International Journal Of

Recent Scientific Research

ISSN: 0976-3031

Volume: 7(3) March -2016

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THE OFFICIAL PUBLICATION OF
INTERNATIONAL JOURNAL OF RECENT SCIENTIFIC RESEARCH (IJRSR)
http://www.recentscientific.com/ recentscientific@gmail.com

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International Journal of Recent Scientific Research
Vol. 7, Issue, 3, pp. 9434-9438, March, 2016

International Journal of Recent Scientific Research

ISSN: 0976-3031

RESEARCH ARTICLE

EFFECT OF PHOSPHORUS ADDITION ON THE TRIBOLOGICAL WEAR BEHAVIOROF HYPEREUTECTIC AL-SI ALLOYS AT ELEVATED TEMPERATURES

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ARTICLE INFO

Article History:

Received 16th December, 2015
Received in revised form 24th January, 2016
Accepted 23rd February, 2016
Published online 28th March, 2016

Keywords:

Hyper-eutectic Al-Si alloys with addition of Phosphorus, casting, wear, SEM and EDS

ABSTRACT

Low density, low expansion and high resistance to corrosion at ambient temperature, high strength to weight ratio, high wear resistance and low coefficient of thermal expansion make the aluminium–silicon alloys very suitable for wear resistance components in the automotive industry. In this study, the dry sliding wear behaviour of Al–Si alloy have been investigated. The cylindrical shaped wear testing specimens were prepared from casting. The wear experiments were carried out on pin-on disc type wear testing machine. Various parameters such as alloy composition, normal pressure, sliding speed and sliding distance were studied on the hypereutectic Al–Si alloys at elevated temperatures. Tests are conducted for varying normal pressure from 0.20 N/mm2 to 0.98 N/mm2, for varying sliding velocity from 0.94m/s to 3.77 m/s and varying sliding distance from 282.74 m to 1696.46 m. The extent of wear damage was estimated by means of weight loss technique. Worn surfaces were examined and analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). The results suggest that the wear resistance increases as the temperature increases due to the oxide layer formation. The results also suggest that the wear resistance decreases as the silicon content increases. The addition of Phosphorus to Al-Si alloys increases the wear resistance at elevated temperatures.

INTRODUCTION

In automotive industry, wear is also a major problem. Aluminium–silicon alloys have properties like light weight, good strength-to-weight ratio, ease of fabrication at reasonable cost, high strength at elevated temperature, good thermal conductivity, excellent cast ability, excellent corrosion resistance and wear resistance.

In this present investigation, hyper eutectic aluminium alloys containing the 13% and 20% weight of Silicon, with and without the addition of Phosphorus were synthesized using casting method. Wear behaviour was studied by using modern computerized pin on disc wear testing machine. The effect of raising the pin temperature on wear characteristics of hyper eutectic Al-Si alloys with and without the addition of phosphorus is analyzed by SEM and EDS analysis method. Wear of hyper eutectic Al-Si alloys such as Al-13%Si, and Al-20%Si with and without the addition of Phosphorus were measured by using experimental method.

Aluminium-Silicon system is a simple binary eutectic with limited solubility of aluminium in silicon and limited solubility of silicon in aluminium. There is only one invariant reaction in this diagram, namely $L \rightarrow \alpha + \beta$ (eutectic)

In above equation, L is the liquid phase, α is predominantly aluminium and β is predominantly silicon. It is now widely accepted that the eutectic reaction takes place at 577°C and at a silicon level of 12.6%.Aluminium-Silicon (Al-Si) casting alloys are the most useful of all common foundry cast alloys in the fabrication of pistons for automotive engines. Depending on the Si concentration in weight percentage, the Al-Si alloy systems are divided into three major categories:

Hypoeutectic (<12 wt % Si)
Eutectic (12-13 wt % Si)
Hypereutectic (14-25 wt % Si)

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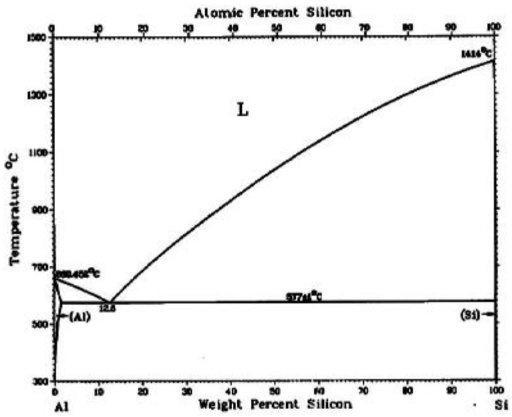


Fig.1 Phase Diagram

EXPERIMENTAL METHODOLOGY

Experimental details- Aluminium-silicon alloys were prepared with different weight percentage of silicon by a stir casting in an induction heating furnace. Samples of different dimensions were cut for different tests. With the help of optical emission spectrometer their composition was analyzed. Wear behaviour of different composition were studied by conducting several wear tests on computerized DUCOM wear and friction monitor TR-20LE-PHM-600 pin on-disc wear test machine.

Fig.2 Pin On Disc

Al-Si alloys are prepared via foundry technique. Calculated quantities of commercial purity aluminium (99.7Wt % purity) and Al-20 Wt % Si master alloy are melted in a resistance furnace under a cover flux (45% NaCl+45% KCl+10% NaF). The melt is held at 7200C±50C. After degassing the melt with solid hexachloro ethane (C2Cl6) the melt is poured into cylindrical graphite mould (25 mm diameter and 100 mm height) surrounded by fire clay brick with its top open for pouring (for preparing the specimen for macro and micro structural studies) and also the melt is poured into the graphite split mould (12.5 mm diameter and 125 mm height- for preparing the specimen for wear pins).

Similarly for preparing grain refined specimen, after degassing with hexachloroethane (C2Cl6), CuP (0.2%P) is added to the melt for grain refinement. The melt was stirred for 30 seconds with zircon coated iron rod after addition of grain refiner after which no further stirring was carried out. Melts were poured after holding for about 30 minutes into cylindrical graphite mould (25 mm diameter and 100 mm height) surrounded by fire clay brick with its top open for pouring and also the melt is poured into graphite split mould (12.5 mm diameter 125 mm height).

(a)

(b)

(c)

Fig.3 Preparation ofAl-Si Alloys.(a) Stir casting set up,(b) Graphite mould, (c) Specimens used for wear test

Wear pins of 30 mm length and 8 mm diameter were machined from the cast specimen obtained from graphite split mould (12.5 mm diameter and 125 mm length). Wear tests were conducted using pin on disc wear testing machine (TR-20LE-PHM-600, DUCOM, and PIN-ON-DISC MACHINE). The disc is made of low carbon alloy steel (EN-32 Steel, 160 mm diameter and 8 mm thickness) having hardness value of about 62RC. Losses of wear were recorded. Wear losses were measured with a linear variable differential transformer (LVDT) and it was monitored by the loss of length due to wear of the specimen of the fixed diameter. The wear loss was measured in microns (μm). Weight loss method is followed to get the more accurate results. In this method weight of the wear pin before and after conducting the wear test is recorded using an electronic weighing machine. Difference between the initial and final weight of the specimen gives the weight loss due to wear.

Three sets of wear testing experiments are conducted to study the Tribological wear behaviour of Al-13SiP, Al-20SiP alloys. Three sets of experiments are:

A. Normal pressure dependent experiments.
B. Sliding distance dependent experiments.
C. Sliding speed dependent experiments.

RESULTS AND DISCUSSION

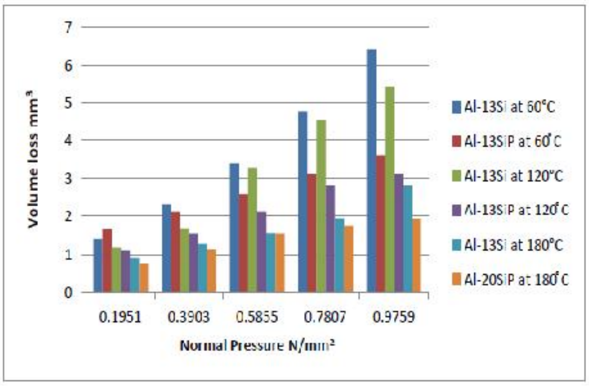
The wear tests of Al-Si alloys were carried out with varying applied load, sliding speed and sliding distance. The results are obtained from the series of tests which is done by keeping two parameters out of the three (sliding distance, sliding speed and load) constant against wear.

Wear behaviour is studied by using computerized pin on disc wear testing machine.

1. Normal pressure Vs volume loss.
2. Sliding distance Vs volume loss.
3. Sliding velocity Vs volume loss.

Effect of normal pressure

The volume loss Vs normal pressure (0.20, 0.39, 0.585, 0.780 and 0.98 N/mm2) of hyper eutectic Al-Si alloys with and without addition of phosphorus at elevated temperature of 60℃, 120℃ and 180℃ at constant sliding velocity of 1.88 m/sec for a constant sliding distance of 565.49 m. The graph is obtained for hyper eutectic Al-Si alloys such as Al-13%Si and Al-20%Si with and without addition of phosphorus. It is clear that, volume loss increases with increase in normal pressures at 60°C, 120°C and 180°C. This is due to the fact that increase in load increases the area of metal to metal contact between rubbing the surfaces. And also as the load is increased, the oxide film becomes sensitive to bulk failure leading to increasing volume loss. In hypereutectic Al-Si alloys, as silicon content increases the wear resistance decreases.



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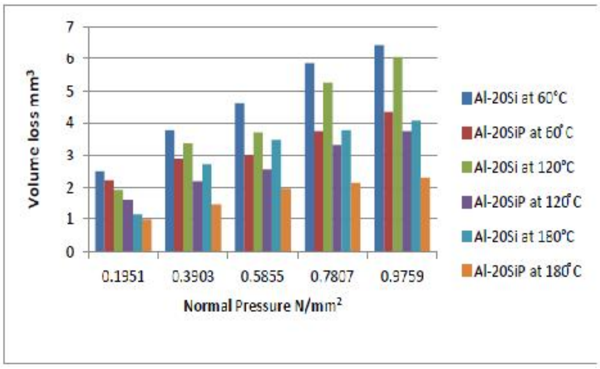
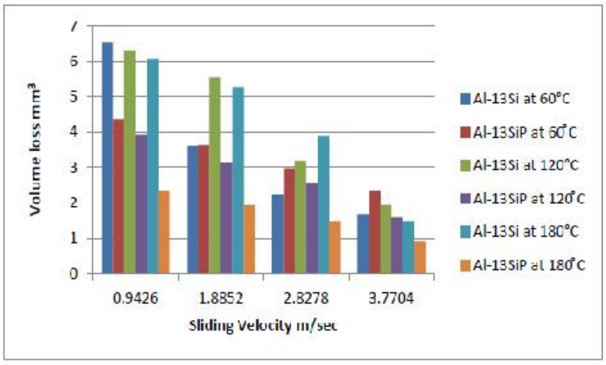


(b)

Fig.4. Comparison of Al-13, 20Si alloys with and without addition of Phosphorus at elevated temperatures of 60℃, 120℃ and 180℃.

Effect of sliding velocity

The sliding velocity is varied from 0.94 m/sec to 3.77 m/sec at constant normal pressure (0.975 N/mm2) and at constant sliding distance (565.486 m).As the sliding speed increases, there is increase in the interface temperature and this may lead to the formation of oxide layer at higher interface temperatures. This volume loss decrease may also be due to the fact that, at low sliding speeds, more time is available for formation and growth of micro welds, which increases the force required to shear off the micro welds to maintain the relative motion, due to which volume loss increases. However, at higher speeds, there is less residential time for the growth of micro welds leading to lesser volume loss which is obtained by using the density value 2.7 g/cm3. Volume loss decreases with increase in sliding velocity from 0.94 m/sec to 3.77 m/sec and the interface temperature increase with increase in the sliding speed. Volume loss with addition of phosphorous decreases as compared to as cast alloys for all elevated temperature tests.



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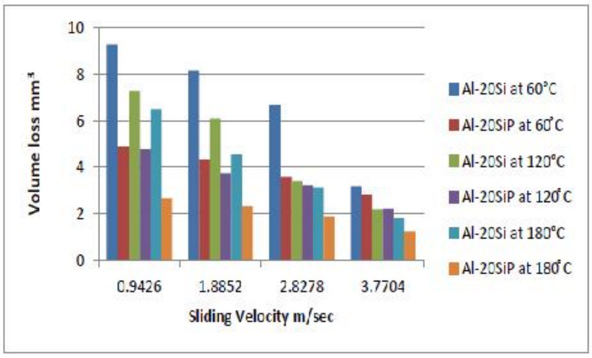
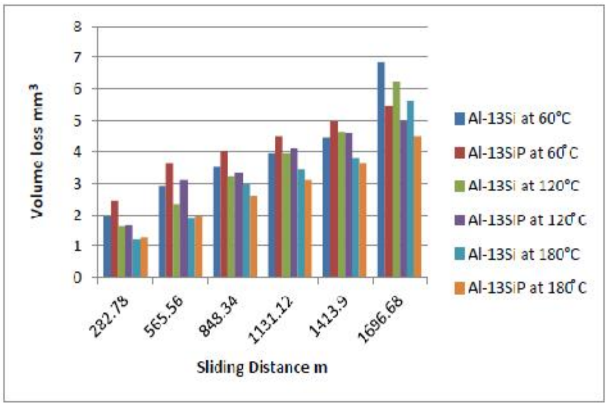


(b)

Fig.5 Comparison of Al-13, 20Si alloys with and without addition of Phosphurus at elevated temperatures of 60℃, 120℃ and 180℃

Effect of sliding distance

The volume loss Vs sliding distance of Al-Si alloys with and without the addition of Phosphorus at elevated temperatures of 60, 120 and 180 are shown in Fig.6. The graph is obtained for hyper eutectic Al-Si alloys such as Al-13%Si and Al-20%Si with the addition of Phosphorus. The sliding distance is varied from 282.743 m to 1696.462 mwith constant normal pressure (0.975 N/mm2) and at constant sliding speed (1.884 m/s). Generally it is known that, with an increase in sliding distance, the volume loss increases due to more intimate contact time of the specimen with the rotating disc. It is observed that volume loss increases with increase in sliding distance. Increase in the silicon content of material decreases the wear resistance. At 180°C the volume loss decreases ascompared to 60ºC and 120ºC and volume loss with addition of phosphorous decreases as compared to as cast alloys for all elevated temperature tests.



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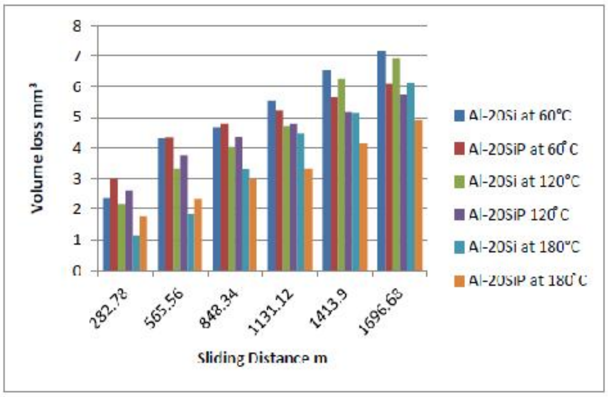

(b)

Fig.6. Comparison of Al-13, 20Si alloys with and without addition of Phosphorus at elevated temperatures of 60℃, 120℃ and 180℃

Topography And Microanalysis of Al-13,20si With And without The Addition of Phosphorous

Scanning electron microscopy of worn surfaces is carried out on Al-13Si, Al-20Si and Al-13SiP, Al-20SiP alloys. For SEM analysis, forty eight specimens and two different magnification (500X,2000X) of Al-13Si, Al-20Si and Al-13SiP, Al-20SiP alloys at 60°C,120°C and 180°C were chosen. The worn surfaces of the samples were examined under SEM to investigate the wear mechanism. The low magnification SEM micrographs show fine scoring marks.

The high magnification SEM micrographs show the evidence of extensive plastic flow and cracking. It is also possible that the hard dispersion particles or fractured pieces are mechanically dislodged during wear. In SEM, the worn surfaces were studied and observed that, under the Normal Pressure and Sliding Distance conditions severe wear caused. The topographical features do not change significantly with increasing silicon content from 13% to 20%. The distinct topographical features indicate that the surface is subjected more than one mode of material removal. As the temperature is increased we can see the increase in oxygen content and the formation of oxide layer due to which the wear is reduced. The EDS analysis indicates that, as the temperature is increased the oxygen content increases leading to the formation of oxide layer due to which the wear is reduced.

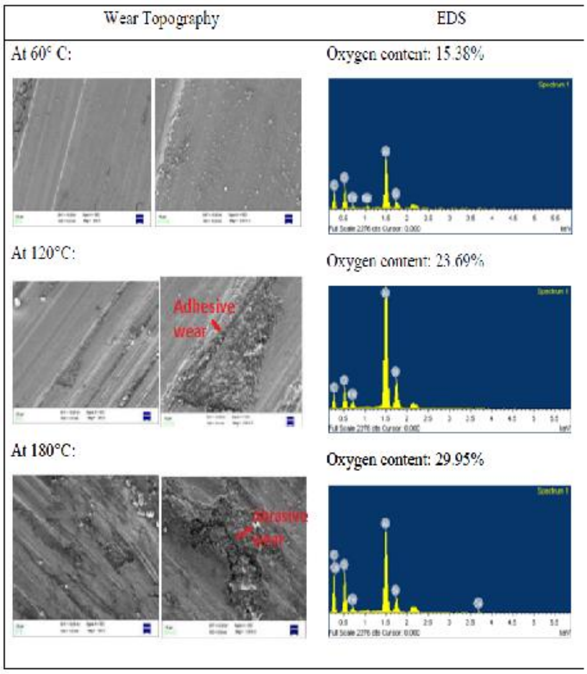

Fig.7 The SEM microphotographs and EDS Analysis of Al-13Si alloy at Normal pressure 0.975 N/mm2

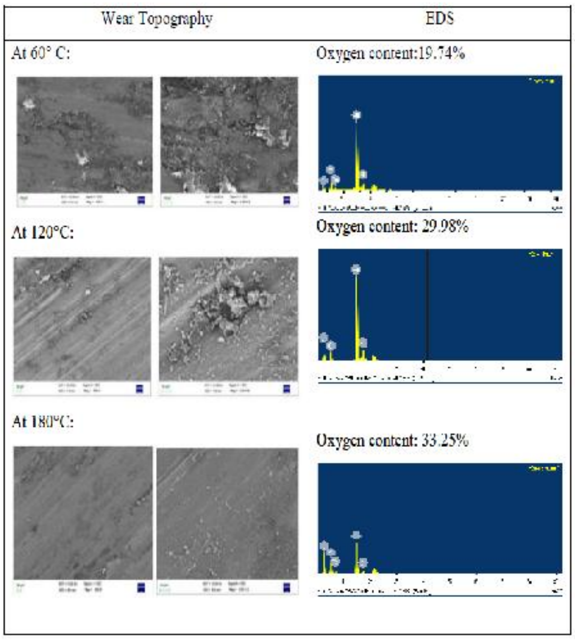

Fig.8 The SEM microphotographs and EDS analysis of Al-13SiP alloy at Normal pressure 0.975 N/mm2

CONCLUSIONS

The dry sliding wear behaviour of Al–13,20Si were studied and compared at elevated temperatures with and without the addition of Phosphorus. The present investigation has led to the following conclusions.

1. Volume loss increases with increasing silicon content because dry sliding wear behavior of as cast hypereutectic Al-Si alloys depend on the shape and size distribution of primary silicon particles.

2. Volume loss decreases with increase in sliding velocity from 0.94 m/s to 3.77 m/s. With increase in the sliding velocity there is an increase in the interface temperature. This may be lead to the formation of oxide layer at higher interface temperatures.
3. The wear rate of the Al-Si alloys increases with increase in the normal pressure and sliding distance.
4. The wear rate of the hypereutectic Al-Si alloys decreases with increase in temperature for both with and without addition of Phosphorous. This effect is due to the oxide film formation on sliding components, which is more rapid at high operating temperatures. This later prevents the direct metal-to-metal contact of sliding surfaces.
5. Wear rate decreases with the addition of phosphorus compared to as cast hyper eutectic Al-Si alloys, as the wear of hyper eutectic Al-Si alloys depend on the shape and size distribution of primary silicon particles.

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How to cite this article:

MalleshJakanur *et al*.2016, Effect of Phosphorus Addition on The Tribological Wear Behaviorof Hypereutectic Al-Si Alloys At Elevated Temperatures. *Int J Recent Sci Res.* 7(3), pp. 9434-9438.

ISSN 0976-3031