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Tribological characteristics of as-cast A356/10wt.% SiC_p functionally graded composite dry sliding against EN-31 steel under unidirectional and oscillatory modes

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Abstract. A comparison in tribological response characteristics of as-cast Al-SiCp functionally graded composite material (FGM) dry sliding against hardened EN-31 steel under unidirectional and oscillatory sliding modes was investigated for a sliding/oscillating velocity of 0.4m/s slid through 500m utilizing a pin-on-disc configuration. The A356/10 wt.% SiCp FGM was prepared using vertical centrifugal casting technique. The microstructure characterization was done by Leica optical microscope, and the microstructural analysis revealed the presence of different zones due to the radial gradient distribution of SiCp reinforcement. The hardness variation was found to have a good correlation with its microstructural features at different zones of FGM. Wear loss against load curve indicated an increase in trend for both sliding modes, whereas the coefficient of friction versus load plot showed a decreasing trend for both cases under an identical set of operating parameters. Further, oscillatory wear loss of FGM/EN-31 steel tribopair was observed to be higher in comparison with unidirectional sliding mode for the entire load range, (30-150N) investigated. At the same time, the coefficient of friction of tribopair in oscillatory sliding mode was found to lower than the unidirectional mode.

1. Introduction

The ceramic particulate strengthened functionally graded composite materials (FGM) has been the excellent contender for the automotive parts which include piston, piston rings, gears, and brake pads/rotors, because of its enhanced strength to weight ratio and wear resistance [1,2]. The use of composite materials with tailored properties known as FGM has nowadays become popular in automobile, aerospace and biomedical sectors. These materials are produced to attain gradient in properties such as strength, wear resistance, high-temperature resistance and corrosion across its geometry, thereby weight savings could be resulted compared to metal matrix composites. Most of the previous studies reported in the literature have shown that dry sliding wear tests for FGMs were investigated utilizing pin-on-disc and block on ring tribometers wherein the relative motion of tribopair is only in one direction (unidirectional). E Jayakumar et al. 2016 [3] investigated wear characteristics of A319-SiC_p FGM using DUCOM pin-on-disc tribometer and reported that the wear resistance of the particle rich zone (outer region) is higher than matrix rich (inner) zone. Zhang et al.

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1997 [4] reported the transition from mild to severe wear characteristics of Al-Si alloys using block-on-ring tribotester. The authors noticed three different forms of transitions, namely, load, sliding velocity and sliding distance induced transitions. Recently, R Jojith et al. 2019 [5] investigated the friction and wear characteristics of heat-treated Al-7Si/B_4C FGM dry sliding against EN-8 steel using a pin on plate tribometer (DUCOM) as a function of load and sliding distance. The authors reported that the heat-treated outer zone of FGM having better wear resistance than as-cast composite. Studies reported on relative friction coefficient, and the wear resistance of these classes of materials in unidirectional and bidirectional/oscillating sliding modes are quite scanty [6-8]. P J Blau et al. 2000 [9] reported friction coefficent and wear characteristics of Mg alloy prepared by two different techniques tested using both unidirectional and reciprocating sliding contacts. The authors reported a higher friction coefficient for the sliding pair in unidirectional mode compared with reciprocating mode.

Etsuo Marui et al. 2001[10] reported the friction and wear characteristics in unidirectional and bidirectional sliding motion tests of Cu on steel. The authors pointed out a weak point in the pin-on-flat tribotester that sufficiently large velocity was difficult to achieve and could reach a maximum sliding speed of 1.11 cm/s only. In the present paper, it was planned to investigate the comparative study on the effect of friction and wear characteristics of as-cast A356/10wt.% SiCp functionally graded composite dry sliding against EN-31 steel under unidirectional and oscillatory modes using DUCOM make pin-on-disc tribometer with a sliding velocity of 0.4m/s.

2. Materials and methods

The material utilized in this investigation was hypo-eutectic Aluminium-Silicon alloy (A356) as the matrix for the preparation of functionally graded composite with 10wt.% SiC_p reinforcement. The composite melt was prepared through stir casting route followed by vertical centrifugal casting technique at a mould speed of 1300 rpm. The size of the prepared FGM disc was having an outer and inner diameters of 240mm and 60mm respectively with thickness 28mm. Microstructure characteristics of the prepared FGM were captured using a Leica optical microscope, and its correlation with hardness data was published elsewhere [11]. Wear test pins, 6 mm diameter whose axis was radial to the cast FGM disc to get particle rich and matrix rich zones at two ends of the pin, were cut from the disc using wire cut EDM machine. The pins were solution heat-treated at 500^0C for 6 hours, followed by water quenching at room temperature. Precipitation hardening was done at 200^0C for 12 hours, followed by furnace cooling to room temperature.

Comparison wear study of prepared FGM pin samples in unidirectional and oscillatory modes was performed under identical sliding conditions using DUCOM TR-20LE pin-on-disc tribometer. The same counter body disc of EN-31 steel was used for both unidirectional and oscillatory tribo testing modes since it is harder than the softer FGM pin. The steel disc was hardened to 55 HRC, ground and polished to a surface roughness value of 0.4μm (Ra). The pin was held stationary and pressed against the rotating/oscillating disc for conducting the wear test in both sliding modes. A sliding distance of 200 mm per cycle of the disc was selected for conducting wear test in oscillating tribotester so that a mean wear track radius calculated as 64mm used with a sector angle of 90^0 Figure 1. The same sliding distance per cycle was also fixed in unidirectional tribotester for comparing the wear characteristics of FGM in two different sliding modes. Accordingly wear track radius in unidirectional sliding condition was calculated as 32mm. Table 1 shows the test types and sliding conditions of FGM/EN-31steel tribopair. Wear tests were conducted in two sliding modes as a function of loads (30-150N) with a constant oscillating/sliding speed of 0.4m/s slid through 500m. The difference in weight of the wear test pin before and after testing was measured by using Shimadzu micro weighing balance having a resolution of 0.01 mg and converted to wear rate in mg/m. Bellows type load cell sensor attached with the tribotester was utilized for frictional force measurement.

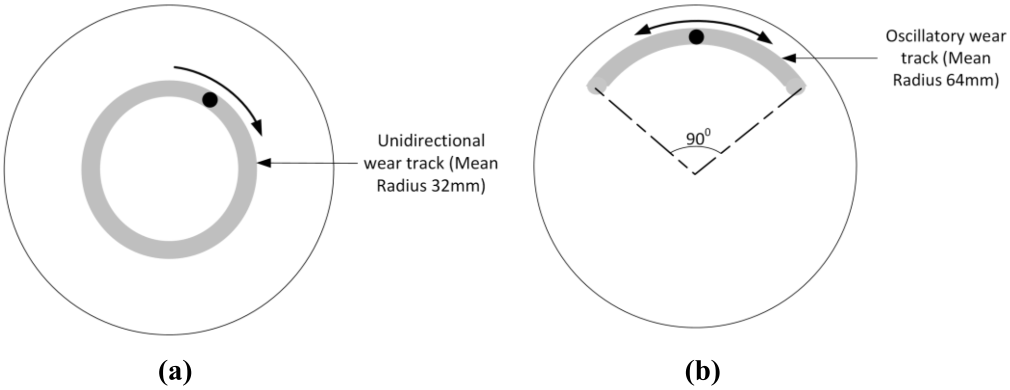

Figure 1. Schematic diagram of (a) Pin-on-rotating disc configuration (b) Pin-on-Oscillating disc configuration

Table 1. Test types and sliding conditions of FGM/EN-31steel tribopair

Operating parameter	Pin-on-Rotating disc	Pin-on-Oscillating disc
Speed/frequency	2 revolution/s	2 cycle/s
Sliding speed/Oscillating velocity	0.4 m/s	0.4 m/s
Mean Wear track radius	32 mm	64 mm
Sliding distance/cycle	200 mm	200mm

3. Results and discussion

A comparison study on dry friction characteristics of A356/10wt.%SiC$_p$ FGM (outer zone cylindrical pin) dry sliding against EN-31 hardened steel disc was performed in unidirectional and oscillating sliding modes Figure 1, under similar conditions of operating parameters using DUCOM-TR20LE tribometer. The effect of load on the frictional characteristics of FGM was discussed as follows.

3.1 Effect of load on dry friction characteristics of FGM in two sliding modes

The Figure 2 showed the frictional behaviour of FGM against load with an oscillating/sliding velocity of 0.4m/s slid through 500m in oscillating and unidirectional sliding modes. It indicates that as the load increases friction coefficient of FGM was found to decrease in both sliding modes and is attributed to increased tribolayer thickness upon the increase of load causing an increase in wear rate, but the decrease in friction coefficient [12]. It was also noticed that the friction coefficient of FGM in unidirectional contact was found higher than oscillating contact in the selected conditions investigated with load in the range of 30-150N. The reason for the higher friction coefficient in unidirectional contact is due to the deposits of ploughed material ahead of the slider for a more extended period compared to that in oscillating contact. P J Blau et al. [9] also noted the same behaviour that friction coefficient of die-cast and Thixo moulded AZ91D alloys dry sliding against 440C stainless steel counter face in unidirectional motion test was found higher than in reciprocating motion test due to the build-up of leading-edge material ahead of the sliding pin for a more extended period. But in reciprocating test chances are there that this leading-edge material to expel at the ends of the reversing stroke. Figure 3(a-d) show continuous data of friction coefficient versus time plot was taken at low load (30N) and high load (150N) respectively in the case of unidirectional and oscillating contacts. It was clear from Figure 3(a, b) that the steady-state friction coefficient value is decreasing from 0.6 to

0.25 at low and high load, respectively, in the case of unidirectional contact. But in oscillating contact, it was found to decrease from 0.4 to 0.1 Figure 3(c, d).

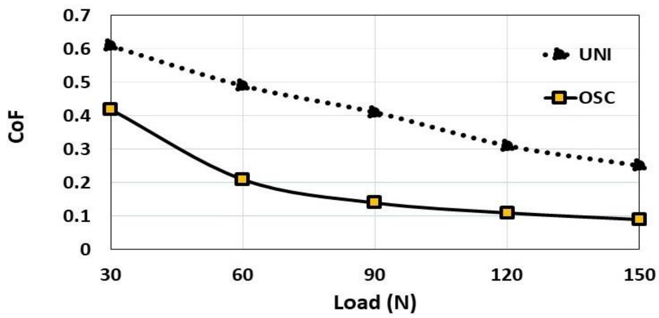

Figure 2. Load against Coefficient of friction (CoF) plot for unidirectional and oscillating wear tests under a test load range of 30-150N loads with a sliding speed/velocity of 0.4m/s slid through 500m.

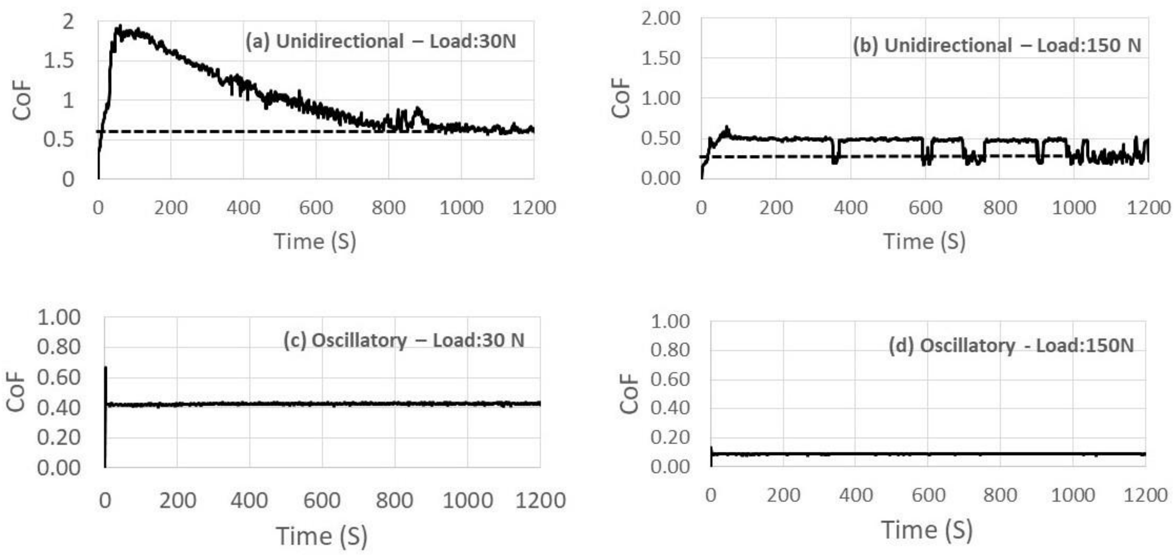

Figure 3. Continuous Coefficient of Friction plots for unidirectional and oscillating wear tests under 30N and 150 N loads with a sliding speed/velocity of 0.4m/s slid through 500m

3.2 Effect of load on dry wear characteristics of FGM in two sliding modes

Figure 4 shows wear characteristics of FGM against load with an oscillating/sliding velocity of 0.4m/s slid through 500m in oscillating and unidirectional sliding modes. It was observed from Figure 4 that as the load increases, the wear rate also increases in both sliding modes and is attributed to increased metallic intimacy due to higher load [13]. It was also noticed that the oscillating wear rate of FGM was found higher compared to unidirectional wear rate under similar operating parameters investigated in the study. This could be attributed to the fact that the additional probably possibilities of entrapment of wear particles within the oscillatory modes compared to the unidirectional mode of sliding that in turn successively roll and slide between the sliding interface and cause three-body abrasion. R Ward [6] also noted the same behaviour that wear rate of steel in reciprocating contacts was higher than in unidirectional contact. The author connected the explanation of it to two main differences; surface stressing and quantity of remaining wear particle within the wear track getting entrapped between the sliding interfaces throughout contact; each possibility of prevalence are comparatively high in reciprocal sliding.

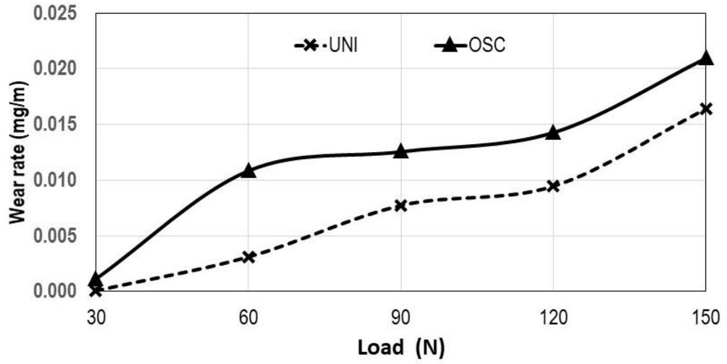

Figure 4. Load vs wear rate plots for unidirectional and oscillating wear tests under a test load range of 30-150 N with a sliding speed/velocity of 0.4m/s slid through 500m.

3.3 Worn out surface features of pin specimen by optical microscope

Figure 5(a-d) represent the stereo micrographs of worn-out surfaces of pin specimen after dry sliding in unidirectional and oscillating contacts with a sliding speed/velocity of 0.4m/s slid through 500m at a load of 30N and 150N respectively. It was observed from Figure 5(a, b) that as the load on the pin increases from 30N to 150N lip growth was found to occur at the trailing edges of the wearing surfaces proportional to the load in unidirectional contact. Since the leading and trailing edges of the sliding pin interchanging every cycle in oscillating contact, the lip growth likely to occur at both ends. However, the motion of the disc is oscillating, and hence the lip growth in the sliding direction is suppressed, and the same behaviour was also reported by Etsuo Marui et al. [10].

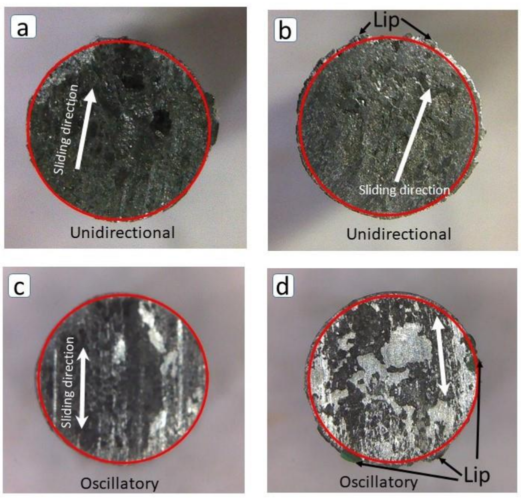

Figure 5. Stereo microscopic images of worn-out pin surfaces sliding in two different modes.
(a) Unidirectional-30N
(b) Unidirectional-150N
(c) Oscillatory-30N
(d) Oscillatory-150N

Figure 6 (a-d) shows the worn-out surface morphology of FGM outer pin specimen dry sliding in unidirectional and oscillating contacts at a load of 30N and 150N. It was observed from Figure 6(a, c) that at minimum load condition presence of fine, shallow scratches and grooves in sliding direction along with delamination at some locations happened in both sliding contacts. But at maximum load condition, SiC particle pullout along with heavy delamination was observed to be predominant in oscillating contact compared to unidirectional Figure 6(b, d).

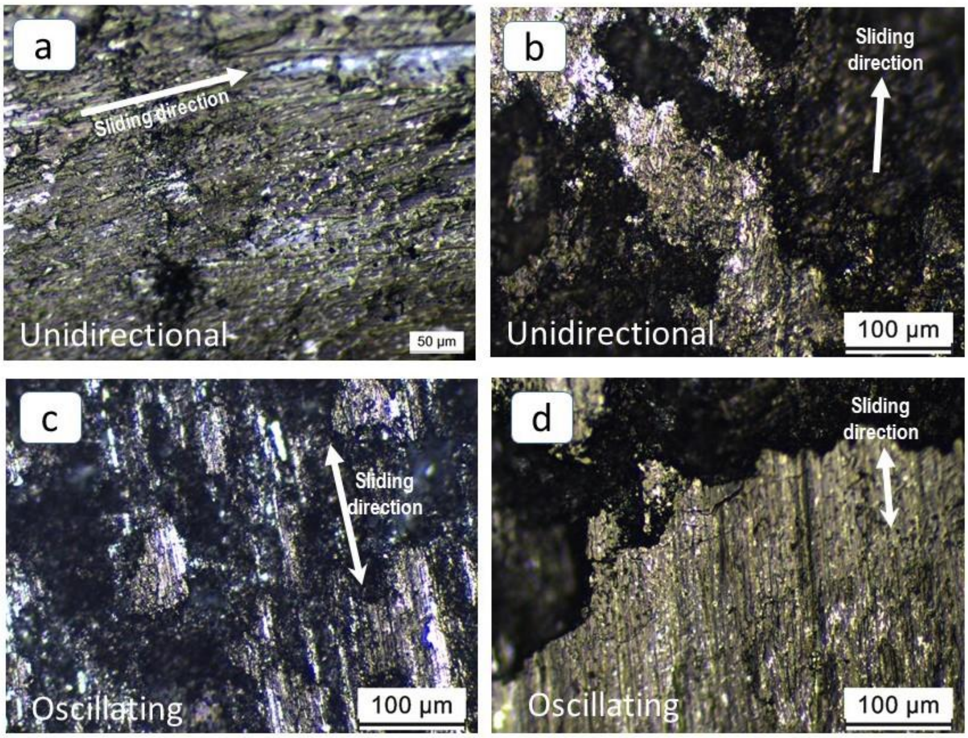

Figure 6. Optical images of worn-out pin surfaces captured at a sliding speed/velocity of 0.4m/s tested in two different sliding modes (a) Unidirectional-30N, (b) Unidirectional-150N, (c) Oscillatory-30N and (d) Oscillatory-150N

4. Conclusion

In the present study, the effect of sliding motion on the friction and wear characteristics of as-cast A356/10 wt.% SiC_p FGM was attempted using pin-on-disc tribometer in unidirectional and oscillating modes. Based on the investigation, the important findings are as follows.

The friction coefficient of as-cast A356/10 wt.% SiC_p FGM tribopair in unidirectional and oscillating sliding modes were found to decrease upon the increase of load from 30N to 150N. The reason is attributed to increased tribolayer thickness upon the increase of load and causing a decrease in friction coefficient.

The steady-state friction co-efficient captured in unidirectional mode was found to decrease from 0.6 at low load to 0.25 at high load. But in the oscillating mode, it was decreasing from 0.4 at low load to 0.1 at high load. Here the unidirectional friction coefficient of FGM was higher compared to that in oscillating mode within the load range investigated.

Lip growth was started to form during the wearing process of FGM tribopairs in both sliding modes except the difference is that it occurred at the leading and trailing edges of sliding pins of oscillating contact compared to that formed only at the leading edge of unidirectional contact.

The wear rate of FGM tribopair in both sliding modes found to increase upon normal load in the range of 30N to 150N. At low load a wear rate of 0.001mg/m while at high load 0.021mg/m noted in the oscillating sliding mode which was higher when compared with unidirectional sliding wherein at low load wear rate of 0.00004mg/m and high load 0.016 mg/m only noticed.

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References

[1] Vieira A C, Sequeira P D, Gomes J R and Rocha L A 2009 *Wear* **267** 585.
[2] Rajan T P D and Pai B C 2009 *Trans. of Indian Inst. of Metals* **62** 383.
[3] Jayakumar E, Jibin C J, Rajan T P D, Joseph M A and Pai B C 2016 *Metallurgical and Materials Trans.* **A 47(8)** 4306.
[4] Zhang J and Alpas A T 1997 *Acta Metallurgica* **45** 513.
[5] Jojith R and Radhika N 2019 *Silicon.* https://doi.org/10.1007/s12633-019-00294-3
[6] Ward R 1970 *Wear* **16**. 423.
[7] Odabas D and Su S 1997 *Wear* **208** 25.
[8] Marcia M M and Deniol K T 2006 *J. of the Braz. Soc. of Mech. Sci. & Eng:* **28** 278.
[9] Blau P J and Walukas M 2000 *Tribology International* **33** 573.
[10] Etsuo Marui and Hiroki Endo 2001 *Wear* **249** 582.
[11] Prem Kumar J, Rajeev V R, Krishnakumar K and Hashim M 2019 *10th Int. Conf. on Industrial Tribology (IndiaTrib 2019 Bangalore, India)* TSI 19219.
[12] Uyyuru R 2007 *Tribology International* **40** 365.
[13] Sannino A P and Rack H J 1995 *Wear* **189** 1.