International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 22 (2015) pp 43225-43232


# Wear Behavior of Hypereutectic Al-Si Alloys at Elevated Temperatures

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**Abstract**
Dry Sliding wear at elevated temperatures is an important phenomenon in several engineering applications such as gas turbines, steam turbines and metal forming processes. Wear in such cases is governed by oxidation. The objective of present work is to throw some light on wear of hypereutectic Al-Si alloys at elevated temperatures using Pin on Disc wear testing machine. Effects of alloy composition, normal pressure, sliding velocity and sliding distance have been studied at 60°C, 120°C and 180 °C. Cast hypereutectic Al-13 and 20 Si alloys and worn surfaces are characterized by SEM/EDX microanalysis. The results suggest that wear in terms of volume loss increases with increase in normal pressure and sliding distances, where as it decreases with increase in sliding velocity for the alloys taken for study. Results also suggest that the wear resistance increases as the temperature increases due to the Fe-rich oxide layer formation between the mating surfaces during sliding which prevents direct metal to metal contact of sliding surfaces. The EDS microanalysis shows that there is almost 15% to 20% increase in Fe-rich Oxide layer formation when temperature increased from 60ºC to 180ºC.

**Keywords:** Elevated, Hypereutectic, Microanalysis, Oxide layer.

## 1 .Introduction
Hypereutectic Al–Si alloys are widely used in different fields of industry. High wear resistance, high strength-to-weight ratio, low coefficient of thermal expansion, high thermal conductivity, high corrosion resistance, excellent castability, hot tearing resistance, good weldability etc., make hypereutectic aluminium silicon alloys very attractive candidate in aerospace and other engineering sectors [1, 2]. These applications demand the study of techniques to improve the wear properties of these alloys. For this purpose, many research works have been carried out to enhance their wear properties. Aluminium silicon alloys are mainly employed to bring the components like connecting rods, pistons, engine blocks, cylinder liners, air conditioner compressors, brake drums etc. The improvement in the tribological properties depends on number of material-related properties like shape, size and size distribution of the second-phase particles in the matrix and microstructures in addition to the operating conditions such as sliding speed, sliding distance, temperature, load etc [3-16]. Even though a large volume of work has been carried out on wear of hypereutectic Al-Si alloys at room temperatures, industrial applications especially in cylinder blocks, cylinder heads, gas turbines, steam turbines and metal forming processes the operating temperature of components reaches to about 0. 4-0. 5 times of melting temperatures [17], making it necessary to study the elevated temperature wear of these alloys. The main objective of the research work is to throw some light on wear of hypereutectic Al-Si alloys at elevated temperature ranging from 60-180$^0$C. Wear tests are carried out using Pin on Disc machine. The results obtained from the wear tests are correlated with topographic observations carried with SEM and EDX microanalysis and are used to arrive at the conclusions.

## 2. Experimental Details
Al-Si alloys are prepared by foundry technique. Calculated quantities of commercial purity aluminum (99. 7 Wt % purity) and Al-20 Si master alloy are melted in a resistance furnace under a cover flux (45% NaCl+45% KCl+10% NaF). The melt is held at 720$^0$C±5$^0$C. After degassing the melt with solid hexachloroethane ($C_2Cl_6$) the melt is poured into graphite split mould (12. 5 mm diameter and 125 mm height- for preparing the specimen for wear pins).
Wear tests are conducted using pin on disc wear testing machine (TR-20LE- PHM-600, DUCOM). 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. Wear pins of 30 mm length and 8 mm diameter are machined from the cast specimen obtained from graphite split mould (12. 5 mm diameter and 125 mm length). Wear losses were recorded. Wear losses were measured with a linear variable differential transformer (LVDT) and it was monitored by the loss of length. The wear loss was measured in microns (µm). Weight loss method is followed to get the more accurate results. In this method using an electronic weighing machine weight of the wear pin before and after conducting the wear test is recorded. Difference between the initial and final weight gives the weight loss due to wear.
Three sets of wear testing experiments are conducted to study the tribological wear behaviour of all these alloys. Three sets of experiments are:
1. Normal pressure dependent experiments.
2. Sliding velocity dependent experiments.
3. Sliding distance dependent experiments

## 3. Results and Discussion
The wear tests are carried out with varying applied load, sliding velocity and sliding distance. The experiments are carried at elevated temperatures. In the present work wear rates in terms of volume loss are recorded for hypereutectic

Al-13 and 20 Si alloys. Series of tests are conducted by keeping two parameters out of the three (Normal pressure, sliding velocity and sliding distance) constant against wear. The pressure is varied from 0.2 N/mm$^2$ to 0.98 N/mm$^2$; sliding velocity is varied from 0.94 m/sec to 3.77 m/sec and sliding distance is varied from 282.74 m to 1413.72 m. For each test the weight loss from the specimens was determined and converted into volume loss using the measured density of the materials.

### 3. 1 Effect of normal pressure.

The effect of varying normal pressures (0.20, 0.39, 0.585, 0.780 and 0.98 N/mm$^2$) on the wear rate is shown in Fig 1. It is clear that, volume loss of Al-13 and 20 Si alloys 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 real area of metal to metal contact between mating surfaces. Also as the load is increased, the oxide film becomes sensitive to bulk failure leading to increasing volume loss.

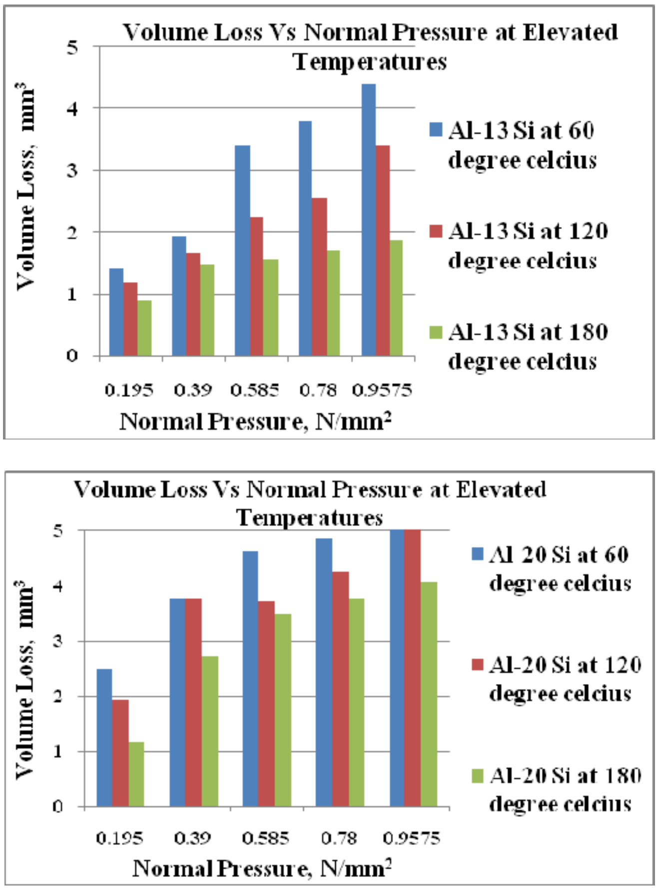


**Fig 1. Volume loss Vs Normal pressure at 60°C, 120°C and 180°C for Al-13 and Al-20Si alloys.**

### 3. 2 Effect of sliding velocity

Figure 2 shows the effect of varying sliding velocity on volume loss. The sliding velocity is varied from 0.94 m/sec to 3.77 m/sec with constant normal pressure (0. 975 N/mm$^2$) and at constant sliding distance (565. 486 m). The volume loss decreases as the sliding velocity is increased from 0.94 m/sec to 3.77 m/sec. 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 prevents direct metal-to-metal contact of sliding surfaces during sliding. 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.

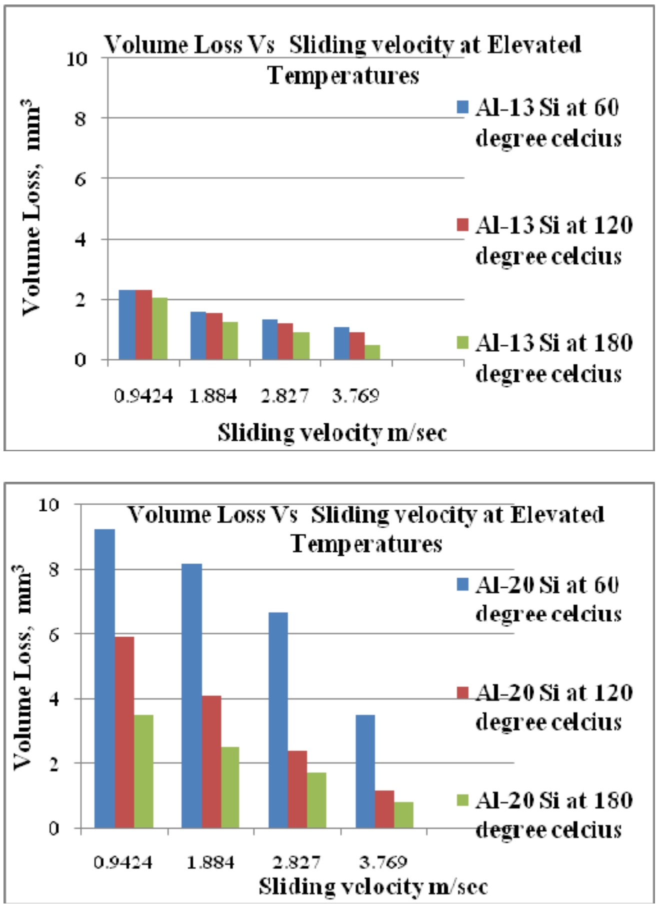


**Fig. 2 Volume loss Vs sliding velocity at 60°C, 120°C and 180°C for Al-13 and Al-20Si alloys.**

### 3. 3 Effect of sliding distance.

Figure 3 shows the effect of varying sliding distance on volume loss. The sliding distance is varied from 282.743 m to 1413.72 m with constant normal pressure (0.975 N/mm$^2$) 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.

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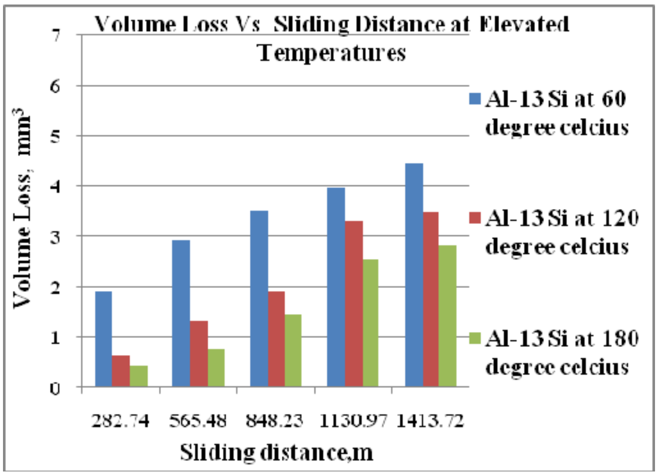


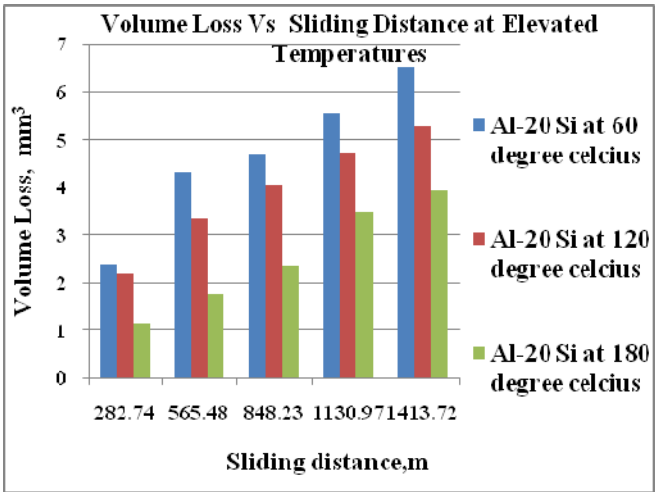




**Fig. 3 Volume loss Vs Sliding distances at 60°C, 120°C and 180°C for Al-13 and 20Si alloys.**

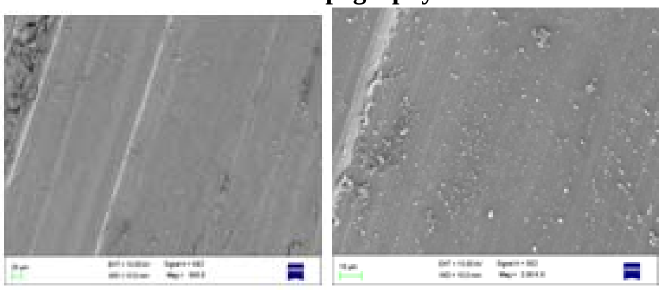
**3.4. Wear of Al-13 and 20 Si alloys at elevated temperatures**.

From Fig. 1, 2 and 3 it is clear that, wear resistance increases as operating temperature increases. This is due to the formation of a glaze layer, which offers protection due to temperature and applied pressure, sintering of fine wear debris occurs. The rate of sintering was increased with an increase in temperature, which results in the formation of solid smooth hard surfaces termed as "glaze". The glaze layers protect the sliding surfaces for a longer time from developed forces and hence the wear rate is reduced. The failure of glaze later leads to the formation of an oxide layer and tearing of oxide layer, resulting in sintering of the wear debris and the process is repeated.

Figure 4-9 shows SEM and EDX analysis of worn surfaces carried out on Al-13Si and Al-20Si alloys at various operating conditions. From SEM photographs it is observed that the topographical features do change significantly with increasing silicon content from 13% to 20% and more craters are seen with increasing silicon content. The distinct topographical features indicate that the surface is subjected more than one mode of material removal. Most of the worn surface consists of smooth strips with fine scoring marks. Scoring may be due to abrasion by entrapped debris, work hardened deposits or hard asperities on hardened steel. This mode does not constitute a major wear mechanism as the amount of material removed is very small.

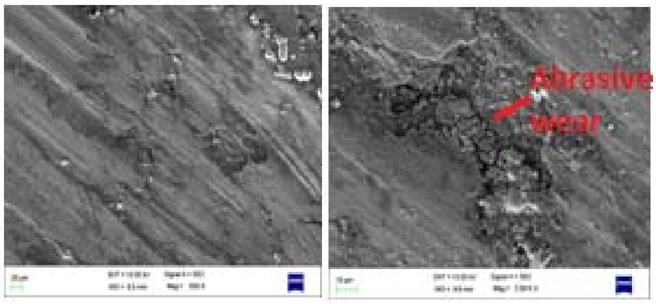
The EDS analysis indicated that, as the temperature is increased the Fe rich-Oxide content increases leading to the formation of oxide layer due to which the wear is reduced.

**Wear Topography**



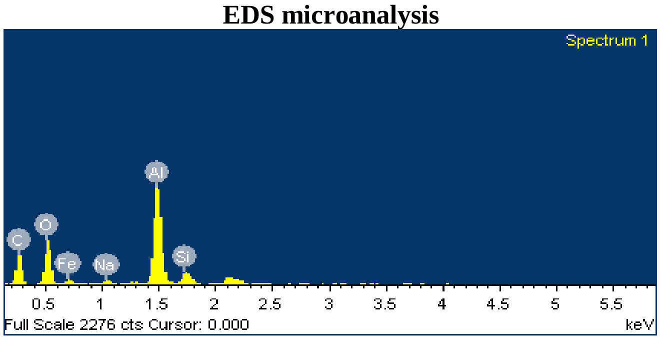
**at 60°C**


**at 120°C**

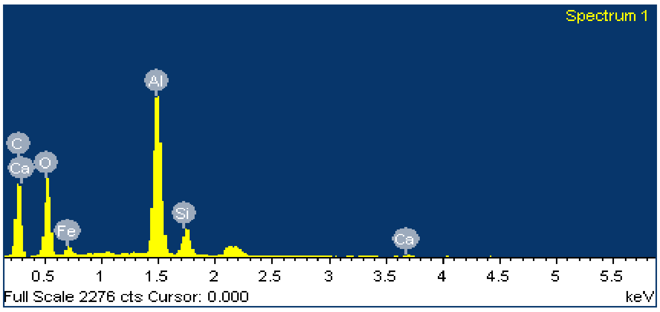



**at 180°C**

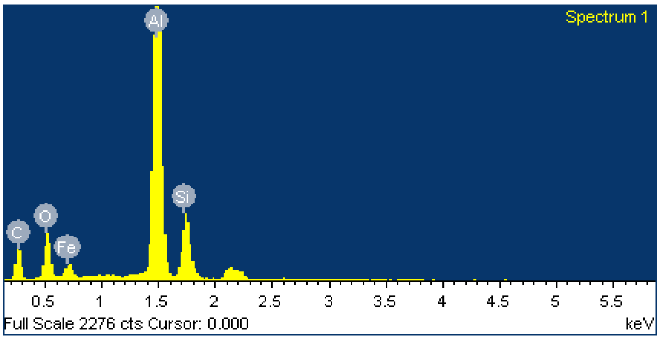
**EDS microanalysis**




**Oxide Content: 15. 38% at 60°C**




**Oxide Content: 23. 69% at 120°C**

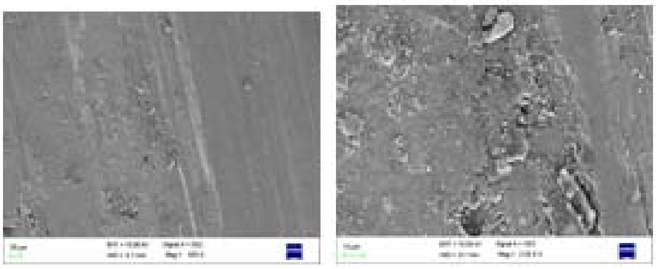



**Oxide Content: 29. 95% at 180°C**

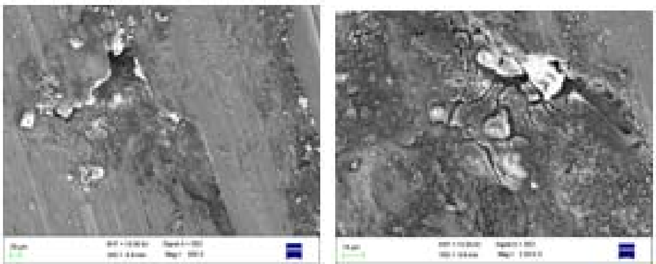
**Fig.4. SEM and Microanalysis of Al-13Si alloy at Normal pressure 0.975 N/mm$^2$ and at Elevated temperatures 60°C, 120°C and 180°C.**

**Wear Topography**

**at 60°C**

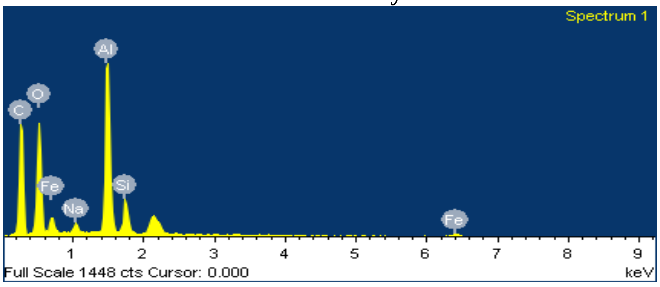


**at 120°C**

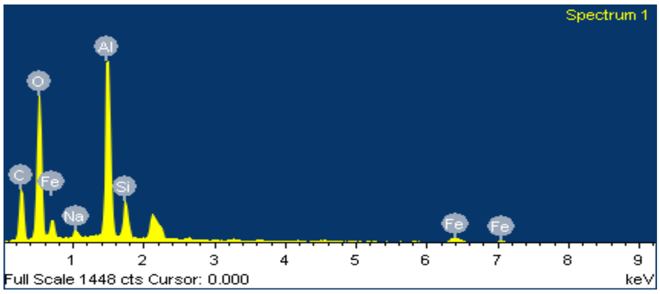


**at 180°C**

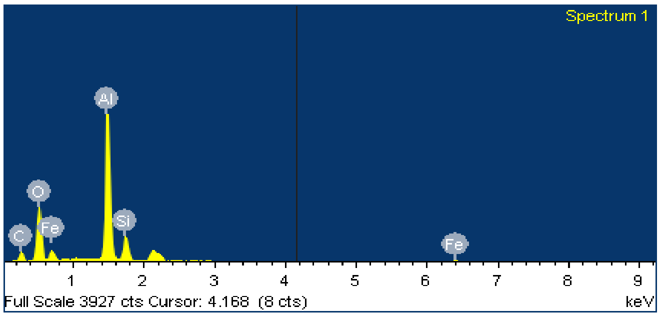
**EDS microanlysis**




**Oxide Content: 24. 59% at 60°C**



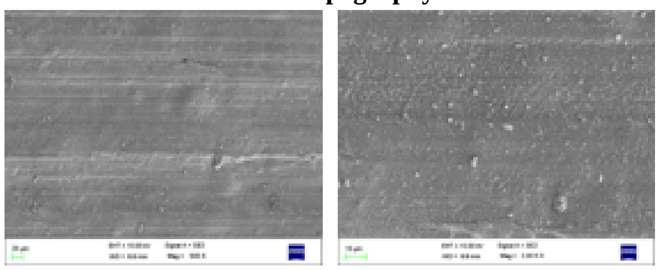

**Oxide Content: 30. 64% at 120°C**



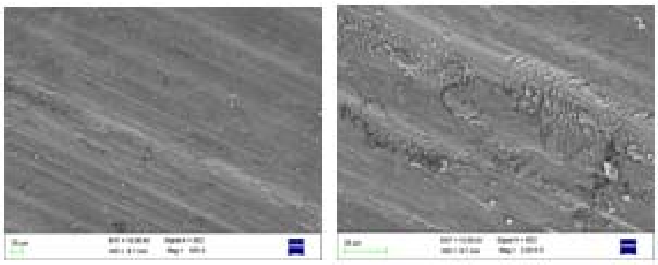

**Oxide Content: 35. 36% at 180°C**

**Fig.5.SEM and Microanalysis of Al-20 Si alloy at Normal pressure 0.975 N/mm$^2$ and at Elevated temperatures 60°C, 120°C and 180°C.**

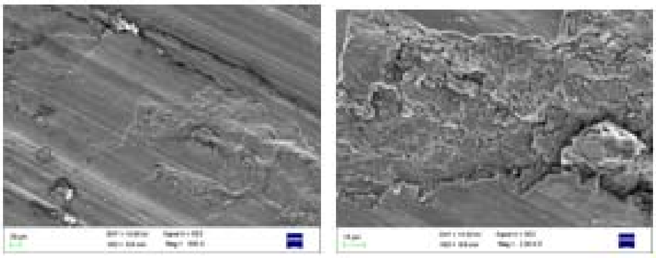
**Wear Topography**



**at 60°C**

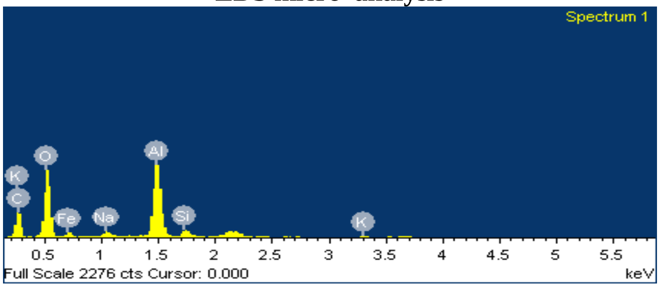


**at 120°C**

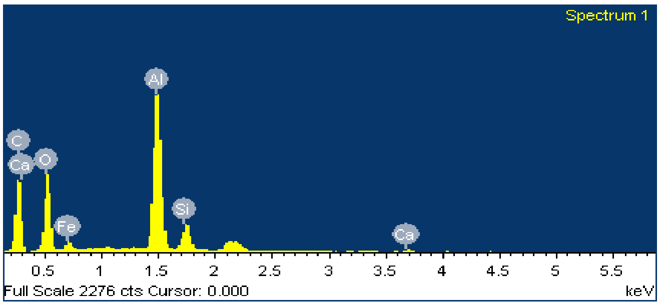


at 180°C

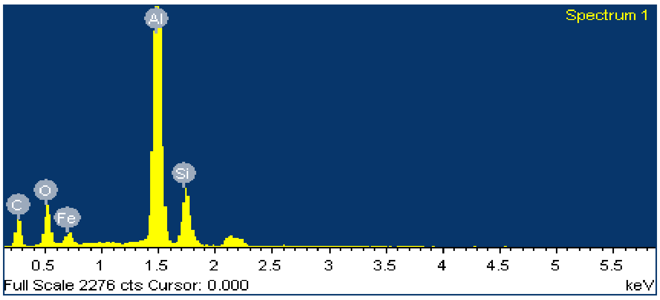
**EDS micro analysis**




**Oxide Content: 13. 95% at 60°C:**



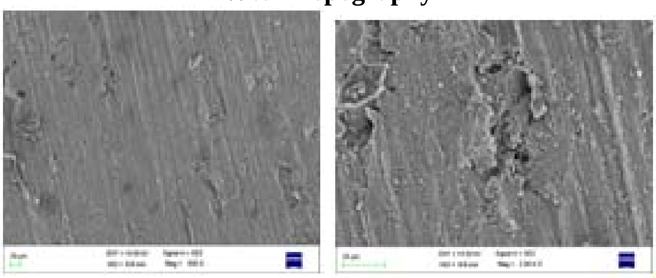

**Oxide Content: 23. 64% at 120°C:**



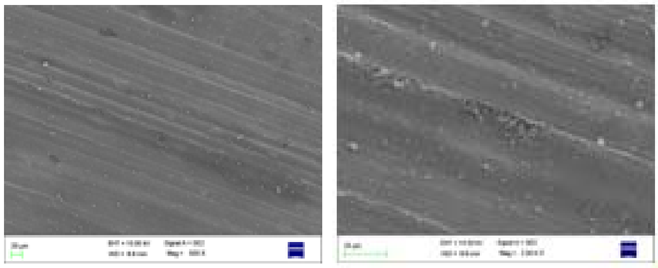

**Oxide Content: 33. 25% at 180°C:**

**Fig.6.SEM and Microanalysis of Al-13 Si alloy at sliding velocity 3.769 m/sec and at Elevated temperatures 60°C, 120°C and 180°C.**

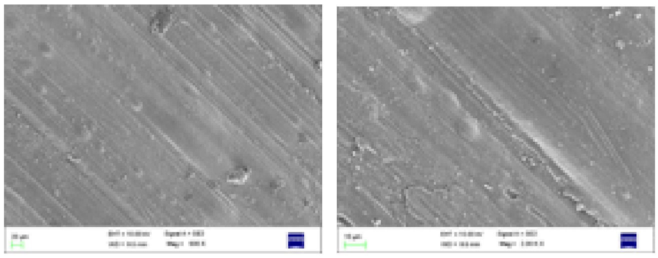
**Wear Topography**



at 60°C

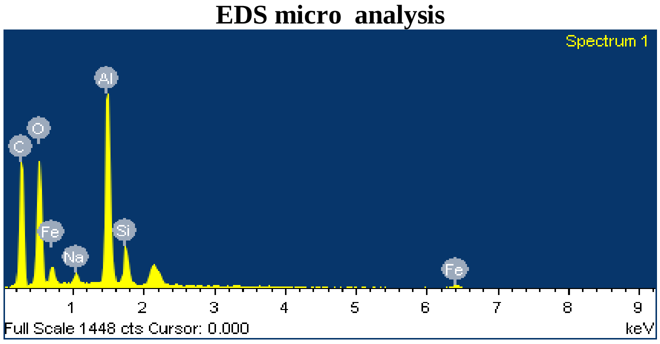


at 120°C

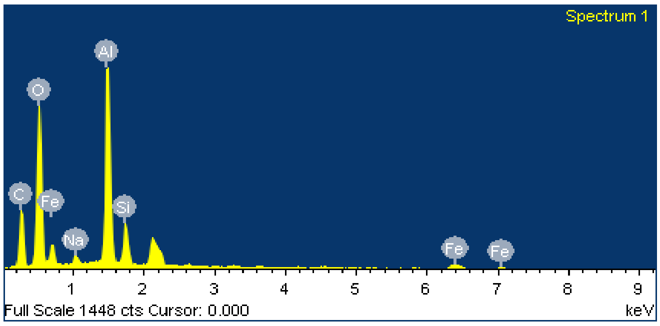


at 180°C

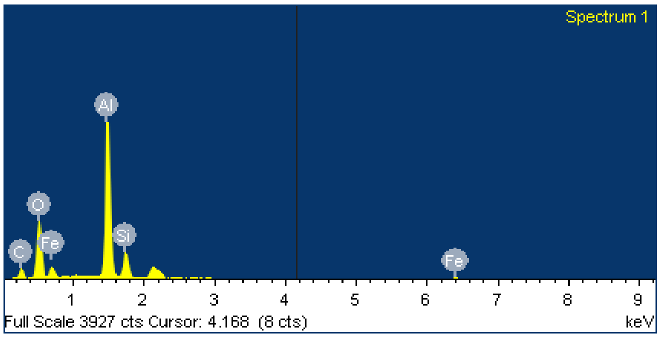
**EDS micro analysis**




**Oxide Content: 08. 75% at 60°C**




**Oxide Content: 18. 89% at 120°C**




**Oxide Content: 32. 15% at 180°C**

**Fig.7.SEM and Microanalysis of Al-20 Si alloy at sliding velocity 3.769 m/sec and at Elevated temperatures 60°C, 120°C and 180°C.**

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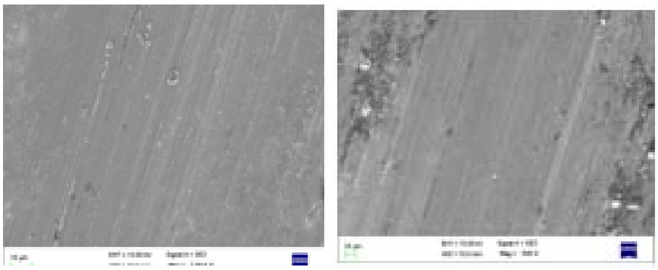
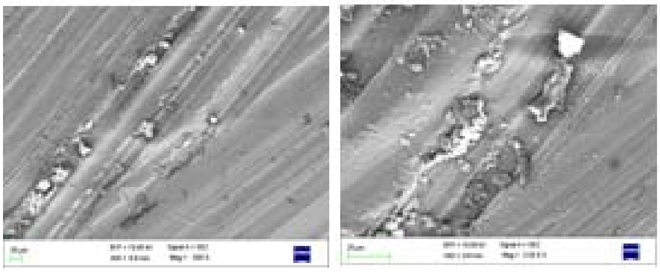
**Wear Topography**



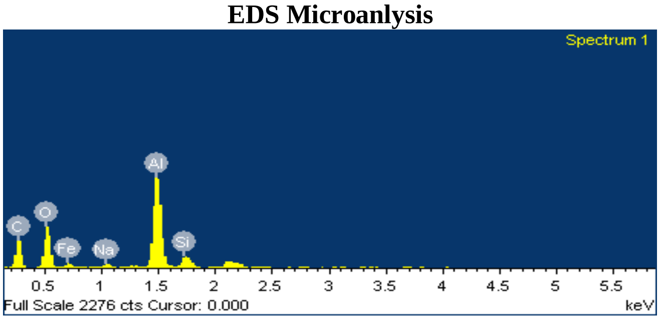
at 60°C

at 120°C

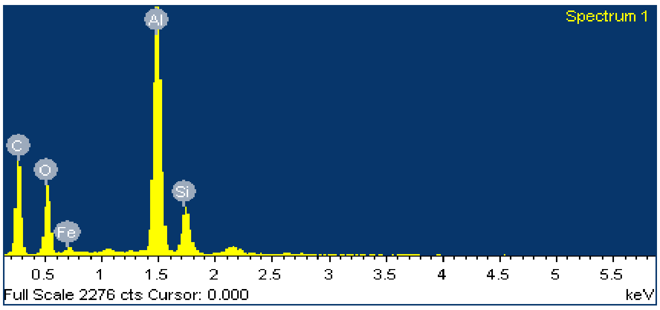


at 180°C

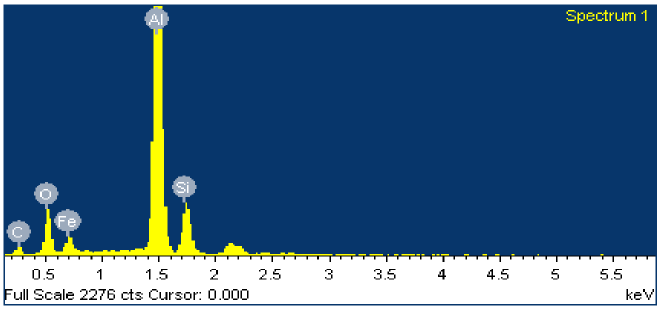
**EDS Microanlysis**




**Oxide Content: 11. 93% at 60°C**



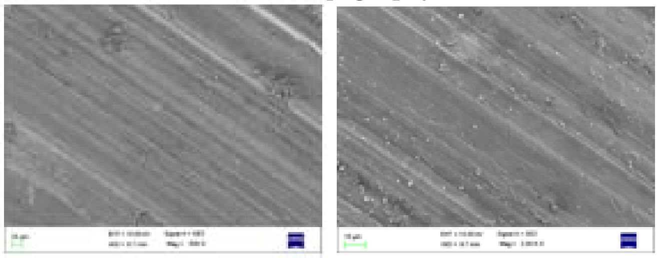

**Oxide Content: 18. 22% at 120°C**



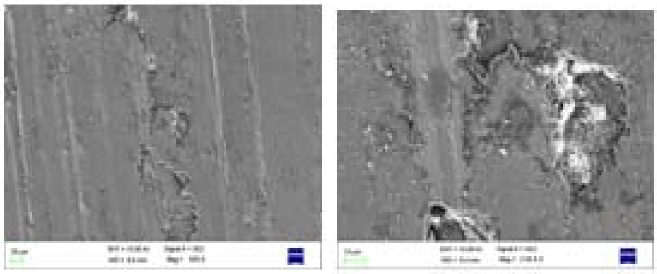

**Oxide Content: 30. 97% at 180°C**

**Fig.8.SEM and Microanalysis of Al-13 Si alloy at sliding distance 1413.72 m and at Elevated temperatures 60°C, 120°C and 180°C.**

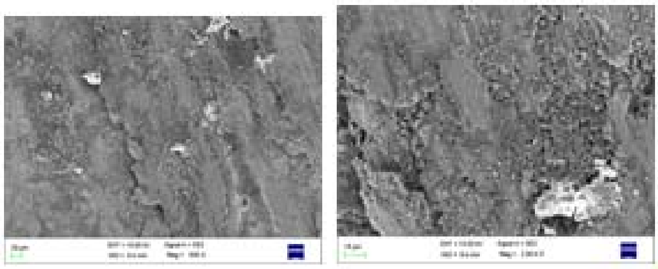
**Wear Topography**



at 60°C

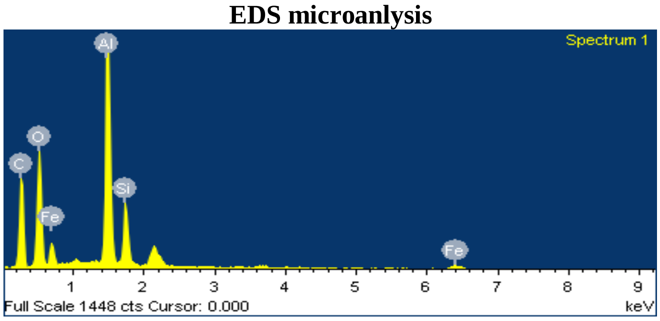


at 120°C

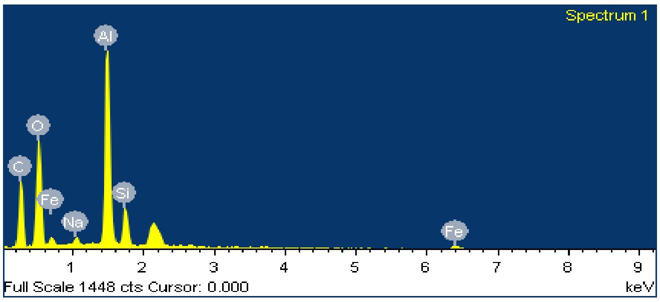


at 180°C

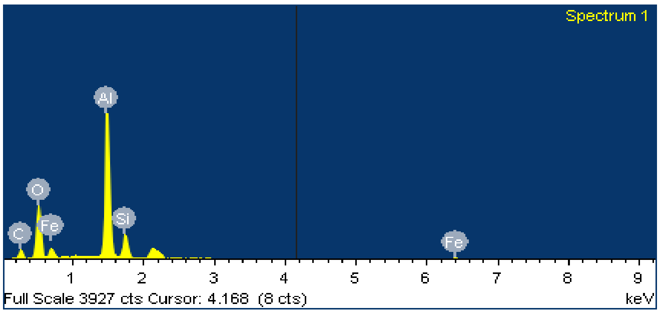
**EDS microanlysis**




**Oxide Content: 17. 68% at 60°C**




**Oxide Content: 22. 04% at 120°C**




**Oxide Content: 27. 58% at 180°C**

**Fig.9.SEM and Microanalysis of Al-20 Si alloy at sliding distance of 1413.72 m and at 60°C, 120°C and 180°C.**

### 3. 4. 1. Topography and microanalysis of Al-13, 20Si alloys at a Normal pressure of 0.975N/mm$^2$.

SEM and EDS micro analysis is carried out for Al-13 and 20Si alloy at a Normal pressure of 0.975N/ mm$^2$ and at 60°C, 120°C and 180°C.

Figure 4 shows EDS micro analysis of Al-13 Si alloy and from figure it is clear that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 15.38 % to 29.95% which leads in reduction of volume loss.

Figure 5 shows EDS micro analysis of Al-20 Si alloy and from figure it is clear that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 24.59% to 35.36% which leads in reduction of volume loss.

### 3.4. 2. Topography and microanalysis of Al-13, 20Si alloys at a sliding velocity3.769 m/sec.

SEM and EDS micro analysis is carried out for Al-13 and 20Si alloy at sliding velocity of 3.769 m/sec and at 60°C, 120°C and 180°C.

Figure 6 shows EDS micro analysis of Al-13 Si alloy and from figure it is clear that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 13.95% to 33.25% which leads in reduction of volume loss.

Figure 7 shows EDS micro analysis of Al-20 Si alloy and from figure it is clear that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 8.75 % to 32.15% which leads in reduction of volume loss.

### 3.4.3 Topography and microanalysis of Al-13, 20Si alloys at a sliding distance of 1413.72 m

SEM and EDS micro analysis is carried out for Al-13 and 20Si alloy at a sliding distance of 1696.46 m and at 60°C, 120°C and 180°C.

Figure 8 shows EDS micro analysis of Al-13 Si alloy and from figure it is clear that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 11.93% to 30.97% which leads in reduction of volume loss.

Figure 9 shows EDS micro analysis of Al-20 Si alloy and from figure it is clear that oxide layer formation increases as the temperature increases from 60°C to 180°C. The Oxide content increases from 17.68% to 27.58% which leads in reduction of volume loss.

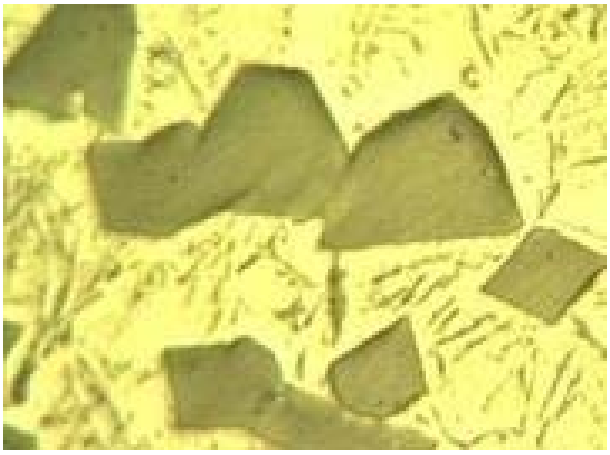
### 3. 5. Morphology

It is well known that the morphology and the distribution of Si crystals play a critical role in determining the properties of hypereutectic Al–Si alloys. Fig. 10 shows the microstructure of Al-13Si and Al-20 Si alloys respectively. As the silicon content increases the size of the primary silicon increases which results in higher wear rate.

**Al-13 Si**

**08 Microns**

**Al-20 Si**



**40 Microns**

**Fig. 10. Optical photographs and average area of primary silicon for Al-13 and 20 Si alloys at 400X**

## 4. Conclusions

The dry sliding wear behaviour of Al–13 and 20 Si alloys are studied and compared at elevated temperatures and the following conclusions are drawn.

1. The wear rate of the Al-13, 20 Si alloys increases with increase in normal pressure and sliding distance. Whereas the wear rate decreases with increase in sliding velocity.
2. Wear rate increases with increase in silicon content for hypereutectic Al-Si alloys.
3. The wear rate of the Al-13, 20 Si alloys decreases with an increase in operating temperature. This effect is due to the Fe-rich oxide layer 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. References

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