s(^{0}C)^{b}$	575.5

[a] Liquidus temperature , [b] Solidus temperature

Specimens in either as cast or heat treated condition were grinded, polished, etched with a solution consist of 0.5% HF and 99.5% H_2O and examined metallographically using an optical microscope and photomicrographs were taken.

Microstructure and iron-rich intermetallics were measured and analyzed with Scentis image analyzer software (with errors 5%). Rockwell hardness test were also performed using 1/16 inch diameter ball and 100 kg_f load. The wear tests were conducted on pin-on-disc machine. It consists of a hardened steel disc and a holder for specimen pin. The tests were conducted at content load of 0.4 bar and a sliding velocity on 150 rpm for constant time of 30 min.

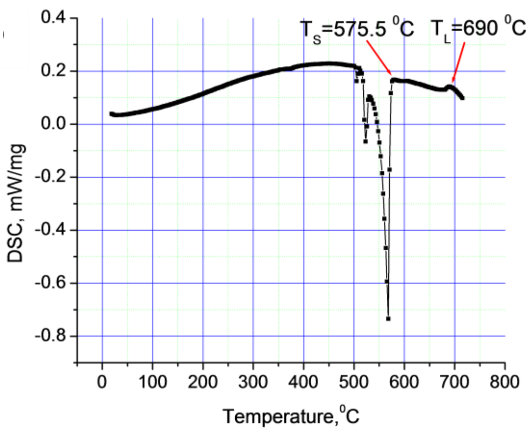


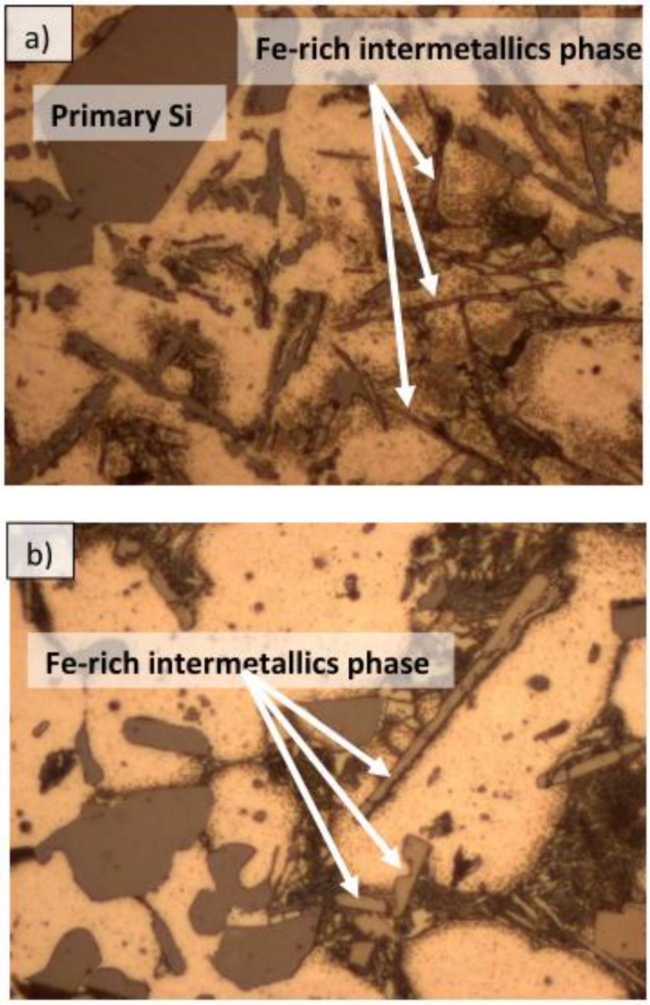
Fig.-1 DSC curve of hypereutectic al-18% Si alloy containing 0.95% Fe.

3. RESULTS AND DISCUSSION

Fig. 2 shows the microstructure of Al-18% Si alloy for as cast and semi-solid isothermal heated samples at 585 °C for range of 10 to 40 min. The microstructure of as cast sample(see **Fig.2** and **Table 2**) is characterized by needle-like iron-rich intermetallics phses, otherwise, plate-like and fine plate-like iron-rich intermetallics phases was observed for all samples heat treated in semi-solid state at 585 ^{0}C for range of 10-30 heating time. Pervious study [5] reported that the microstructure of semi-solid isothermal heat treated Al-18% Si alloy is characterized by a relatively fine primary Si particles in a matrix of □-Al, eutectic Si and some intermetallic particles compared with as-cast one, moreover, At the early stages of heating time (up to 25 min), A significant refinement of primary Si particle is observed in Al-18% Si alloy when semi-solid isothermal heat treatment was applied at 585° C heating temperature.

Table-2 Quantitative measurement of structural features of as cast Al-18% Si alloy.

α-Al grain size, μm	155
α -Al grain sphericity	0.35
Primary Si particle size, μm	70
Primary Si particle sphericity	0.50
Hardness, HRB	62



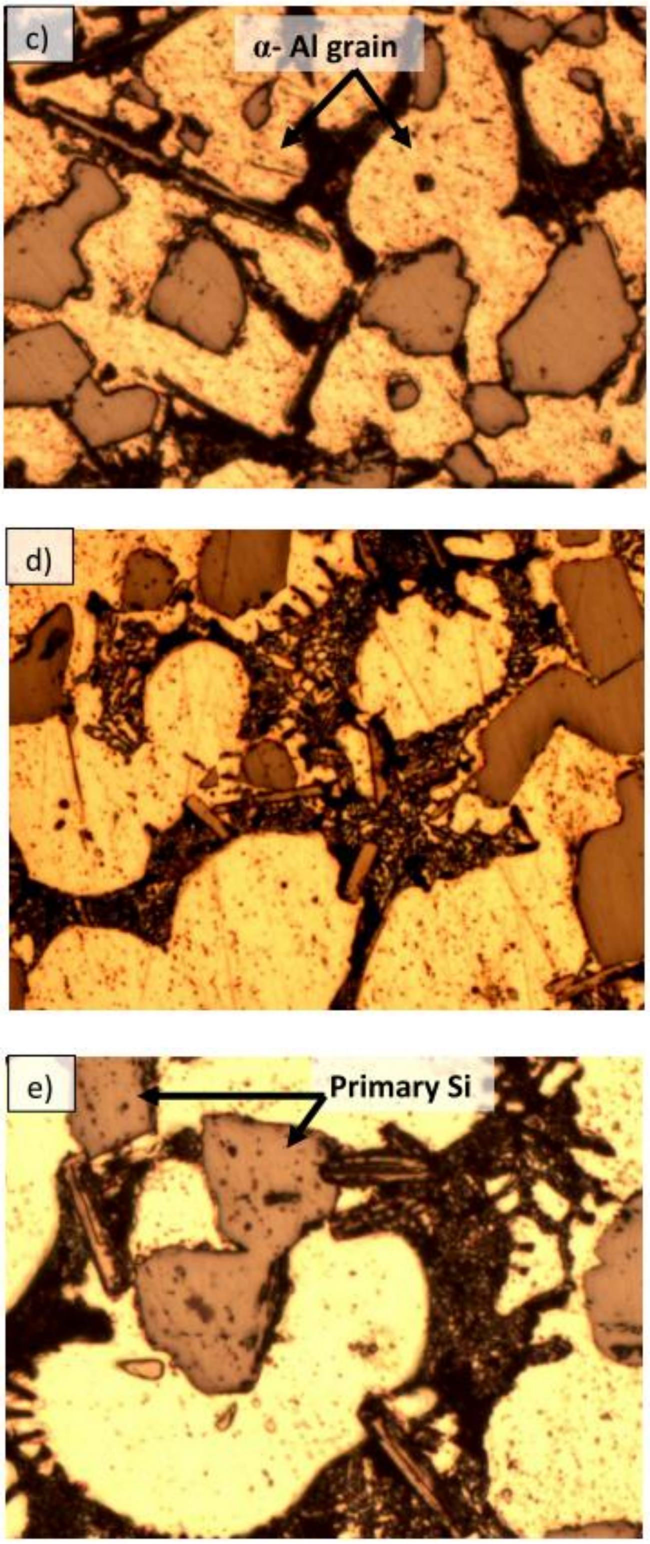


Fig.-2 Microstructure of Al- 18% Si alloy for as cast and isothermal heat treated at 585 ^{0}C; a) As cast b) heating time of 10 min; c) heating time of 20 min; d) heating time of 30 min; e) heating time of 40 min.

Fig.3 shows generally that hardness values for semi-solid heat treated Al-18% Si Alloy for all heating time range (10-40 min) are relatively higher compared with the as cast one. Hardness value of 72.5 HRB is achieved by heating Al-18% Si alloy at heating temperature of 585 ^{0}C for 25 min. Hardness value increases with heating time up to 20 min due to the grain refining of primary Si particle and α-Al grain, meanwhile, hardness value decreases with heating time above 25 min due to coalescence and particles agglomerations.

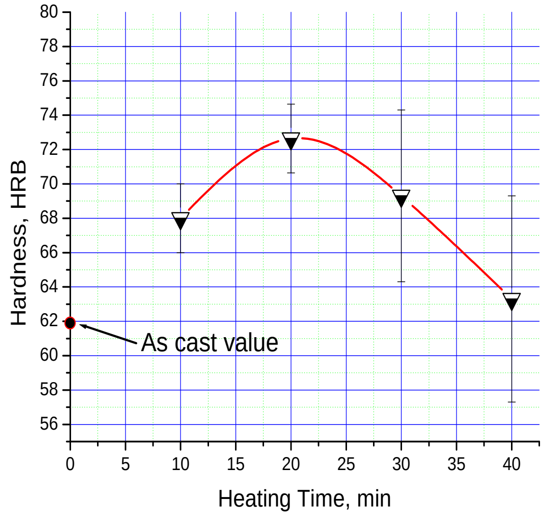


Fig.-3 Hardness of as cast and isothermal heat treated Al-18% Si alloy at 585 ^{0}C as a function of heating time.

The variation in weight loss of Al-18% Si alloy containing 0.95 % Fe measured as a function of semi-solid heating at 585^{0}C for 10 to 40 min heating time is presented in **Fig.4**. It is clear that at early stage of heating time (up to about 25 min.) the weight loss significantly decreases (wear resist increases) by increasing the heating time. Increasing the heating time above 25 min. shows increasing in weight loss (wear resist decreases).

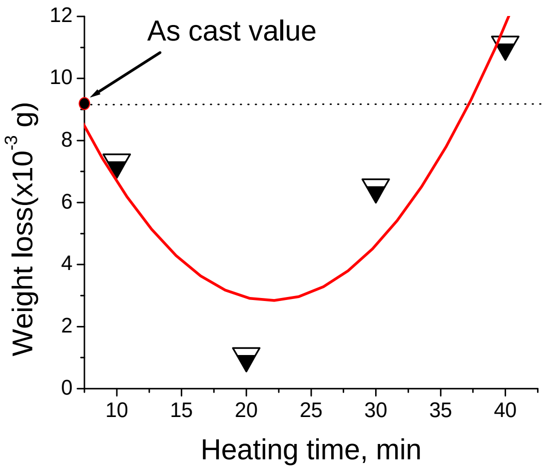


Fig. - 4 Weight loss as a function of heating time.

Pervious study [6] indicate that The isothermal holding at the temperature near the eutectic point enhances the separation of α (Al) and Si eutectic phases, and therefore, the Al in the solution can easily precipitate on the existing α (Al). After the fine holding time, low melting point phase melts which distributes in the recrystallization grain boundaries or within grain as a result of the holding temperature that is higher than the solidus. With increasing holding time, many small liquid droplets within grain combine and form several big liquid drops in order to reduce the interfacial energy. After full recrystallization and then increasing the holding time, Ostwald ripening and coalescence play an important role to make the average size of the solid particles increase. Ostwald ripening involves the growth of large particles at the expense of small particles, and it is governed by the Gibbs–Thompson effect which alters the chemical potential of solutes at the particle/liquid interface, depending on the curvature of the interface [**7**].

The reduction of interfacial energy between the solid phase and liquid phase provides the driving force for grain coarsening. Note that there are still a small number of irregular-shaped grains, which probably result from the coalescence of two spheroidal grains. Moreover, these irregular-shaped grains possibly originating from the extruded grains have not yet been completely broken up. When the holding time is long enough, which makes the solid volume fraction lower down, the Ostwald ripening mechanism also begins after the structural coarsening. The larger grain gradually becomes spheroidal to lower the solid/liquid interfacial energy. It is clear that the high semisolid It is clear that the high semisolid isothermal temperature reduces the volume fraction of solid and accelerates the spherical evolution of the solid particles, long isothermal time makes the semisolid particles more globular, but the size of the particles would grow larger [6].

It is clear that by increasing the heating time at semi-solid temperature the amount of liquid will increases. The separation of α-Al phase leads to segregation of iron-rich intermetallic phase to the liquid grain boundary that change its morphology make it fineer and wider(plate-like), as shown in **Fig.2**. Increasing of hardness by heating time up to 25 min (**see Fig. 3**) could be due to improve matrix structure and primary Si as well as the iron-rich intermetallic phase morphology. However, semi-solid isothermal heat treatment performed above heating time of 25 min might result in coarsening and agglomeration of primary Si.

Current and previous study [1] in a good agreement that the reduction in wear resistance of as-cast alloy compared to the semi-solid heat treated one, as shown in **Fig. 4**, can be explained based on the microstructural features of the alloys. **Fig. 2** shows that addition semi-solid heat treatment of Al-18% Si alloy containing Fe led to change of the precipitation β-phase intermetallic in the matrix. β-Al5FeSi from needle-like(as- cast samples) to fine plate-like(heat treated samples).

3. CONCLUSIONS

The effect of the semi-solid heat treatment on microstructure hardness and wear resist of hyper-eutectic Al-18% Si alloy iron-rich intermetallics phses was investigated, which led to the following conclusions:

1. In as cast samples ,needle-like iron-rich intermetallics phases was observed, otherwise, plate-like and fine plate-like iron-rich intermetallics phases was observed for all samples heat treated in semi-solid state.

2.Hardness values for semi-solid heat treated Al-18% Si Alloy for all heating time range (10-40 min) are relatively higher compared with the as cast one. Hardness value of 72.5 HRB is achieved by heating Al-18% Si alloy at heating temperature of 585 °C for 20 min.

3. At the early stages of heating time (up to 25 min), a significant decreases of weight loss is observed in Al-18% Si alloy when semi-solid isothermal heat treatment was applied at 585° C heating temperature. However, semi-solid isothermal heat treatment performed above heating time of 25 min might result in increases of weight.

4. The optimum semi-solid heating treatment condition was achieved at the temperature of 565 ◦C for the range of 15 to 25 mins.

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