

Effect of Ti-B Addition on the Tribological Wear Behavior of Hypereutectic Al-Si Alloys at Room and At Elevated Temperatures

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ABSTRACT: Effect of titanium boron addition on the dry sliding wear behavior of hypereutectic Al-Si alloys are investigated at elevated temperatures. Wear tests are conducted for varying normal pressure from 0.20 N/mm² to 0.98 N/mm². In this present investigation, hyper eutectic aluminum based alloys containing 13% and 20% weight of silicon; with addition of titanium boron is synthesized using casting method. Wear behavior is studied by using computerized pin on disc wear testing machine. Worn surfaces were examined and analyzed by scanning electron microscopy (SEM) and energy dispersive X-ray spectroscopy (EDS). The wear results show that the wear rate increases with increase in normal pressure (0.20 N/mm² to 0.98 N/mm²) and wear rate decreases with increase in temperature due to oxide film formation at interface of the specimen. The addition of titanium boron to Al-Si alloys increases the wear resistance at elevated temperatures and in comparison with addition of Ti and TiB, wear resistance with addition of TiB has better results as compared to bare Ti addition.

KEYWORDS: Titanium, Hypereutectic, X-ray spectroscopy, electron microscopy.

I. INTRODUCTION

Use of cast Al-Si alloys as a tribological component in recent years has been expanding widely in military, automobile and general engineering industry. Aluminum-silicon eutectic and near-eutectic alloys are cast to produce majority of pistons and are known as piston alloys. Silicon is probably one of the least expensive alloying additions commonly made to aluminum, which improves cast ability, increases strength to weight ratio, enhances corrosion resistance, decreases the coefficient of thermal expansion and imparts wear resistance to aluminum. The eutectic in the Al-Si alloys occur at about 12% Si and the microstructure of Al-12Si alloy should contain only the eutectic mixture (α -Al + eutectic Si). Usually, pro eutectic α -Al dendrites are also found in the eutectic Al-Si alloy (up to 14% Si) along with the eutectic mixture under non-equilibrium cooling conditions.

a).Physical properties of titanium

Melting point	1660°C
Density	4.51
Co-efficient of expansion	8.9 x 10-6/°C
Electrical resistivity at 20°C	48.2 micro-ohms/ cm
Standard potential	-1.63 volts
Elastic modulus	105,000 N/mm ²

Table-1: The Physical properties of titanium

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b).Introduction to Boron

Boron is a chemical element with symbol B and atomic number 5. Because boron is produced entirely by cosmic ray spallation and not by stellar nucleosynthesis,^[5] it is a low-abundance element in both the solar system and the Earth's crust. Boron is concentrated on Earth by the water-solubility of its more common naturally occurring compounds, the borate minerals. These are mined industrially as evaporates, such as borax and kernite. Chemical properties of boron Atomic number 5, Atomic mass $10.81\text{g}\cdot\text{mol}^{-1}$, Electronegativity according to Pauling 2.0, Density $2.3\text{g}\cdot\text{cm}^{-3}$ at 20°C , Melting point 2076°C .

d). Experimental setup used



Fig 1: DUCOM friction and wear monitor with pin on disc wear machine.

Pin-on-Disc wear testing is a method of characterizing the coefficient of friction, frictional force, and rate of wear between two materials. During this tribological test, a stationary disk articulates against a rotating pin while under a constant applied load.

Pin-on-disc wear testing can simulate multiple modes of wear, including: unidirectional, bidirectional, multi directional, and quasi-rotational. Accutek performs pin-on-disk wear testing in accordance with ASTM G99 and ASTM G133 on our in-house, 12-station wear test frames. These unique, high capacity machines allow for the testing of several material combinations at a time, on a single test frame. The 12-station setup also allows for additional statistical confidence by testing multiple samples per condition.

II. EXPERIMENTAL METHODOLOGY

1. Preparation of the Alloys

Al-Si alloys are prepared via foundry technique. Calculated quantities of commercial purity aluminum (99.7 Wt. % 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 $720^\circ\text{C}\pm 5^\circ\text{C}$. After degassing the melt with solid hexachloroethane (C_2Cl_6) 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 (C_2Cl_6), Al-5Ti-1B (0.15Wt %) in the form of chips were added to the melt for grain refinement. The melt was stirred for 30 seconds with zircon coated iron rod after addition of Al-5Ti-1B chips, after which no further stirring was carried out. Melts were poured after holding for about 5 minutes into cylindrical graphite mould (25 mm diameter and 100 mm height) surrounded by fire

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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).

Photographs of materials for preparation of Al-Si alloys and prepared specimens

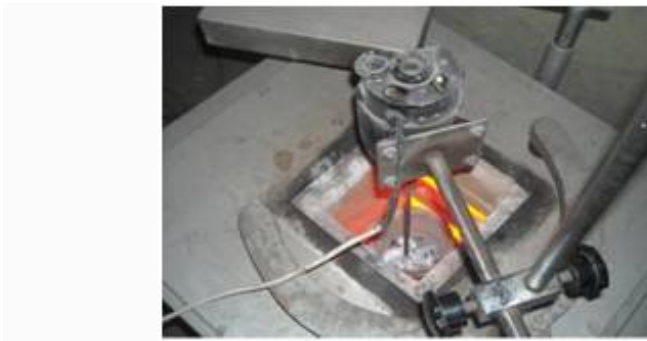


Fig-2. Stir casting set up

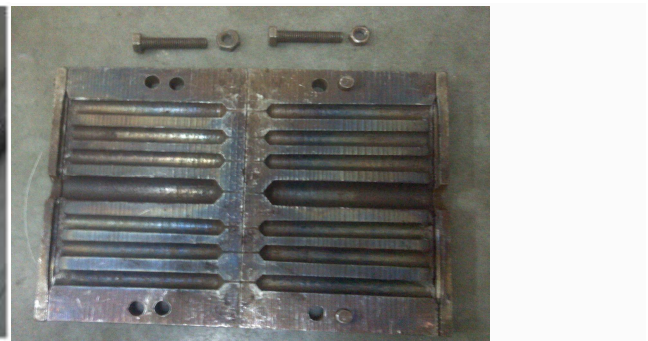


Fig-3. Graphite mold



Fig-4. Al-Si alloys after casting



Fig-5. Specimen used for wear test

III. RESULTS AND DISCUSSION

1. Dry sliding wear test

The wear tests of Al-Si alloys were carried out with varying applied load, sliding speed and sliding distance. The experiments are carried at elevated temperatures. In the present study, hypereutectic aluminum based alloys containing 13% and 20% weight of silicon with and without addition of titanium. 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. The normal pressure is obtained by varying the Normal Pressure from 0.2 N/mm² to 0.98 N/mm²; At each condition, the weight loss from the specimens was determined, and converted into volume loss using the measured density of the materials. The volume loss is obtained by using the density value 2.7g/cm³. Wear behavior is studied by using computerized pin on disc wear testing machine.

a) Normal pressure vs. volume loss for Al-Si alloy with and without addition of titanium and Titanium

Boron:

The volume loss versus normal pressure of Al-Si alloys with addition of titanium and titanium boron at elevated temperature of 60°C, 120°C and 180°C are shown in Fig. 6-9. The normal pressure is obtained by varying the pressure from 0.2 N/mm² to 0.98 N/mm² at constant sliding velocity of 1.88 m/sec for a constant sliding distance

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of 565.49 m. The graph is obtained for hyper eutectic Al-Si alloys such as Al-13%Si and Al-20%Si with addition of titanium and boron. It is observed that volume loss increases with increase in normal pressure and decrease with increases in temperature due oxide layer formation at the interface of the specimen surface. Under dry sliding conditions contact load is important parameter which affects the wear response of aluminum silicon alloys. In dry sliding wear contact load is main variable as it controls the degree of adhesion, sub-surface damage on the sliding surface. Increase in deformation increases real area of contact of rubbing surfaces.

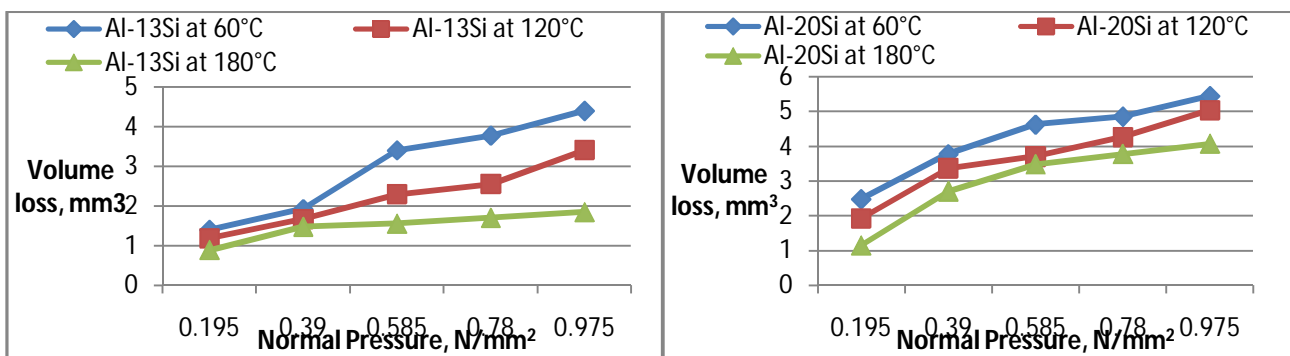


Fig-6. Normal pressure vs. volume loss for Al-Si alloy without addition of titanium

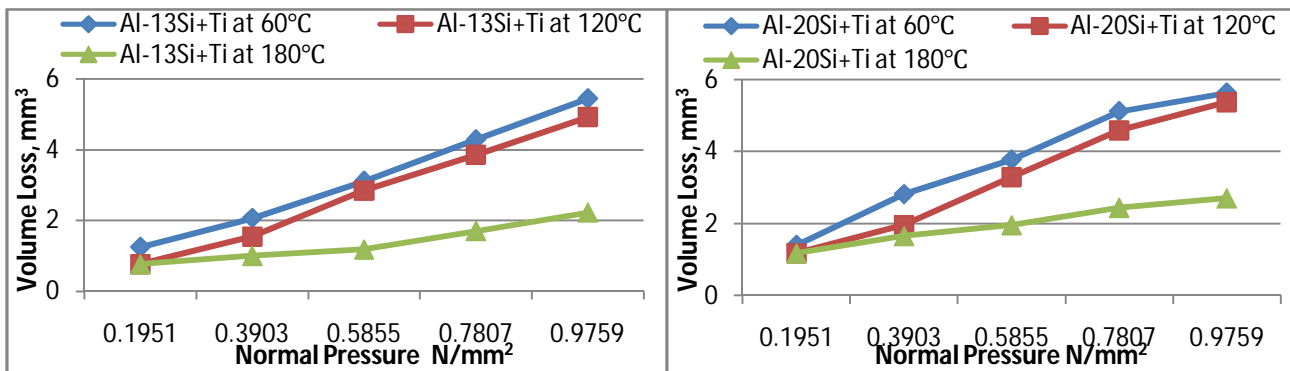


Fig-7. Normal pressure vs. volume loss for Al-Si alloy with addition of titanium

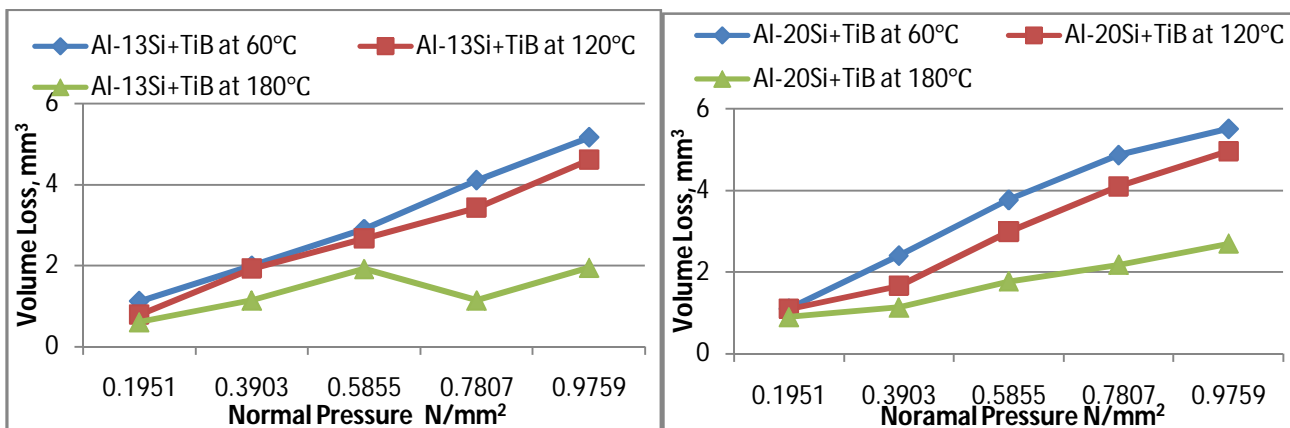


Fig-8. Normal pressure vs. volume loss for Al-Si alloy with addition of Titanium Boron

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It is observed that from fig (6,7,8) volume loss increases with increase in normal pressure and decrease with increases in temperature due to oxide layer formation at the interface of the specimen surface.

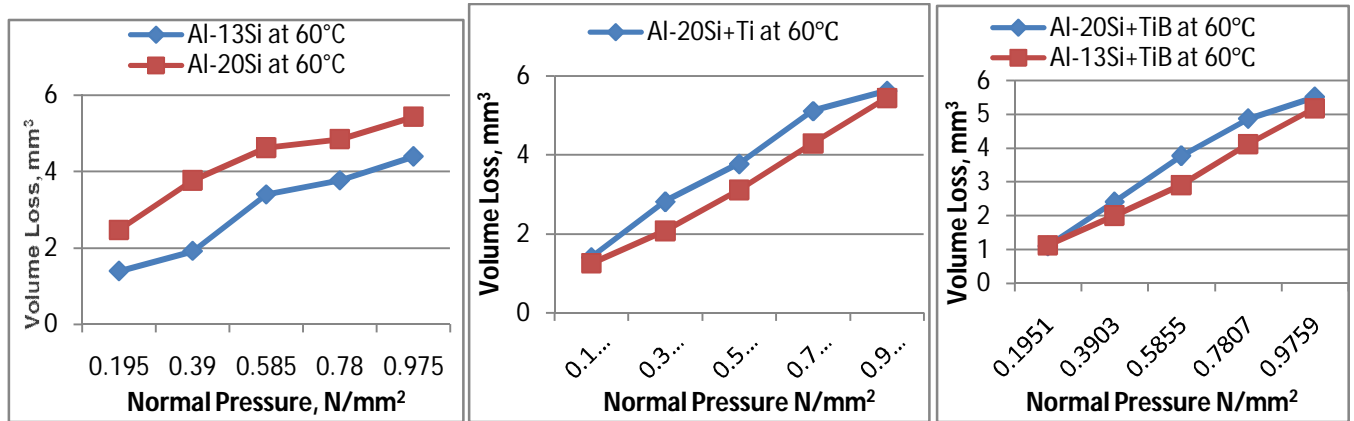


Fig-9. Comparison study of Normal pressure vs. Volume loss for Al-Si alloy with and without addition of titanium and Titanium Boron at 60°C⁰

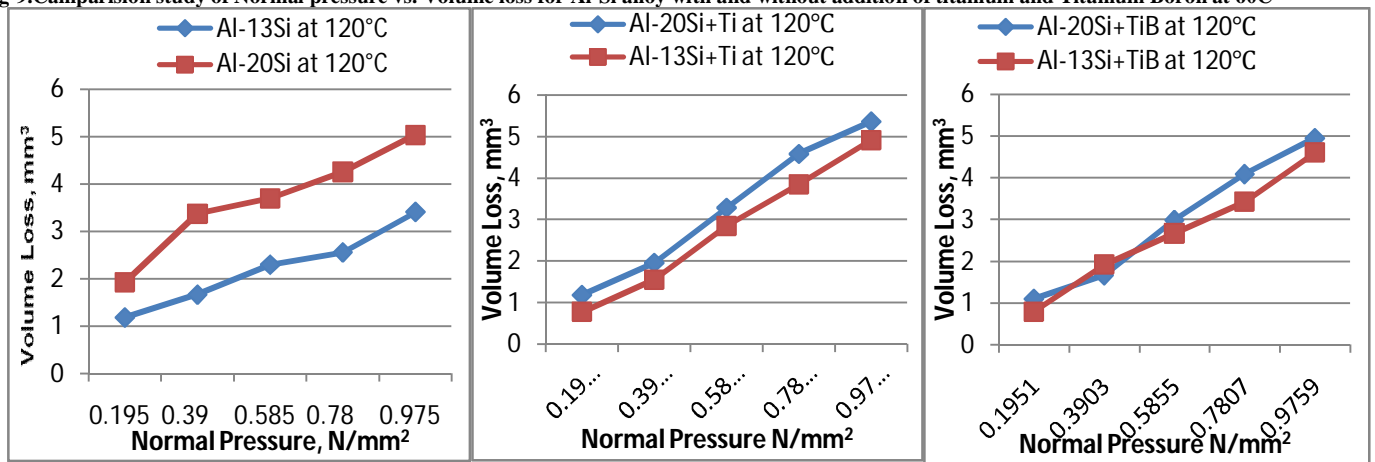


Fig-10. Comparison study of Normal pressure vs. Volume loss for Al-Si alloy with and without addition of titanium and Titanium Boron at 120°C⁰

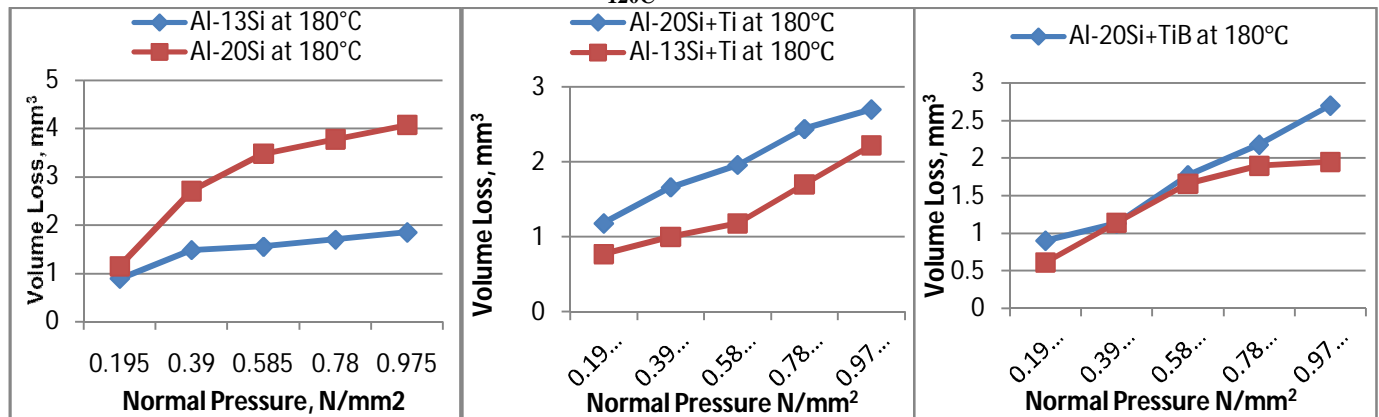


Fig-11. Comparison study of Normal pressure vs. Volume loss for Al-Si alloy with and without addition of titanium and Titanium Boron at 180°C⁰

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From the fig 9, 10, 11 Wear resistance decreases with the increase in the silicon content of the material. In hypereutectic Al-Si alloys, as silicon content increases the wear resistance decreases. The addition of titanium and titanium boron to the hyper eutectic Al-Si alloys reduces the wear rate as compared to as cast hyper eutectic Al-Si. But in comparison with addition of Ti and TiB, wear resistance with addition of TiB has better results as compared to bare Ti addition.

a) **Topography and microanalysis of Al-13+TiB, 20Si+TiB alloys for normal pressure:**

The following SEM and EDS micro analysis was carried out for the specimen Al-13, 20Si alloy under Normal pressure 0.975N/mm² at 60°C, 120°C and 180°C.

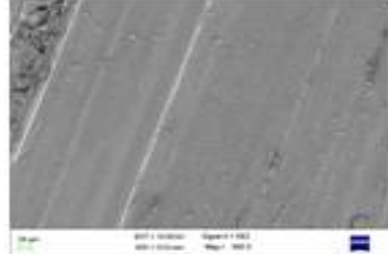
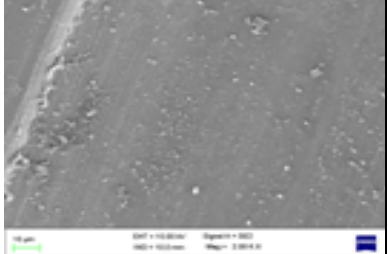
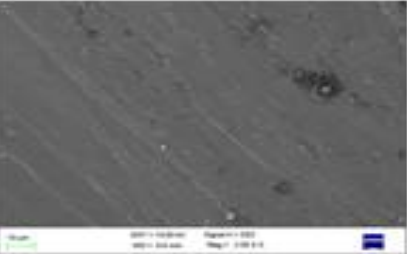
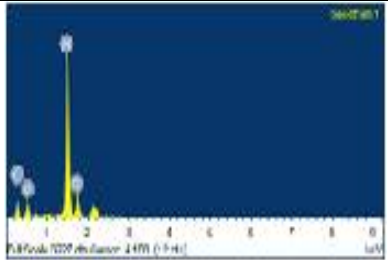
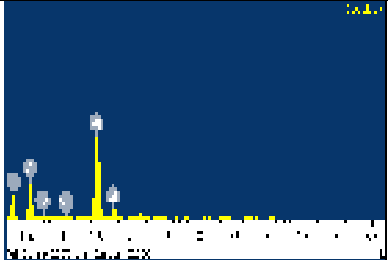
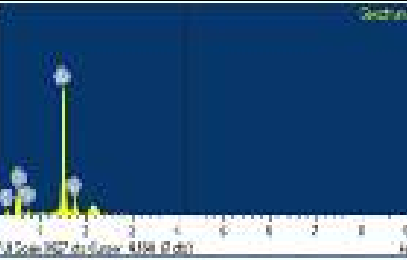
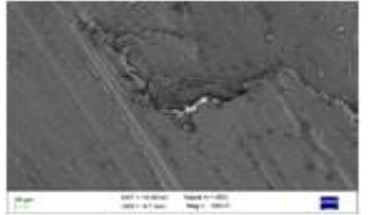

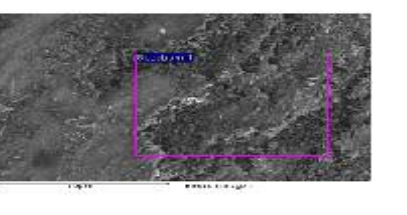
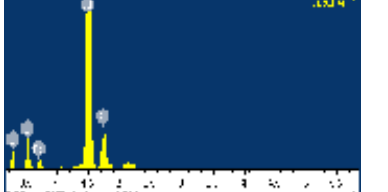

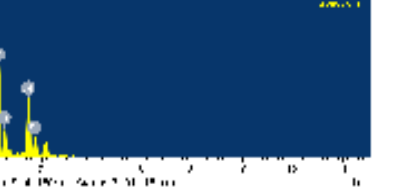
AT: AT 60°C Al-13Si oxygen content:13.2%	AT: AT 60°C Al-13Si+Ti oxygen content:14.53%	AT: AT 60°C Al-13Si+TiB oxygen content:15.89%
		
		
AT: AT 120°C Al-13Si Oxygen content:24.62%	AT: AT 120°C Al-13Si+Ti oxygen content:22.35%	AT: AT 120°C Al-13Si+TiB oxygen content:21.37%
		
		
AT: AT 180°C Al-13Si oxygen content:36.72%	AT: AT 180°C Al-13Si+Ti oxygen content:36.72%	AT: AT 180°C Al-13Si+TiB oxygen content:34.89%

Table 2: The SEM microphotographs and EDS of Al-13Si+TiB alloys at Normal pressure 0.975N/mm²

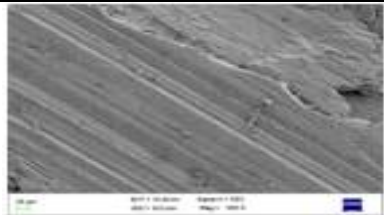

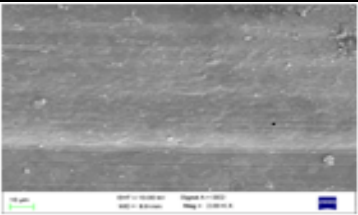
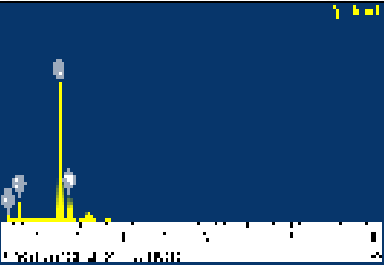
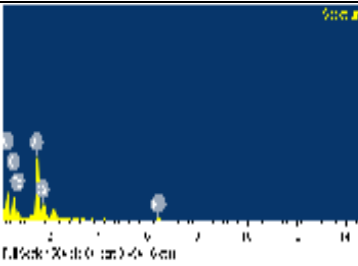
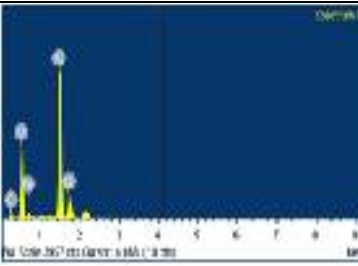
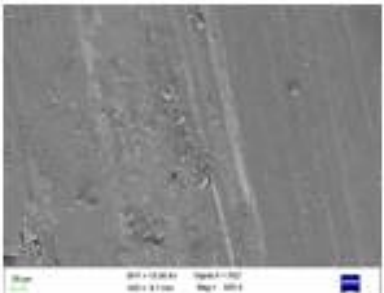
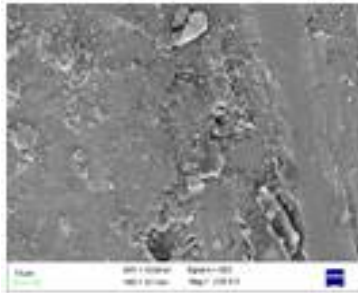
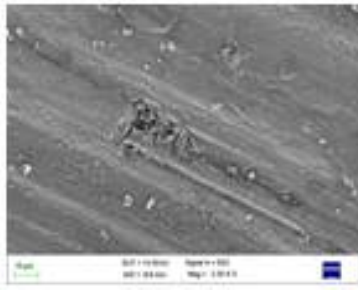
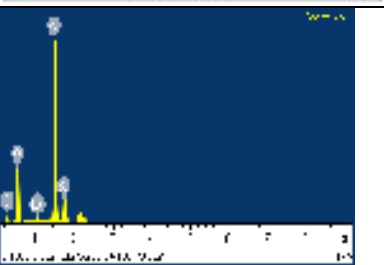
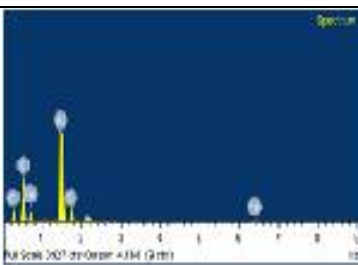
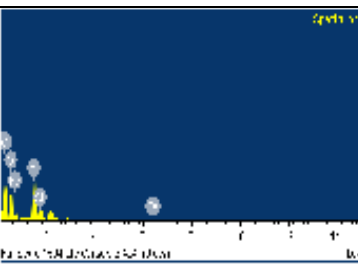
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The EDS micro analysis clearly shows that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The oxygen content increases from 15.38% to 29.95%. This leads to reduction in volume loss.

b) Specimen: Al-20Si+TiB:

AT: AT 60°C Al-20Si oxygen content:17.2%	AT: AT 60°C Al-20Si+Ti oxygen content:14.6%	AT: AT 60°C Al-20Si+TiB oxygen content:16.7%
		
		
AT: AT 120°C Al-20Si oxygen content:24.67%	AT: AT 120°C Al-20Si+Ti oxygen content:26.4%	AT: AT 120°C Al-20Si+TiB oxygen content:27.43%
		
		
AT: AT 180°C Al-20Si oxygen content:31.32%	AT: AT 180°C Al-20Si+Ti oxygen content:35.8%	AT: AT 180°C Al-20Si+TiB oxygen content:35.32%

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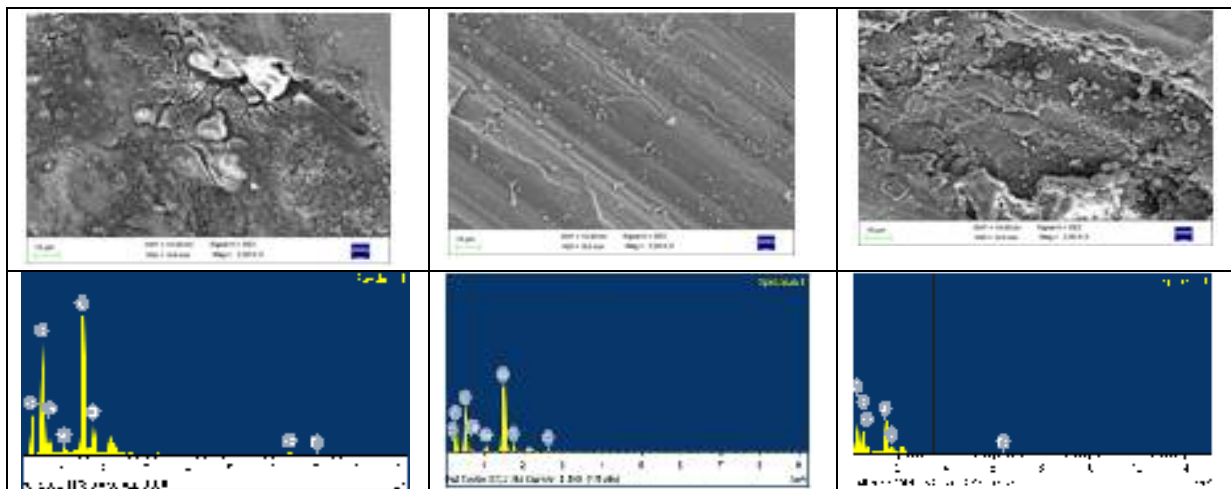


Table 3: The SEM microphotographs and EDS of Al-20Si+TiB alloys at Normal pressure 0.975N/mm²

The EDS micro analysis clearly shows that the oxide layer formation increases as the temperature increases from 60°C to 180°C. The oxygen content increases from 24.59% to 35.36%. This leads to reduction in volume loss.

IV. CONCLUSION

The dry sliding wear behavior of Al-13,20Si alloys have studied with and without addition of bare titanium and titanium boron at elevated temperatures and the following conclusions have drawn.

- The wear resistance of the hyper eutectic Al-Si alloys improves with the addition of titanium boron as compared to bare titanium.
- The wear rate of the Al-13, 20Si alloys with and without the addition of TiB increases as the normal pressure and sliding distance is increased.
- Wear rate increases with increase in silicon content for hyper eutectic Al-Si alloys.
- The wear rate of the Al-13, 20Si alloys with and without the addition of TiB decreases with an increase in temperature. 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.

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