Int. J. Mech. Eng. & Rob. Res. 2013

International Journal of Mechanical Engineering and Robotics Research

ISSN 2278 – 0149 www.ijmerr.com
Vol. 2, No. 4, October 2013

Research Paper

INFLUENCE OF SLIDING SPEED ON TRIBOLOGICAL BEHAVIOR OF HYPEREUTECTIC AL-15SI-4CU CAST ALLOY WITH MELT TREATMENTS

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Hypereutectic aluminum silicon alloys are mainly used in cast form in important components like pistons, cylinder liners, rocker arms, air conditioner compressors, brake drums, engine blocks, etc. These have inherent advantages of being high wear resistance, high strength to weight ratio, high corrosion resistance, good cast performance, high thermal conductivity, good weldability, etc. The influence of sliding speed on tribological behavior of hypereutectic Al-15Si-4Cu cast alloy with melt treatments like grain refinement, modification and refinement was investigated in the present study. Dry sliding wear tests were conducted for varying speeds from 1 m/s to 3 m/s insteps of 0.5 m/s for a constant sliding distance of 1000 m and at constant load of 40 N. The results suggest that increase in the sliding speed of the pin decreases the wear volume, wear rate and coefficient of friction of the cast alloys. These cast alloys exhibited more wear resistance when the sliding speed of the pin is increased.

Keywords: Grain refinement, Modification, Refinement, Sliding speed, Wear resistance

INTRODUCTION

The development of aluminum silicon alloys is very important due to their high wear resistance, high strength to weight ratio, low coefficient of thermal expansion, high thermal conductivity, high corrosion resistance, good cast performance, good weldability, etc., which makes them potential candidate material in many tribological applications, aerospace and other engineering sectors where they can successfully replace ferrous components in heavy wear applications. These applications demand the study of techniques to improve the wear properties of these alloys. For this

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purpose many researches had been done to enhance their wear properties. Aluminum silicon alloys are mainly used in cast form in important components like pistons, engine blocks, cylinder liners, rocker arms, air conditioner compressors, brake drums, etc. The improvement in the sliding wear resistance and mechanical 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. With the development of automobile industry, the need of hypereutectic Al-Si alloys increasing greatly. Al-Si alloys containing more than 13 wt% silicon are known as hypereutectic Al-Si alloys. The hypereutectic Al-Si alloys contain hard primary particles of non-metallic silicon embedded in an Al-Si eutectic matrix. These alloys have serious machinability problems due to the presence of the hard primary silicon phase which acts as abrasives. In order to obtain the best machinability and low wear rate the size of silicon phase must be controlled through melt treatment. Wear rate of the material decreases with increase in hardness of the material. It should be noted that it is the hardness of the contacting asperities that will improve the wear resistance.

Wear resistance in Al-Si alloys is primarily due to the presence of silicon in the aluminum matrix. Increasing the silicon content in Al-Si alloys increases the wear resistance and strength at the expense of machinability. Aluminum silicon alloys can be strengthened by adding small amount of Cu, Ni or Mg and the presence of silicon provides good casting properties. Copper results in the precipitation of $CuAl_2$ particles in the structure. A number of studies have been reported on the dry sliding wear behavior of the cast Al-Si alloys. A number of studies have been reported on the dry sliding wear behavior of the cast Al-Si alloys. These reports are very conflicting in nature.

Various studies have been reported on the dry sliding wear behavior of the cast aluminum silicon alloys. Sarkar and Clarke (1980) investigated the dry sliding wear behavior of aluminum silicon alloys using pin-on-disk wear and friction machine and concluded that silicon composition in aluminum alloy does not appear to be a dominant factor in the calculation of wear resistance. Pramila and Biswas (1987) investigated the wear behavior of aluminum silicon alloys and concluded that wear rate of an alloy with out silicon is significantly higher than the binary modified alloys containing silicon composition between 4% and 24% and also concluded that there is no systematic trend in wear of aluminum silicon alloys containing 4-24% wt silicon. Sarkar (1975) studied the wear of aluminum silicon alloys against hardened steel disc and gray cast iron and reported that the wear rate of hyper-eutectic alloys is more than the hypo eutectic alloys. Shivanath *et al.* (1977) reported that wear resistance is good for the hypereutectic aluminum silicon alloys. Somi *et al.* (1994) investigated the wear and seizure behavior of Al-Si alloy containing silicon composition up to 23 wt% using Pin-On-Disc wear and friction testing machine under various loads. It was observed from the results that wear and seizure resistance increases with the addition of silicon to aluminum. Clarke and Sarkar (1979) investigated wear behavior of binary Al-Si alloys and reported that wear rate of the aluminum silicon alloys is not linear with the applied load on the pin and near eutectic alloy is the idea material from the point of view of wear and load carrying capacity. Sarkar and Clarke (1982) conducted experiments on aluminum silicon alloys and suggested that war fragments are produced from the transferred material and high Young's modulus of the hypereutectic cast alloys increases their propensity to wear. Subramanian (1991) studied the effect of sliding speed on wear behaviour of aluminum silicon alloys and reported that the wear rate decreases with increasing sliding speed up to a critical speed. Elmadagli *et al.* (2007) have done a parametric study of the relationship between microstructure and wear resistance of Al-Si alloys and concluded that increasing the alloy hardness and Si volume fraction increased the transition loads and also concluded that they did not have a significant effect on the wear coefficients. Anasyida *et al.* (2009) has investigated the effect of element additions on the dry sliding wear of Al-Si alloys. Rohitgi and Pai (1974) investigated the effect of microstructure and mechanical properties on the seizure resistance of aluminum alloys and concluded that seizure resistance of aluminum can be improved by alloying with silicon and nickel. This is due to the precipitation of hard particles in the matrix. Chandrashekharaiah and Kori (2009) investigated on the wear resistance of eutectic Al-Si alloys and suggested that wear resistance increases with the addition of grain refiner and modifier. Dwivedi (2006) reported that the addition of alloying element to the Al-Si alloy reduces the wear rate and increases the transition load. Hence it is obvious from the above that there is still no clear agreement in the literature regarding the wear resistance of Al-Si alloys. The dry sliding wear behavior of a poly phase alloys is difficult and it is not a simple function of alloy composition.

The present work investigates the influence sliding speed on the tribological behavior of Al-15Si-4Cu cast alloy with grain refiner or modifier or refiner and combined addition of all against a hardened steel disc by using a Pin-On-Disc tribometer. Table 1 gives the details of the alloys, grain refinement, modification and refinement of various alloys.

Table 1: Test Specimens of Al-15Si-4Cu Cast Alloys

S. No.	Alloy Designation	Alloy Composition	GR (wt %)	Modifier and/or Refiner (wt%)
1.	P-1	Al-15Si-4Cu	–	–
2.	P-2	Al-15Si-4Cu-0.04Sr	–	0.04
3.	P-3	Al-15Si-4Cu-0.04P	–	0.04
4.	P-4	Al-15Si-4Cu-0.04Sr-0.04P	–	0.04
5.	P-5	Al-15Si-4Cu-0.04Sr-0.04P-1M13	1.0	0.04
6.	P-6	Al-15Si-4Cu-0.04Sr-0.04P-1M51	1.0	0.04

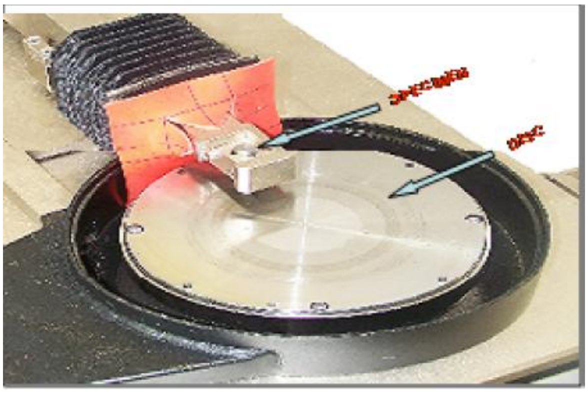
Note: Grain Refiners: M13=Al-1Ti-3B, M51=Al-5Ti-1B. Modifier/ Refiner: Strontium(Sr)/Phosphorus(P).

EXPERIMENTAL PROCEDURE

Al-15Si-4Cu alloy was prepared by melting high purity aluminum (99.7%) with master alloy Al-20%Si and Al-30%Cu in clay graphite crucible in a furnace and the melt was held at 850 °C. Melt was degassed with 1% solid hexachloroethane before the addition of modifier/grain refiner Modification was done by the addition of 0.04%wt Sr in the form of Al-10%Sr master alloy. Refinement of the Al-

15Si-4Cu was done by the addition of 0.04%wt P in the form of red phosphorus. Grain refinement was done with the master alloys Al-1Ti-3B or Al-5Ti-1B. The melt was stirred for 30 seconds after the addition of modifier and/or grain refiner. The melt was poured into a cylindrical graphite mould of 25 mm internal diameter and 150 mm in height. The microstructures of the test samples are cut in the longitudinal direction and were studied. A pin on disc type wear and friction monitor (TR-20LE, DUCOM, Bangalore) with data acquisition system was used for tribological behavior of aluminum silicon alloys. Figure 1 shows the photograph of the test specimen on the tribometer disc.

Figure 1: Test Specimen on the Tribometer Disc



The pins of 8 mm diameter and 25 mm length were fabricated from castings against hardened ground steel (En-31) disc having hardness of RC 62 and surface roughness (Ra) 0.1 µm. Dry sliding wear tests were conducted for varying speeds from 1 m/s to 3 m/s insteps of 0.5 m/s for a constant sliding distance of 1000 m and at constant load 40 N. Track diameter of 100 mm was selected for the experimental tests. The friction force was recorded during the experiment by using a load cell. It has a maximum load capacity of 200 N and measures the frictional load at an accuracy of ±0.1 N in the load range of 0-200 N. Frictional force (N) was measured as a function of time. Figure 2 shows the photograph of the controller of the Pin-on-Disc wear testing machine.

Figure 2: Controller of the Wear Testing Machine

The pins were weighed before and after each test to measure the change in weight for wear loss calculations. Before the test, the polished pins were cleaned first with water and soap, followed with ethanol and finally with acetone. Cleaned samples were dried in an oven for 30 min at 80 °C. Table 2 gives the details of the chemical analysis of master alloys.

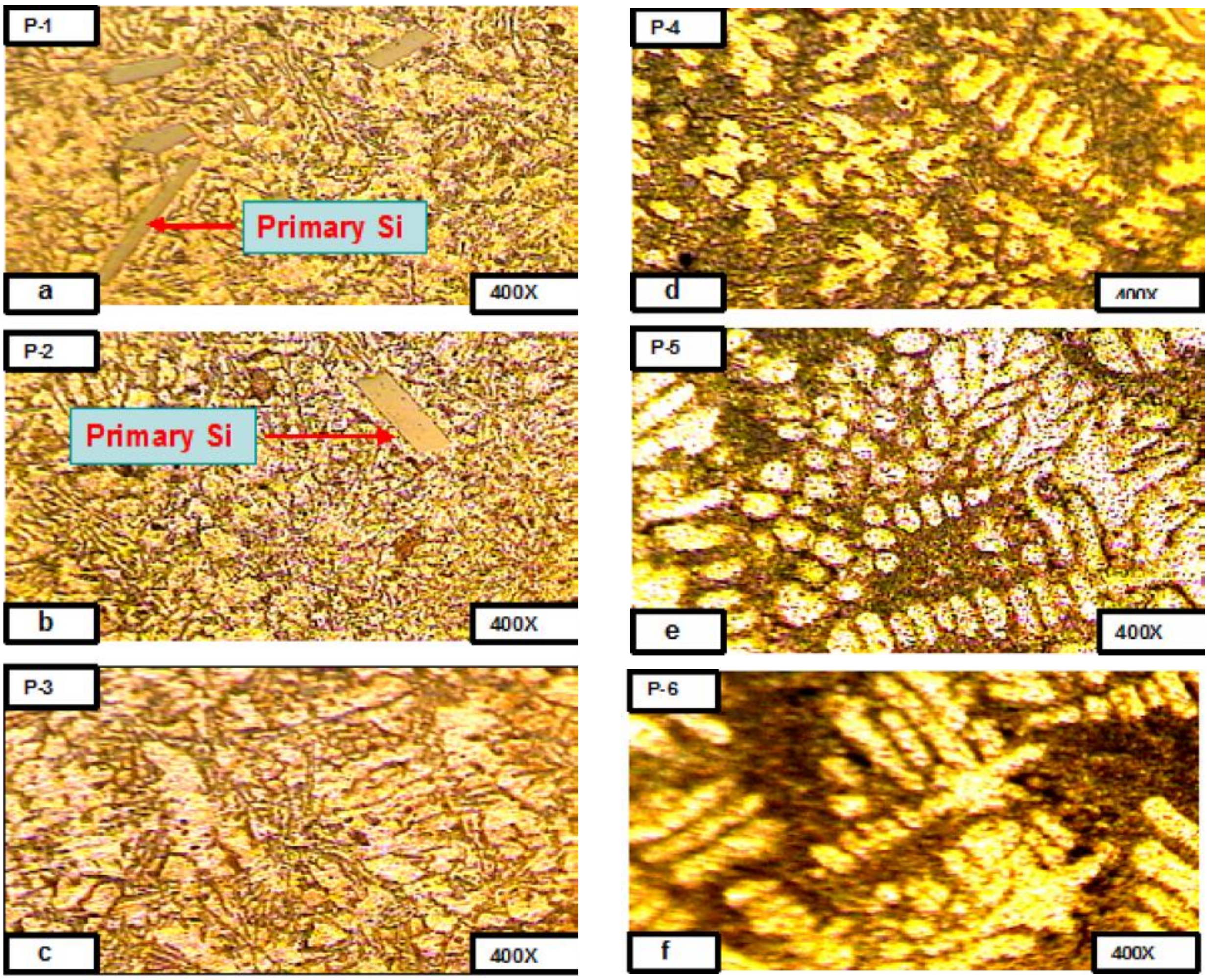
RESULTS AND DISCUSSION

Dry sliding wear behavior of Al-15Si-4Cu cast alloys depends on the size, shape of the silicon particles and size distribution of the α-Al grains in the interdendritic region. Figure 3a shows the microstructure of unmodified Al-15Si-4Cu alloy containing primary silicon and eutectic silicon. Unmodified acicular silicon acts as internal stress riser in the microstructure and provides easy path for fracture. Figure 3b

Table 2: Chemical Analysis of Master Alloys

Alloy	Composition (% wt)						
	Fe	Si	Sr	Cu	Ti	B	Al
Al	0.15	0.08	–	–	–	–	Balance
Al-20Si	0.10	20.2	–	–	–	–	Balance
Al-10Sr	0.19	0.12	10	–	–	–	Balance
Al-30Cu	0.18	–	–	30.3	–	–	Balance
Al-1Ti-3B	0.17	0.16	–	–	1.13	2.25	Balance
Al-5Ti-1B	0.17	0.15	–	–	5.62	1.04	Balance

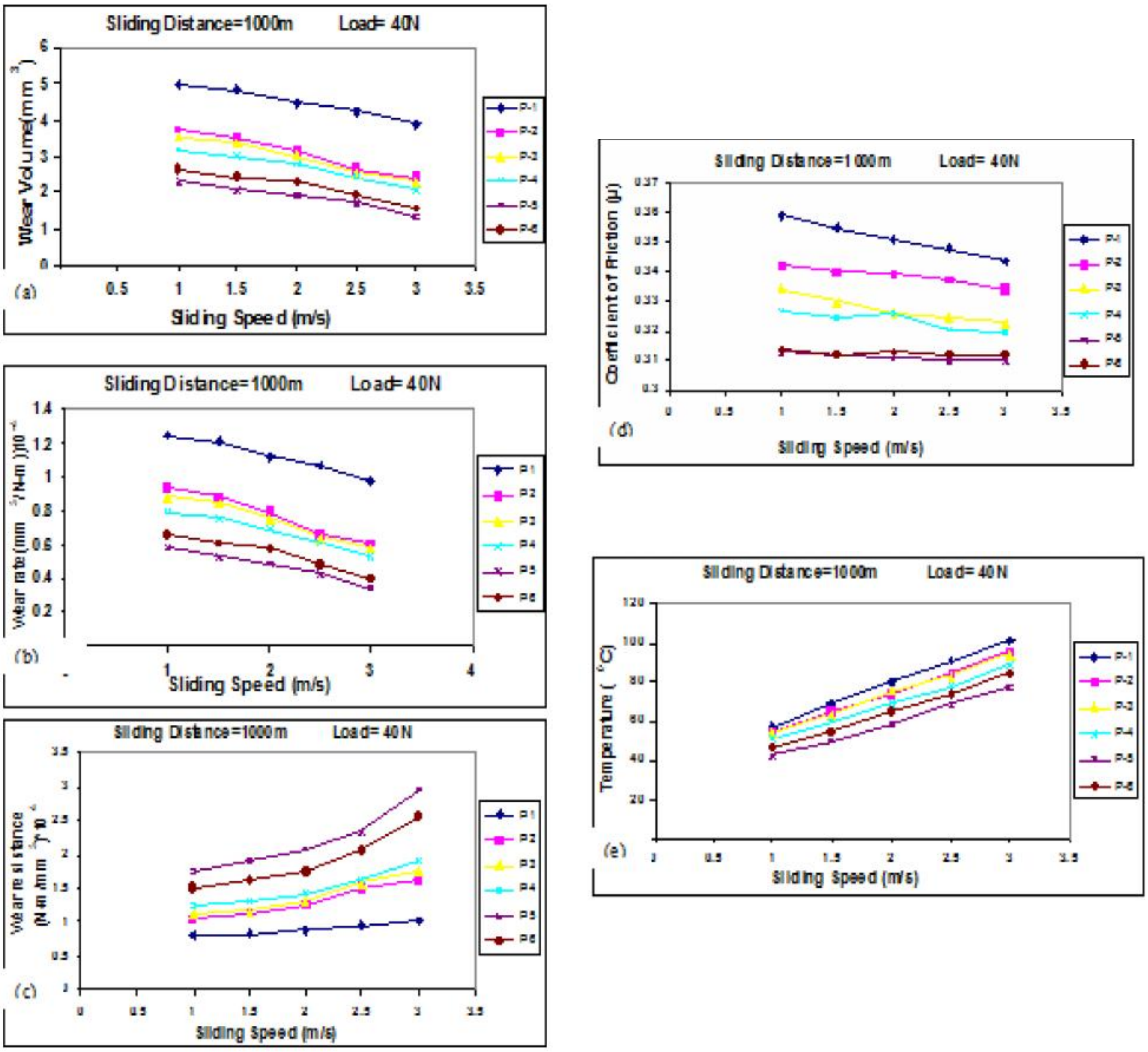
Figure 3: Optical Microphotographs of Al-15Si-4Cu Cast Alloy: (a) Un-modified (b) with Modifier (0.04% Sr) (c) with Refiner (0.04% P) (d) Combined Addition of Modifier (0.04% Sr) and Refiner (0.04% P) (e) with Grain Refiner (1% of M13) in Addition to the Combined Addition of Modifier (0.04% Sr) and Refiner (0.04% P) (f) with Grain Refiner (1% of M51)



shows the microstructure of Al-15Si-4Cu alloy after modification. The addition of modifier (Sr) to Al-15Si-4Cu cast alloy changes the eutectic silicon to fine particles in the interdendritic region. But strontium does not refine primary Si particles. In hypereutectic alloys, refinement is also achieved through the addition of phosphorus. The phosphorus has a marked effect on the size, shape and distribution of the primary silicon. The addition of refiner phosphorus to Al-15Si-4Cu alloy significantly refines the coarse platlet, star-like and irregular primary silicon to fine and uniformly distributed silicon particles possibly due to aluminum phosphide (AlP) acting as nucleating agent for silicon. This is shown in the Figure 3c. Figure 3d shows the combined addition of both refiner and modifier to the Al-15Si-4Cu unmodified alloy. After the addition of refiner and modifier, the microstructure shows fine fibrous silicon particles. Grain refiners are materials added to alloys to aid in nucleation, and lead to the production of fine and uniform grain size. There are several types of grain refiner available for aluminum-silicon alloys, based on aluminum-titanium or aluminum-titanium-boron master alloys, and titanium or titanium-boron containing salt tablets for hypereutectic alloys. Figures 3e and 3f shows the optical microphotographs of Al-15Si-4Cu cast alloy with grain refiners (by 1% of Al-1Ti-3B and 1% of Al-5Ti-1B master alloys) in addition to the combined addition of modifier (0.04% Sr) and refiner (0.04% P). The additions of grain refiners (Al-1Ti-3B and Al-5Ti-1B), modifier (Sr) and refiner (P) converts large α-Al grains in to fine equiaxed á-Al grains and forms fine fibrous silicon particles in the interdendritic region. This improves the wear properties of the cast alloy. The results also suggest that, the addition of Al-1Ti-3B master alloy along with Sr and P to the alloys show more uniformly distributed α-Al grains and fine broken grains of silicon particles in the interdendritic region compared to the microstructure obtained with individual additions of modifier and/or refiner.

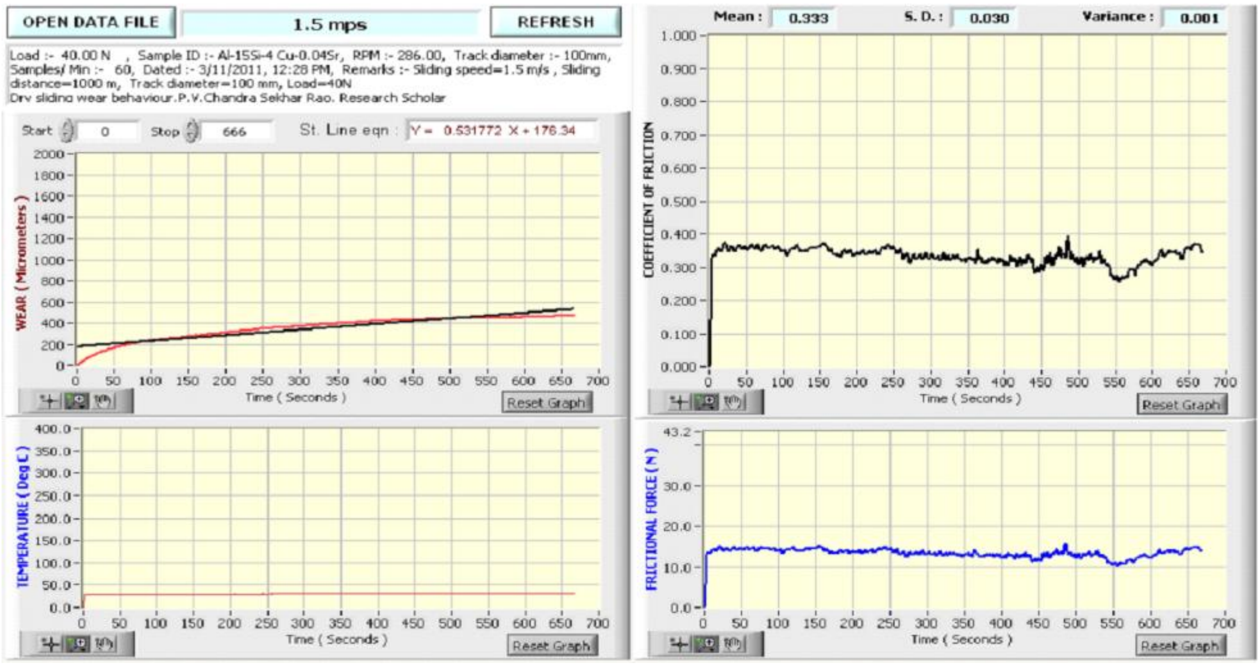
Dry sliding wear tests were conducted for varying speeds from 1 m/s to 3 m/s insteps of 0.5 m/s for a constant sliding distance of 1000 m and at constant loads of 40 N. Figures 4a-4e show the effects of sliding speed on the dry sliding wear behavior of hypereutectic Al-15Si-4Cu cast alloy with grain refinement, modification and refinement at a constant load of 40 N respectively for a sliding distance of 1000 m. It is observed that the wear volume and volumetric wear rate decreases with increasing sliding speed. This may be due to the more contamination of sliding interface by oxide layer. The oxide layer reduces the chance of direct metallic contact due to which tiny contact points (asperities) interaction is decreased. The wear test of the Al-15Si-4Cu unmodified alloy was carried out at the highest sliding speed of 3 m/s. It was observed that seizure does not take place at this speed and load. At seizure there will be more noise and vibrations. Tests were stopped at this speed and load. The unmodified Al-15Si-4Cu recorded highest wear rate due to the presence of primary silicon and eutectic silicon in the interdendritic region. The wear volume and wear rate are less and wear resistance is more for the combined addition of grain refiner, refiner and modifier due to refinement of silicon and aluminum particles. It was observed that the coefficient of friction is decreasing for all

Figure 4a-e: Effect of Sliding Speed on the Dry Sliding Wear Behavior of Al-15Si-4Cu Alloy with Various Melt Treatments at Constant Load of 40 N and Constant Sliding Distance of 1000 m



the alloys when the sliding speed is increased. This may be due to the presence of oxide layer. Temperature measurement of wear pin during the sliding wear was carried out using chromel-alumel thermocouple. Temperature of the pin was recorded with the help of digital temperature indicator of the tribometer. Temperature is very important parameter for explaining the wear and friction behavior. It was also observed that increase in sliding speed increases the interface temperature. Increase in temperature increases the ability of soft aluminum matrix to have enough space for hard and brittle second phase silicon particles. Figure 5 shows the data acquisition report of the test specimen.

Figure 5: Data Acquisition Report of the Test Specimen



CONCLUSION

Influence of sliding speed on tribological behavior of hypereutectic Al-15Si-4Cu cast alloy with melt treatments for different conditions was investigated and the following conclusions could be drawn:

- Increase in the sliding speed of the pin decreases the wear volume and wear rate of the alloys.
- The coefficient of friction is decreasing for all the alloys when the sliding speed is increased.
- Increase in the sliding speed of the pin increases the wear resistance of the alloys.
- The interface temperature of the all alloys increases when the sliding speed of the pin is increased.
- The results say that the wear behavior of Al-15Si-4Cu cast alloy depends on the size, type of second phase particles in the matrix.
- The grain refinement, modification and refinement increase the wear resistance during dry sliding of cast Al-15Si-4Cu alloy.

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