A study on the effect of semi solid heat treatment of a cast Al-Sn alloy on its microstructure and wear behaviour

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Abstract: A typical bearing alloy Al-1Sn has been subjected to isothermal holding in the semi-solid temperature range (400oC for 2 hours) instead of conventional solid state heat treatment. A detailed TEM study was carried to find out the root of micro-structural modification as a result of semi solid heat treatment (SSHT) of the alloy. Dry sliding wear testing of the alloy was performed under three different micro-structural conditions namely as cast, conventional solid state heat treated and semi-solid heat treated. It was observed that solid state heat treated sample performed better in the wear testing than semi solid heat treated one, though the cast structure modification was better after semi solid heat treatment than after conventional solid state heat treatment (CHT).
Key words: Al-Sn alloy, semi-solid heat treatment, micro-structural modification, dry sliding wear testing.

I. INTRODUCTION:

For years, aluminium alloys have been used for crankshaft main and big end bearings. Research works [1,2] have been carried over years to make the alloys suitable for above mentioned purposes. In the present study an attempt has been made to observe the wear behaviour of Al-1Sn subjected to SSHT [3,4]. Comparative study has been made with the wear behaviour of the investigating alloy in as cast, conventional solid state heat treated and semi-solid heat treated condition. A detailed TEM study has been carried out to find out the root of microstructural modification following SSHT and to compare the observation with the reported findings by the author related to Cu-Sn alloy [5].

II. EXPERIMENTAL APPARATUS:

2.1. Alloy preparation:
Vacuum induction furnace. Liquid metal poured in graphite moulds.

2.1.1 Chemical Composition
Optical Emission Spectrometer

Al (wt%)	Si (wt%)	Sn (wt%)
balance	0.38	0.97

With some trace elements.

2.2. Heat treatment
Muffle furnace (in ambient atmosphere) along with temperature controller (accuracy+ 2oC).

2.3. Optical microscopy
Leica image analyser (Model: DM 2500M, Leica Microsystems, Wetzlar, Germany).

2.4. Transmission Electron Microscopy
JEOM – JEM 2200FS, Japan.

2.5. Pin-on-disc Wear Testing
Monitor – TR – 20LE, DUCOM, Bangalore, Indian.

III. RESULTS:

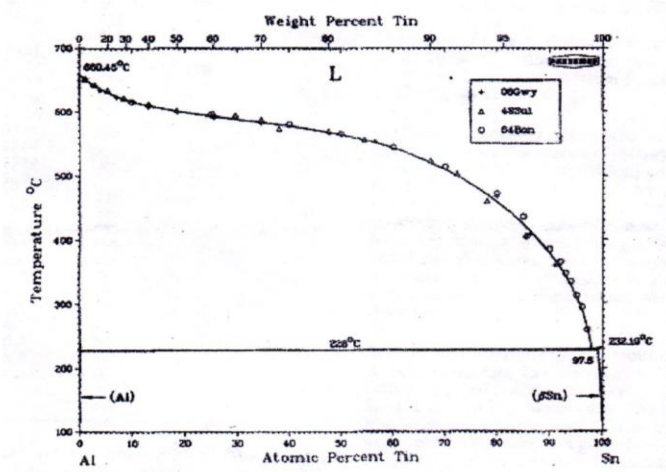
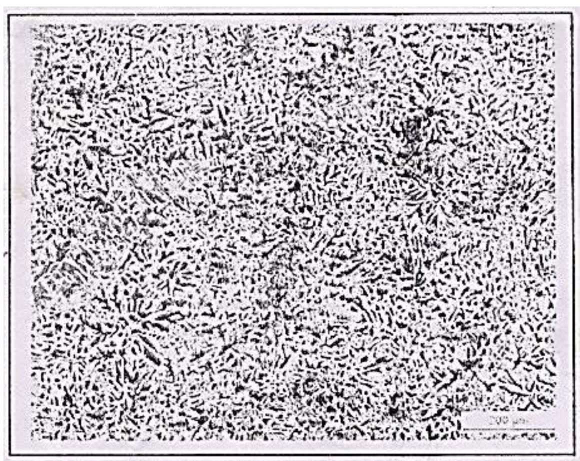
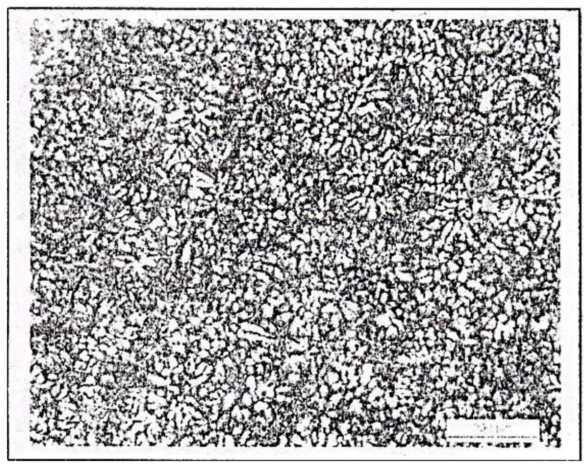


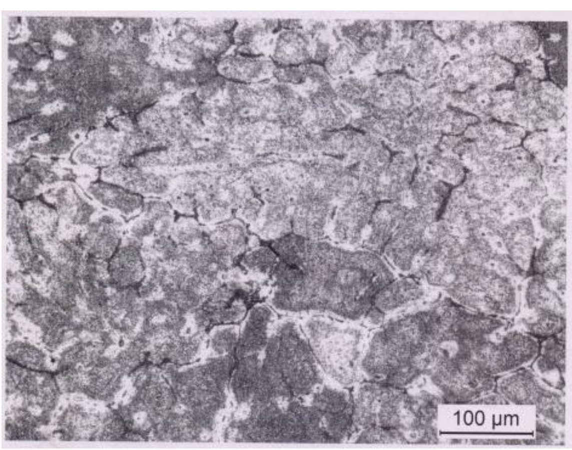
Figure 1. Al-Sn phase diagram (courtsey Bull. of Alloy Phase Diagrams 1983)



(a)



(b)



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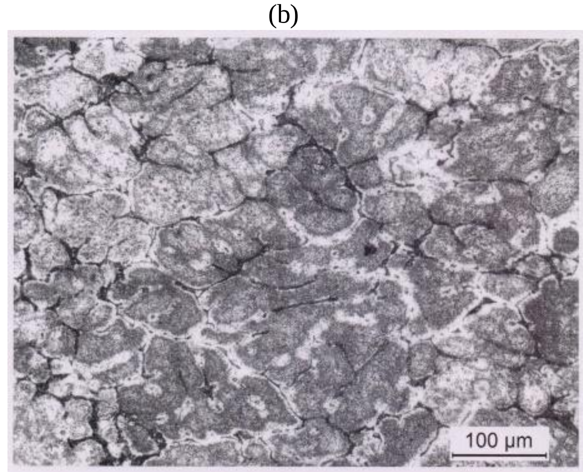
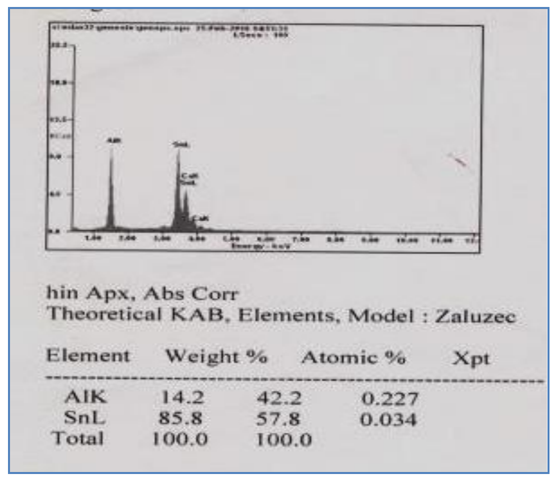


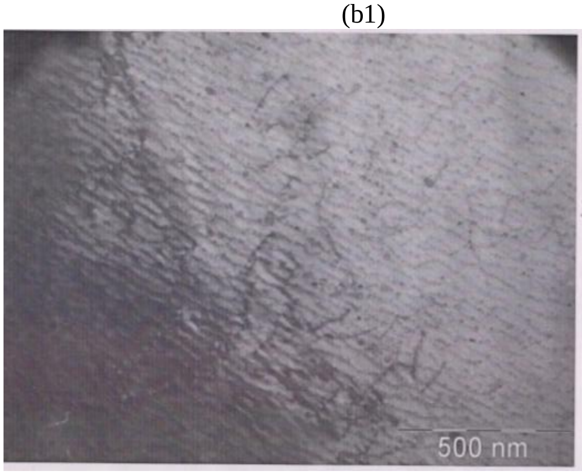
(d)

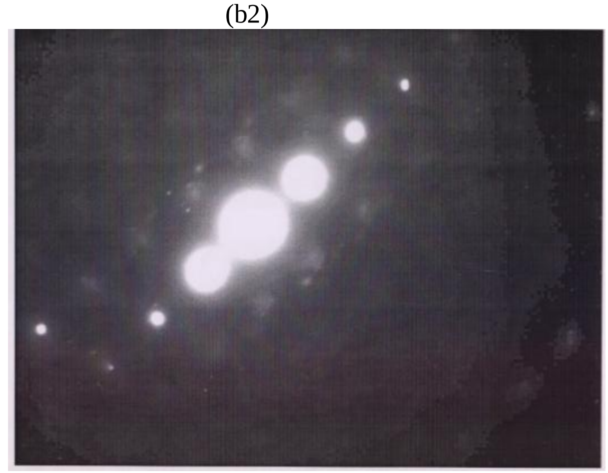
Figure 2. Optical Microscopy of investigating Al-1Sn alloy (a) as cast alloy showing typical dendritic structure (b) no noticible change of cast structure after SSHT (400oC for 2hours) (c) after CHT (200oC for 2hours) with prior cold forging shows fragmented dendrites and irregular shapped large grains (d) after SSHT (400oC for 2hours) with prior cold forging shows partially modified structure with a tendency to form spheroidized grains.

(a)



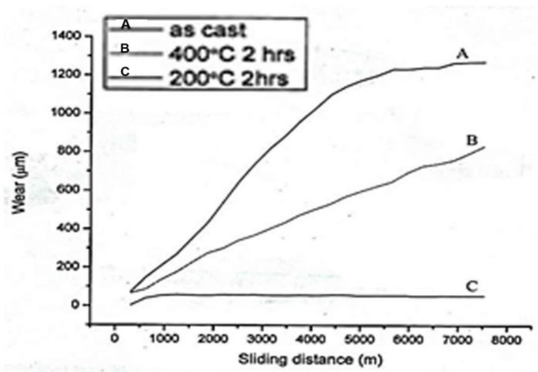
(b1) (b2)



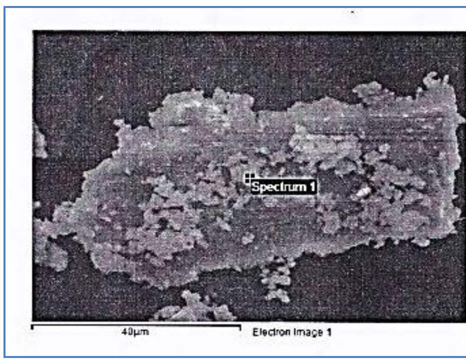


(c) (d)

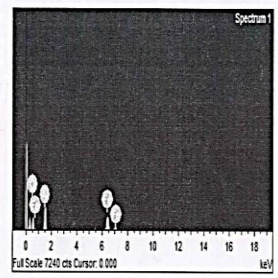
Figure 3. Transmission Electron Microscopy of SSHT sample (a) BF image reveals fine fragmented dendritic structure. Al-Sn near eutectic phase dispersed at dendrite boundaries in the form of fine particles (b1) BF image of the said particles (b2) corresponding EDS of the particle matrix (c) BF image indicates subgrains and dislocation (d) corresponding SADP.



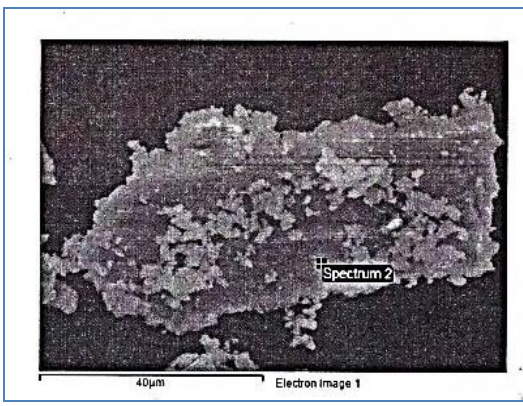
(b)



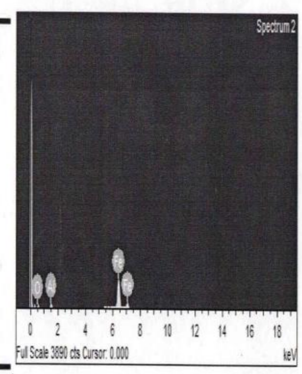
Element	Weight%	Atomic%
O K	24.65	45.85
Al K	23.82	26.27
Si K	0.94	1.00
Fe K	50.31	26.81
Sn L	0.28	0.07
Totals	100.00	



(c)



Element	Weight%	Atomic%
O K	5.29	15.37
Al K	6.25	10.77
Fe K	89.11	74.12
Sn L	-0.66	-0.26
Totals	100.00	



(d)

Figure 4. Wear testing of SSHT sample (a) Wear vs sliding distance plot for Al-1Sn samples at 49N load under different conditions. Scanning Electron Microscopy of SSHT sample for wear testing (b) Wear surface indicates a typical adhesive wear (c) and (d) EDS of wear debris at two different spots.

IV. DISCUSSION:

4.1 Optical Microscopy

The as cast alloy (Figure. 2a) shows a typical dendritic structure. At first, the as cast alloy was subjected to SSHT, but unlike Cu-Sn alloy as investigated by the author earlier [5], the micro-structural modification was not satisfactory (Figure 2b). The proper clarification of this is beyond the scope of the present study. Then the investigating alloy was cold forged (10% reduction in thickness) prior to subsequent CHT and SSHT respectively. Difference in micro-structural modification is visible from Figure 2 (c and d). After CHT (200oC for 2hours) with prior cold forging shows fragmented dendrites and irregular shapped large grains and after SSHT (400oC for 2hours) with prior cold forging shows partially modified structure indicating a tendency to form spheroidized grains. It may be presumed that stored mechanical energy after cold forging along with enhanced thermal energy provided during SSHT might have brought about the near desired micro-structural modification (Figure 2d). The concept of fragmentation and spheroidization of dendrites by different semi solid processing has already been reported [6].

4.2 Transmission Electron Microscopy

A detailed TEM study was performed mainly of the SSHT sample to get an idea about the root of micro-structural modification and to compare the observations made by the author while studying the Cu-Sn alloy in the similar condition [5]. TEM study reveals (i) fine fragmented dendrites (ii) Al-Sn near eutectic phase dispersed at the dendrite boundary in the form of fine particles (iii) subgrain formation and dislocation. These findings are similar in nature to the earlier findings by the author related to Cu-Sn alloy [5]. So it is reasonable to assume that the probable high dislocation density in the as cast condition compared to SSHT condition (Figure 3c) is the result of residual stress related to graphite mould casting. Such residual stress along with stored mechanical energy as a result of prior cold working may act as a driving force for recrystallization during SSHT which may leads to almost fine and nearly spheroidized grains. As observed polygonized sub-grains (Figure 3c) presumably also act as pre-cursor for the same.

4.3 Wear Testing

Main features of wear testing as observed in the presnt study are (i) rapid wear (ii) rapid diffution of iron (Fe) during wear testing of SSHT sample (iii) wear resistance of the alloy has been reduced due to rapid Fe pick up for SSHT sample (iv) wear resistance is comparitably better for CHT sample.

Wear testing results justify the comments made by Prasad [7] that the is no direct correlation between mechanical property like tensile toughness and wear response of a material. The wear behaviour is better understood in terms of microstuctural features. In the present study though the alloy after SSHT supposed to exhibit better tensile toughness owing to its relatively fine spheroidised grains but it may not leads to better wear resistance of the same compared to the wear sample of the alloy subjected to CHT.

The wear surface and debris (Figure 4(a-d)) indicates a typical adhesive wear [8,9] followed by subsequent cracking and delamination [10]. As such delamination may be considered as primary wear mechanism for the investigating alloy. It is well established from the previous studies [7,10] that during dry sliding wear testing extensive plastic deformation , work hardening and oxidation of the specimen matrix occures. Fe pick up by the specimen surface results from plastic deformation and transfer between the contacting surfaces (steel disc – a typical of pin-on-disc wear test and Al-1Sn alloy subjected to SSHT; in the present study). It is to be noted that more matrix area has been exposed to steel disc due to better micro-structural modification of the alloy subjected to SSHT. The observations made in the present investigation conforming the established above mentioned concepts of wear mechanisms[7,9,10].

V. SUMMARY:

In an attempt to study the effect of SSHT of cast Al-1Sn alloy on its microstructure and wear behaviour, the present investigation may be summarized as follows:

Unlike Cu-Sn system [5], the stored mechanical energy after cold working along with enhanced thermal energy provided during SSHT might have brought about the near desired micro-structural modification of the investigating alloy as observed by optical microscopy of SSHT sample.

From thorough TEM examination of SSHT sample, it is reasonable to assume that probable high dislocation density in the as cast condition is the result of graphite mould casting. The associated residual stress along with mechanical energy stored as a result of prior cold working may act as a driving force for recrystallization during SSHT which may leads to almost fine and nearly spheroidized grains. As observed polygonized sub-grains presumably also act as pre-cursor for the same.

Wear resistance of the alloy in the semi-solid heat treated condition has been reduced compared to conventional solid state heat treated condition due to high Fe pickup during wear testing of SSHT sample.

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