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Effect of Variation in Stroke Length on Dry Reciprocating Wear of Aluminium Alloys☆

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Abstract

The dry reciprocating sliding wear studies of aluminium alloys was carried out at three large stroke lengths of 50 mm, 100 mmand 150 mm. The aluminium alloys varied in silicon content with 7% Si, 13% Si and 18% Si. The wear tests were conducted onan in-house designed pin on plate reciprocating tribometer. The results showed upward trend for wear loss with increase strokelength. The tests revealed that the rate of increase in wear loss with stroke length was not linear even under similar test conditions. In the present study, wear loss was highest for 50 mm stroke length followed by 150 mm and 100 mm respectively. The CoF was decreasing with increasing loads for the sliding distance considered. This is due to the plastic deformation at higher loads that permitted the asperities to bend. Increase of silicon content in aluminium is not advisable for larger stroke length without thorough wear evaluation. The results confirm the importance of stroke length as a parameter in reciprocating wear evaluation.
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*Keywords:*stroke length; reciprocating sliding; frictional temperature; aluminium alloys

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1. Introduction

Aluminium and its alloys have high specific strength and good heat transfer ability which enables it to replace ferrous alloys. Aluminium and its alloys are used in sliding contacts which may be unidirectional or reciprocating. Reciprocating sliding contact results in higher wear rate than under unidirectional sliding contact. Hence every material system of reciprocating contact has to be tested separately [1]. Several studies were reported on variation of wear rate with stroke length or amplitude under reciprocating sliding wear tests [2, 3, 4, 5, 6, 7, 8].

Bethune et al. 1968 [9] had compared the effect of stroke length with coefficient of adhesion. Coefficient of Adhesion (CoA) was defined as the ratio of load required to separate the surfaces to the normal load applied. Several materials including aluminium and its alloys were tested. All results showed increase in CoA with stroke length. Amplitudes were from 0.0127 mm (0.0005 inches) to 0.1016 mm (0.004 inches). Rapid increase was observed in CoA with stroke length upto 0.0381 mm (0.0015 inches) and then the rate of increase got flattened. It was also proved that atmospheric exposure hence oxidation and larger amplitudes reduced adhesion hence the reduced CoA.

Ohame et al. [2] studied the effect of slip amplitude in fretting wear for mild steel. From the range of 0 to 600 μm, the wear loss was smaller up to 70 μm there after increased steadily. But after 300 μm the wear loss again become nearly constant. Initial lower wear was attributed to the oxidative wear mechanism. At larger amplitudes, it was explained that, the wear mechanism followed the following sequence (1) Virgin surface roughness diminished by the plastic deformation of each asperity (2) Mechanical type of wear phenomenon, especially initial adhesion, became a significant factor (3) Oxidative and abrasive wear acted simultaneously at the steady state.

Hu et al.[3] examined the nature of the debris generated during the fretting wear of the SiC particle reinforced 2124 Al-Cu-Mg alloy matrix composite against medium carbon steel. It was then related to fretting stroke of lengths which were 40 μm, 80 μm and 120 μm. In this paper, it was reported that, there was no significant relationship between Coefficient of Friction (CoF) and stroke length. Total wear loss volume followed the similar pattern for all stroke lengths. The total wear volume increased with fretting stroke length. The size of wear particle and content of counterface material in debris increased with stroke length. This effect was attributed to the decreased debris buildup on the counterface with increased stroke length which produced earlier abrasion of the steel specimens. There was reduction in inclined cracks with increasing stroke length and was related to the reduced number of stress reversals per unit sliding distance at larger stroke length.

Chen et al.[4] explored the changes in characteristics of wear before and after the transition between fretting and reciprocating sliding wear. ASI52100 steel was used as ball and counter surface material with stroke lengths from 10 μm to 2000 μm. It was found that wear rate increased rapidly when the amplitude was in the range of 60 - 70 μm. But above 100 μm wear was steady. The change in wear loss was taken as an indicator of transition in wear mechanism. The CoF was reported to be higher for stroke length of 100 μm than 700 μm for smaller sliding distance and was nearly equal when the distance slid increased. The wear loss increased with sliding distance when the stroke length was 70 μm. At 300 μm, the wear rate increased rapidly with sliding distance and then nearly stable. It was pointed out that, at 70 μm stroke length, the mechanism was abrasive initially, then adhesive and abrasive wear. In case of 300 μm, the mechanism was abrasive as reported. To distinguish between fretting and reciprocating wear, it was suggestedthat the frictional force is not sufficient.

Gomes et al [5] had studied the reciprocating wear characteristics of Al-Si/SiCp composites with stroke lengths of 0.25 μm, 0.5 μm, 0.75 μm (called fretting) and 2 mm, 4 mm, 6 mm (called reciprocating wear). It was reported that wear loss increased with stroke lengths. In both cases after the first two stoke lengths, wear loss increased suddenly. The wear loss variation was correlated to energy dissipation mechanism. As stroke length increased more energy had to be dissipated hence the increased wear volume. No temperature measurement was done in this study. Wear loss in reciprocating wear was reported to be 125 times that of fretting wear.

Shen et al. [6] studied the effect of fretting amplitudes on fretting wear behavior of steel wires in coal mines. It was reported that fretting regime of steel wires transformed from partial slip regime into mixed fretting regime and then to gross slip regime with an increase in fretting amplitude under a given contact load. The fretting wear mechanisms of steel wires as reported were abrasive wear, surface fatigue and friction oxidation in mixed fretting and gross slip regime.

Li at al. [7] studied the effect of displacement amplitude on fretting wear behavior and mechanism of Inconel 600 alloy. It was reported that the increase of fretting amplitude increased the CoF and wear volume. Wear mode changed from adhesion to slide. Wear mechanism transformed from local adhesive damage to a combination of oxidation and delamination wear. Fluctuations in the CoF observed were attributed to actual changes of the contact surface. The increased wear volume with amplitude was attributed to more oxide debris was generated during the fretting test as stroke length increased.

Yun et al. [8] examined the effect of frequency and amplitude on the wear mode changes for Inconel 690 SG tubes slid against SUS 409. It was reported that wear mode changed from stick to gross slip as amplitude increased from 25 μm to 300 μm. But duration or frequency of sliding had no effect on the wear mode. The CoF followed the same pattern and is attributed to stick phenomenon, that occurred at low amplitude and high normal load. The high CoF from 25 to 50 μm was attributed to change in the wear mode and was the mixed stick and slip phenomenon.CoF mildly increased above 50 μm , indicating the wear mode as gross slip. The constant value of wear coefficient indicated reciprocating sliding wear condition as reported.

Hardness is affected by higher temperature due to frictional heating in sliding contacts. The frictional energy generated at interface depends on factors like applied load and velocity along with other factors like material properties. Contact size also influences the distribution and dissipation of the frictional energy [10]. Studies were conducted for frictional temperature and its effect on wear loss and wear mechanism [11, 12]. In reciprocating sliding, stroke length is an important parameter determining the generation of frictional heat energy and its dissipation.

The parameters affecting wear rate are sliding speed, normal load, temperature, environment and counter surface. The percentage of silicon in aluminium alloys significantly affects wear rate. Biswas et al.[13] studied the effect of silicon content on the wear of Al- Si alloys. It was reported that wear rate decreased with increased percentage of silicon content. The temperature built up in the reciprocating wear was higher than unidirectional at a speed of 0.6 m/s and 0.8 m/s respectively for 17% Si alloy but showed similar decreasing trend with increasing silicon content.

The present authors eariler conducted experiments on the wear response of A 390 alloy produced by gravity and squeeze casting [14]. It was reported that squeeze casting improved wear resistance. Further it was proved that unless the effect of stroke length is not considered, the wear tests from reciprocating tests is less confirming.

It is evident that wear under reciprocating contact depends on amplitude or stroke length. But studies on the variation in stroke length is limited to 6 mm Gomes et al.[5] from the literature reviewed. However applications like engine and cylinder pair, the stroke length is greater than 50 mm. Hence it is worth to study the effect of stroke length on wear and in particular of aluminium alloys. This study reports the dry sliding wear studies for varying stroke lengths (50mm, 100 mm and 150 mm). The materials used were three different aluminium alloys with silicon content with 7% Si, 13% Si and 18% Si. Results showed that smaller and larger stroke length have higher wear rate.

2. Experimental section

Wear tests were carried out on a pin-on-plate tribometer (in house fabricated; reciprocating wear test rig) under dry sliding condition [15]. The schematic diagram of the test rig is given in the Figure 1. The dimensions of the pins were 30 mm length and 5.9 mm diameter. Initially specimens were thoroughly cleaned by using acetone and waited few seconds to dry. Then wear specimens were accurately weighed three times in a Shimadzu Micro-analytical Balance with a least count of 0.0001 mg and averages were taken. Specimens were then loaded on to the wear test rig, load is applied through the lever mechanism. Load was varied from 15 N to 75 N in steps of 15 N. The average velocity was kept constant at 0.4 m/s. The reciprocating motion was provided by a rotating crank which has a provision to change the radius. Thus radius of crank used were 25 mm, 50 mm and 75 mm resulting in reciprocating sliding stroke lengths of 50 mm, 100 mm and 150 mm. The wear was measured by weight loss method using the microbalance. For estimating the coefficient of friction, the lateral forces was measured by two force sensors (load cells). Data was recorded using a Keithley make DAQ of Model Integra Series 2700 Multimeter.

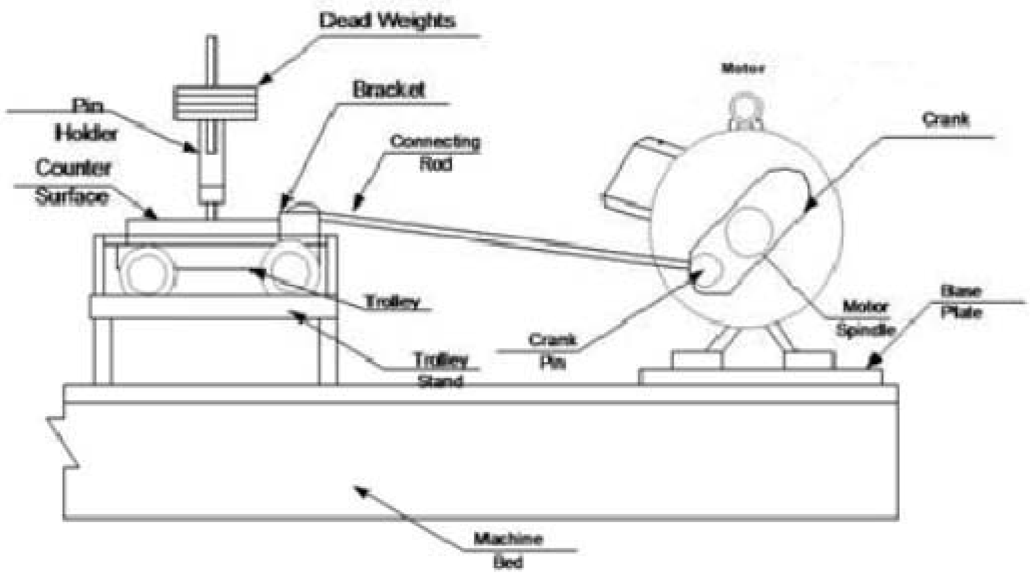

Fig. 1. Schematic Diagram of Reciprocating Wear Test Rig.

3. Results and discussion

3.1. Coefficient of Friction (CoF) Vs Stroke length

The Coefficient of friction was estimated as the ratio of normal load to tangential load. The tangential load was measured using load cell and DAQ as mentioned in Section:2. Al-7%Si alloy is reported to have least wear resistance [13] compared with other alloys of this investigation. The CoF of 7% Si alloy decreases with stroke length and increases with the stroke length as in Figure : 2. As load increased, the alloy deformation increased as it contains less silicon. This deformation increased stick phenomenon and hence the increased coefficient of friction. But as stroke length increased, more frictional energy was released per cycle and hence more frictional heat was generated. This frictional heating softened the matrix hence the reduced the CoF for same load at higher stroke length.

Al-13%Si in this investigation had higher CoF at lower loads as in Figure : 3. At lower loads, asperties resisted deformation. Higher silicon content increased strength of asperities, which increased resistance to relative motion, hence the higher CoF. But as load increased, the deformation of asperities increased and CoF decreased and got stabilized in the load range examined. CoF at 50 mm and 150 mm stroke length was lower than 100 mm. This was due to the more time available at 150 mm stroke to cool the materials and less energy available per stroke at 50 mm. Hardness was preserved at 100 mm compared to other stroke length for this 13% Si alloy.

The CoF decreased with load for 18% Si alloy Figure : 4. This was due to normal load as explained before for the range examined. Silicon provided more strength to the aluminium alloy. Hence, as the stroke length was extended and thus energy per cycle was increased. This resulted in substantial interlocking of hard asperities. Hence in this case, CoF increased with stroke length.

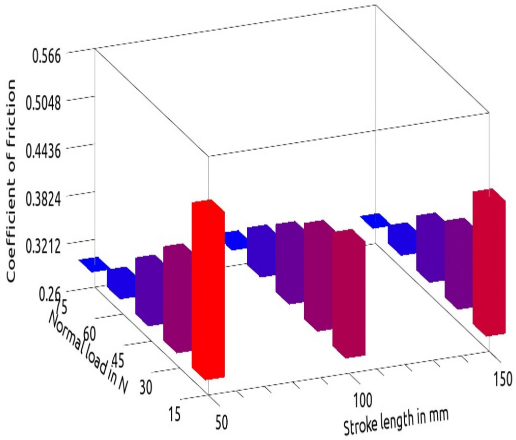

Fig. 2. CoF vs Stroke length vs Normal load plot for a 7% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

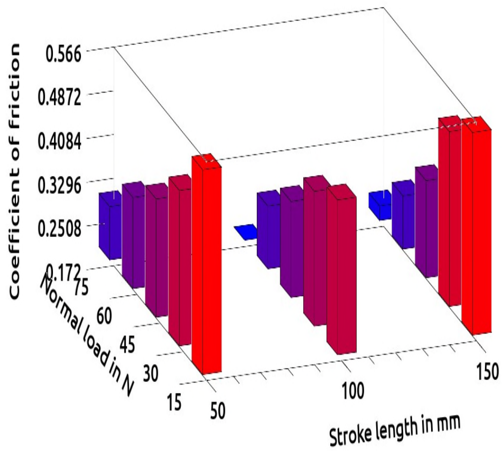

Fig. 3. CoF vs Stroke length vs Normal load plot for a 13% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

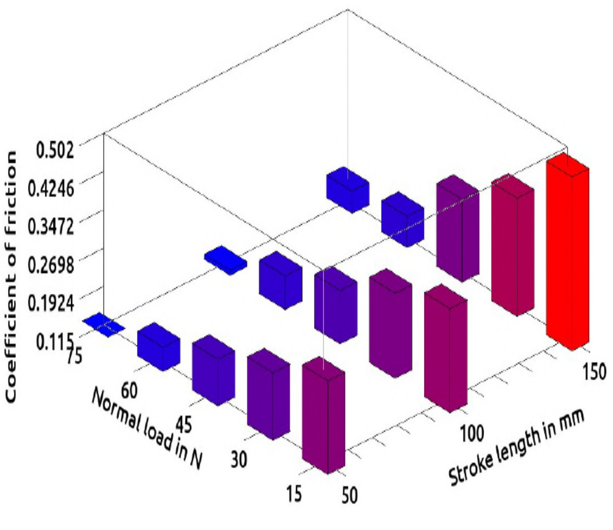

Fig. 4. CoF vs Stroke length vs Normal load plot for a 18% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

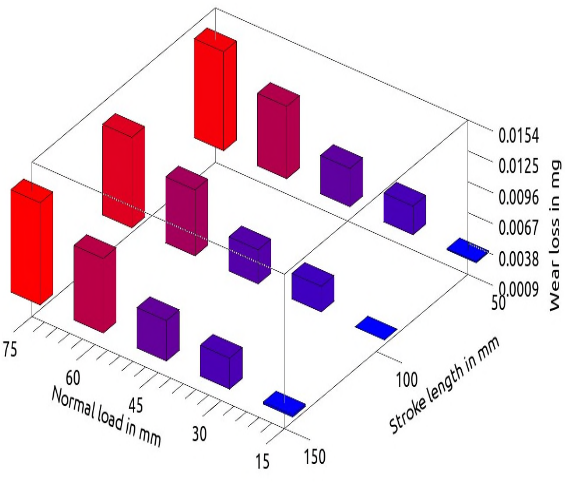

Fig. 5. Wear loss vs Stroke length vs Normal load plot for a 7% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

3.2. Wear loss Vs Stroke length

The wear loss for the Al-7%Si alloys is shown in Figure 5. Wear loss was larger at 50 mm and 150 mm compared to 100mm. At 50 mm the fatigure failure of asperities increased, since the frequency was higher at 4 Hz. In the case of 150 mm stroke length, large amount of energy per stroke was available and this ploughed more materials. For 100 mm it was lower due the present setup becomming optimum with respect to heat generation and dissipation mechanism was considered. This factors lead to lower thermal softening of the material at 100 mm.

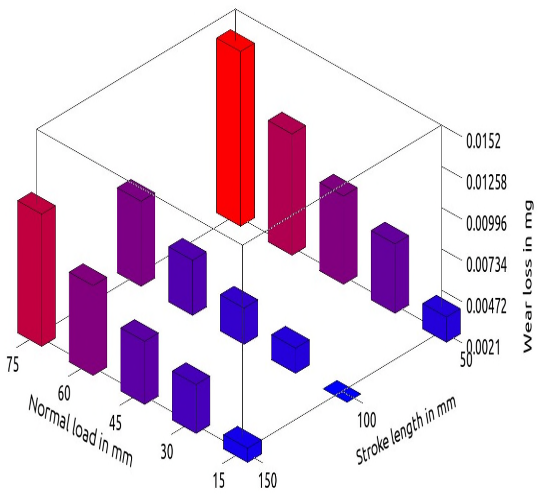

Fig. 6. Wear loss vs Stroke length vs Normal load plot for a 13% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

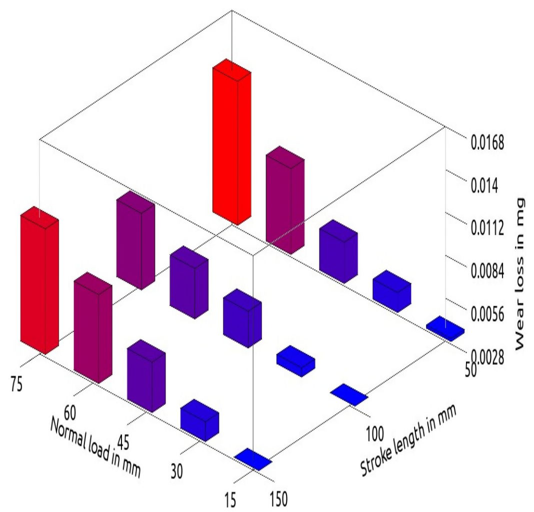

Fig. 7. Wear loss vs Stroke length vs Normal load plot for a 18% Silicon alloy, 400 m sliding and average velocity of 0.4 m/s

Al-13%Si alloy the wear loss increased with the normal load, Figure 6. But wear loss was higher for 50 mm and 150 mm stroke length compared to 100 mm. Hadness of this alloy increased due to higher silicon content. Harder material increased frictional heating at smaller stroke length. Futher, the fatigue fracture was more at lower stroke length due to the higher frequency of oscillation compared to other stroke length. This two factors increased the wear rate at 50 mm. The increase in wear loss at 150 mm is due to the larger amount of energy dissipated per cyle.

Wear loss was found to increase with normal load for all stroke length for the Al - 18% Si alloy, Figure : 7. As the silicon content increased to 18 % in aluminium its high temperature hardness increased. At lower stroke length, oscillating frequency was higher to maintain the speed. Hence reversal of load was more frequent. This fractured more material and thus produced more wear at smaller stroke length. At larger stroke length, the force per cycle was more. This had induced more energy at each asperity per cycle and reduced chance to dissipate this energy. Increase in wear loss was the result. Present test setup is thus producing less wear loss of material at 100 mm stroke. Hence the experimental setup of present study is optimized for 100 mm stroke length leading to lower wear loss.

4. Conclusion

The dry reciprocating wear studies on Al with 7%, 13% and 18%Si alloys was conducted at room temperature using an inhouse designed reciprocating tribometer at different stroke lengths. The effects of stroke length on CoF and wear volume were analyzed. The following are the conclusions:

1. The stroke length had a strong effect on dry reciprocating wear. The wear was more at lower and higher stroke length. This is due to higher frequency of variation at smaller stroke length and larger energy per stroke available at larger stroke length.
2. The increase in silicon content will not raise the wear resistance at higher stroke length for all Al-Si alloys. The frequency and material combination is also important.
3. The frictional heating, silicon content and stroke length combination can significantly affect the wear strength. Hence more investigation need to be done on that combination

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