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Effects of Test Environment on the Sliding Wear Behaviour of Cast Iron, Zinc-Aluminium Alloy and Its Composite

Mohammad M. Khan, Gajendra Dixit

***Abstract*—**Partially lubricated sliding wear behaviour of a zinc-based alloy reinforced with 10wt% SiC particles has been studied as a function of applied load and solid lubricant particle size and has been compared with that of matrix alloy and conventionally used grey cast iron. The wear tests were conducted at the sliding velocities of 2.1m/sec in various partial lubricated conditions using pin on disc machine as per ASTM G-99-05. Base oil (SAE 20W-40) or mixture of the base oil with 5wt% graphite of particle sizes (7-10 μm) and (100 μm) were used for creating lubricated conditions. The matrix alloy revealed primary dendrites of α and eutectoid $\alpha + \eta$ and $\in$ phases in the Inter dendritic regions. Similar microstructure has been depicted by the composite with an additional presence of the dispersoid SiC particles. In the case of cast iron, flakes of graphite were observed in the matrix; the latter comprised of (majority of) pearlite and (limited quantity of) ferrite. Results show a large improvement in wear resistance of the zinc-based alloy after reinforcement with SiC particles. The cast iron shows intermediate response between the matrix alloy and composite. The solid lubrication improved the wear resistance and friction behaviour of both the reinforced and base alloy. Moreover, minimum wear rate is obtained in oil+ 5wt % graphite (7-10 μm) lubricated environment for the matrix alloy and composite while for cast iron addition of solid lubricant increases the wear rate and minimum wear rate is obtained in case of oil lubricated environment. The cast iron experienced higher frictional heating than the matrix alloy and composite in all the cases especially at higher load condition. As far as friction coefficient is concerned, a mixed trend of behaviour was noted. The wear rate and frictional heating increased with load while friction coefficient was affected in an opposite manner. Test duration influenced the frictional heating and friction coefficient of the samples in a mixed manner.

***Keywords*—**Solid lubricant, sliding wear grey cast iron, zinc based metal matrix composites.

I. Introduction

METAL Matrix Composites (MMCs) have gained attention of several researchers due to the increase in demand for lightweight, rigid and strong materials. They possess excellent mechanical & tribological properties and are considered as potential engineering materials for various tribological applications [1]. Amongst a wide range of available matrix material, zinc aluminium based alloys are most appropriate owing to their good bearing and wear properties, lower casting temperatures and lower cost [2]. Formation of Zinc–aluminum (ZA) alloys containing trace amount of copper have been observed to be possible as cost and energy efficient substitutes for a variety of ferrous and non-ferrous alloys owing to their higher strength, better wear resistance, lower casting temperature and abundant resources [3]. ZA alloys are important bearing materials, especially suitable for high-load and low-speed applications [4]. Due to good tribo-mechanical properties such as low weight, excellent foundry casting ability, fluidity, good machining properties, hardness, corrosion resistance, low initial cost, energy-saving melting, environmental friendly technology and equivalent or even superior bearing and wear properties, ZA alloys are capable of replacing aluminum cast alloys and bearing bronzes [4]. An important aspect that makes these alloys attractive is the reduction in cost from 25 to 50% and 40 to 75%, compared with aluminum and brass alloys respectively [5]. In recent years, reinforcing with second phase particle (SPP) has been noted to substantially improve the mechanical properties and wear response of zinc based materials. Various kinds of reinforcements like alumina [6]-[14], TiC [15], fly ash [16], zircon [17], [18], SiC [13], [19]-[22], mullite, i.e., aluminosilicate [10], [11], aluminite [23] in the form of particles [13], [15]-[23] and fibres [6]-[14] have been tried out with an objective to realize property improvement of the alloy system. The effects of size [15], content [6]-[15], [17], [18], [23] and orientation of the reinforcement phase [8], [9] on mechanical and wear properties have also been earlier investigated. Hard and thermally stable ceramic reinforcements in zinc based alloys leads to less strength than the matrix alloy at ambient temperature [6], [14] although depending on the nature and type of the dispersoid phase, illustration of an opposite trend also exists [14]. Moreover, the composites attained improved and elevated temperature strength, increasing reinforcement content bringing about further improvement in the property. The dispersoid phase also caused higher hardness [6], [8], [10], [11], [13], [16]-[18], superior elastic modulus [6], greater dynamic modulus, better damping capacity [23] and less coefficient of thermal expansion [17] of the matrix alloy.

As far as the utilization of cast iron and zinc-based alloys for tribological applications is concerned, it has been initially proved through actual applications of engineering components [24]-[26] and scientific understanding of wear phenomena [27]-[43] in the materials followed latter. Recent studies have led to limited understanding of some of the aspects but the role

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of solid lubricants in the liquid lubricant has practically not been studied on the wear behaviour of cast iron and zinc-based alloys. Moreover, the influence of hard particle reinforcement on the wear behaviour of the (zinc-based) matrix alloy(s) has also not been examined.

In view of the above, an attempt has been made in this study to analyze the sliding wear behaviour of a zinc-based alloy and its composite reinforced with 10 wt% SiC particles under the influence of varying applied loads in partial lubricated conditions [oil, oil+ 5wt %graphite (7-10 µm), and oil+ 5wt % graphite (100 µm)]. The influence of changing particle size of graphite in the oil lubricant towards controlling the wear behaviour of the samples has been studied. The Grey Cast Iron has also been tested in identical conditions to understand the influence of the various parameters.

TABLE I
ELEMENTAL COMPOSITION OF THE TEST MATERIAL

Element %	Zinc-based alloy	Composite	Cast iron
Zn	*	*	-
Al	37.5	37.5	-
Cu	2.5	2.5	-
Mg	0.2	0.2	-
SiC	-	10	-
Si	-	-	2.32
C	-	-	3.35
Mn	-	-	0.56
P	-	-	0.08
S	-	-	0.08
Fe	-	-	*

II. EXPERIMENTAL

A. Synthesis of Test Material

The grey cast iron and (zinc based) alloys and composite were synthesized by melting and casting technique. Melting was carried out in graphite crucibles using an oil fired furnace. The cast iron was solidified in sand moulds in the shape of 10 mm diameter, 150 mm long cylindrical castings. The zinc-based alloy and composite melts were solidified in cast iron moulds in the form of 20 mm diameter, 150 mm long cylindrical castings. The (zinc-based) alloy melt was dispersed with 10% SiC particles (size: 63-100 µm) using a mechanical stirrer by vortex technique. The chemical compositions of materials used in wear studies are shown in Table I.

B. Microstructural Observation

Specimens (10 mm diameter, 15mm long) for microstructural analysis were prepared by cutting and machining. The samples were polished metallographically as per standard metallographic techniques. Various steps involved during the process were polishing the specimen with different grades of emery papers and then finally with fine alumina paste using polishing clothe. After polishing the cast iron was etched with 0.5% nital while diluted aqua regia was used for etching the (zinc-based) matrix alloy and composite. Microstructural studies were carried out by using a Leitz make optical microscope.

C. Density Measurement

Density of Grey Cast Iron, Zn-37Al alloys and (Zn-37Al)-10SiC composite were measured using Mettler microbalance. Water displacement technique was used for measuring the density. The samples required for density measurement were sectioned in rectangular shape (15 x 15 x 10 mm). The sectioned samples were polished up to 800 grit polishing paper for all the surfaces of all test materials.

D. Hardness Measurement

Hardness of the test materials were measured using Vickers's hardness tester. Before taking hardness the samples were metallographically polished and cleaned properly. The 30 kg load was applied while measuring hardness for all the samples. Averages of 10 readings were taken.

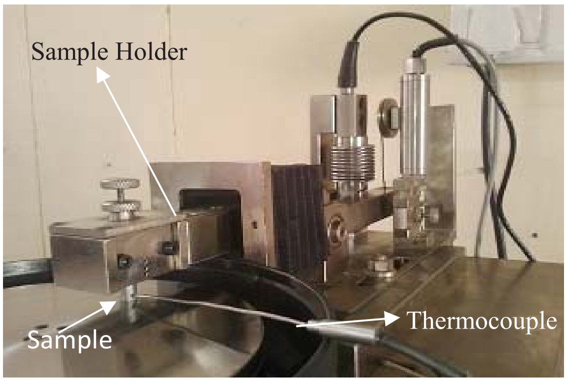
E. Sliding Wear Test

Sliding wear tests of the specimen were carried out using a Ducom (India) make pin-on-disc machine shown in Fig. 1 (a). Cylindrical test pins (8 mm diameter and 30 mm length) were held against a rotating heat-treated En31 steel disc conforming to AISIE 52100 (1.0% C, 1.4% Cr, 0.40% Mn, 0.2% Si, 0.05% S, 0.05% P and balance Fe). Hardness of the disc was HRC 62. The steel disc was polished mechanically up to a roughness (Ra) level of 1-2 µm prior to each test. SAE 20W-40 oil, SAE 20W- 40 oil plus (5 Wt %) graphite particles (size 7-10 µm), and SAE 20W- 40 oil plus (5 Wt %) graphite particles (size 100 µm) was used as lubricant. Wear tests were conducted over a range of applied loads and sliding speeds. The wear testing procedure involved, inserting the disk in to lubricant /lubricant mixture and allowing it to rotate at a speed of 3.35 m/s for 5 s. The lubricated disk was rotated in order to generate low and uniform thickness by spinning off the excess lubricant. Thereby, maintaining conditions close to mixed lubrication generally encountered by components in situations dealing with sparse lubrication as well as during starting and stopping operations in the case of fully lubricated sliding. Further sample was fixed in the specimen holder, allowing the disk to rotate at the predetermined sliding speed up to the fixed distance of 2500 m or until specimen seizure, whichever occurred earlier. The track diameter of 100 mm enabled the rotational speeds of 400 rpm (selected in the present investigation) to attain linear sliding velocities of 2.09m/s. Load was applied on the sample with dead weights using a cantilever mechanism. The applied load was varied over a range of 1-20kg. The test duration in this case was 20 minutes corresponding to a sliding distance of 2500 m.

Frictional heating was monitored using a chromel-alumel thermocouple inserted in a 1.5 mm diameter hole on the test pin 1.5 mm away from the sliding surface (shown in Fig. 1 (b)). Output of the thermocouple is fed into a PC-based data logging system which continuously records the frictional heating of sample during each test. The loads were vertically applied on to the pin sample against the disc. Output from strain gauge is also fed into a PC-based data logging system which continuously records the tangential load on the pin sample during each test.

Coefficient of friction was calculated by dividing the tangential load with the applied normal load. The specimens were thoroughly cleaned in acetone for 10 min using ultrasonic cleaner (34 ± 3 kHZ), dried and weighed prior to and after each test. A Denver instrument make microbalance was used for weighing the specimens. Weight loss was then converted into volume loss per unit sliding distance to compute wear rate.

(a)



(b)

Fig. 1 (a) Schematic diagram of the wear testing machine (b) Magnified view of Pin-Disc Test Assembly

III. Results

A. Microstructure

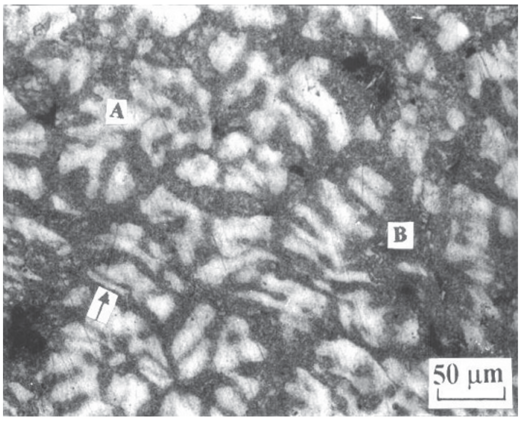
Fig. 2 represents the microstructure of the samples. The matrix alloy revealed primary dendrites of α and eutectoid α + η and ∊ phases in the Inter dendritic regions (Fig. 2 (a), regions marked A, B and arrow respectively). The composite showed features similar to the matrix alloy except the presence of the dispersoid SiC particles. (Fig. 2 (b), region marked by C). In the case of cast iron, flakes of graphite were observed in the matrix; the latter comprised of (majority of) pearlite and (limited quantity of) ferrite (Figs. 2 (c) & (d), regions marked by doule arrow, D and E respectively)

B. Hardness and Density

Table II represents various properties of the specimens. The composite attained somewhat higher hardness than the corresponding (ZA-37) matrix alloy while that of the grey cast iron was the maximum. So far as the density of the specimen is concerned, it was highest for the cast iron followed by that of the (ZA-37) matrix alloy and the composite.

TABLE II
HARDNESS AND DENSITY OF SPECIMEN

S. No.	Type	Vickers Hardness	Density g/cm^3
1	ZA-37 Matrix Alloy	125	4.45
2	ZA-37 Matrix Alloy Composite	135	4.41
3	Grey Cast Iron	220	7.2



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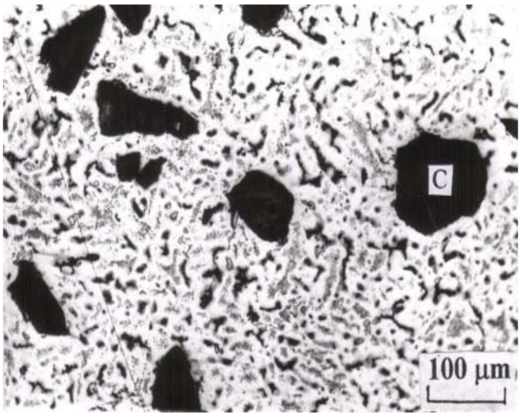

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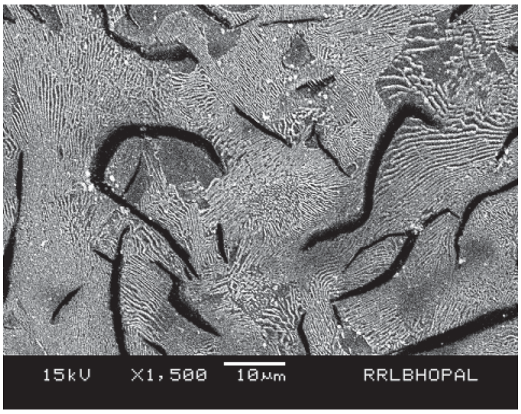

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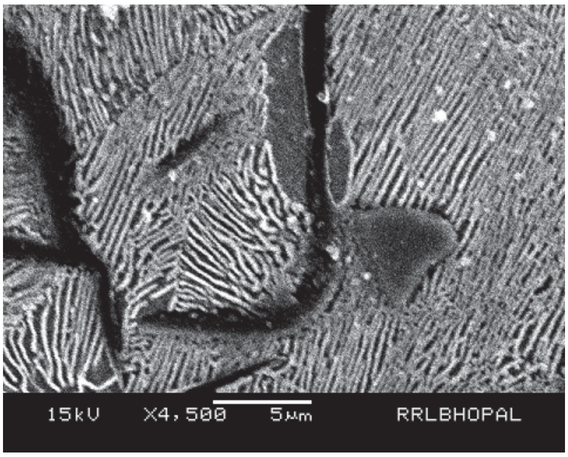


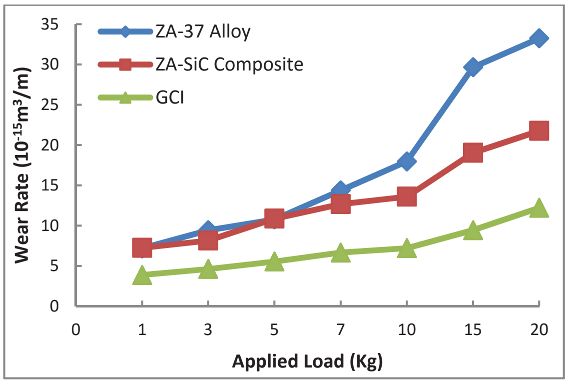
(d)

Fig. 2 Microstructure of the (a) Matrix Alloy, (b) Composite, (c) and (d) cast iron

C. Wear Behaviour

1) Wear Rate

Wear rate of the samples as function of applied load in various lubricated environment has been plotted in Fig. 3. The wear rate increased with load irrespective of the test material and environment. In oil lubricated condition matrix alloy delineates maximum wear rate followed by the SiC reinforced composite and grey cast Iron. However, addition of graphite in oil alters the pattern of behavior of the test material. In oil +5 wt% Graphite (7-10 µm) lubricated condition maximum wear rate is obtained by the matrix alloy and minimum by the composite however grey cast iron shows intermediate response at all the loading conditions. Although in oil +5 wt% Graphite (100 µm) lubricated condition, up to 10 kg load maximum wear rate is obtained by the grey cast iron and after that matrix alloy attains maximum wear rate however minimum wear rate is obtained by the composite at all the loading conditions. Moreover, wear rate of the test materials plotted as function of applied load in various lubricated environment for matrix alloy, composite and grey cast iron are depicted in Figs. 4 (a)-(c), respectively. The matrix alloy and composite shows similar response, in both the cases maximum wear rate is obtained in the oil lubricated environment and minimum in the oil +5 wt% Graphite (7-10 µm) lubricated condition while oil +5 wt% Graphite (100 µm) lubricated condition shows intermediate response. However, in the case of grey cast iron maximum wear rate in oil + 5wt% Graphite (100 µm) lubricated condition followed by the oil +5 wt% Graphite (7-10 µm) and oil lubricated condition.



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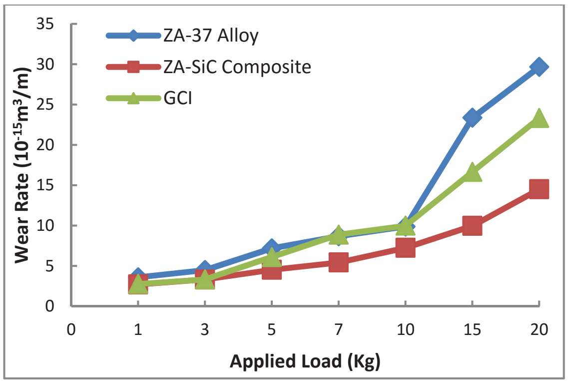

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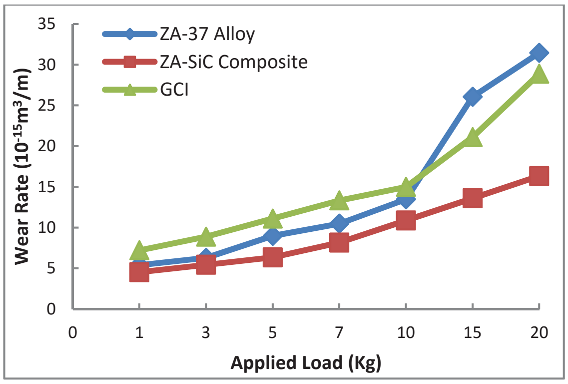
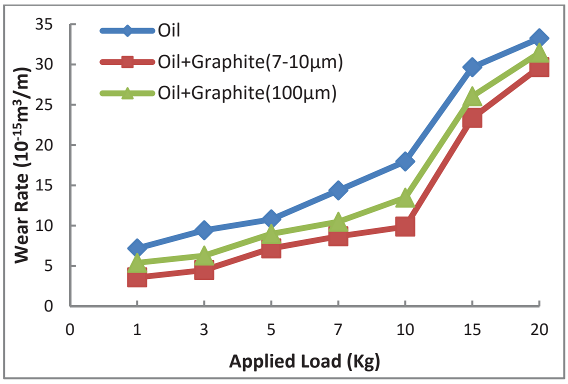


(c)

Fig. 3 Wear Rate of the samples plotted as a function of applied load in (a) oil (b) oil + (7-10µm) size graphite and (c) oil + (100µm) size graphite lubricated environment



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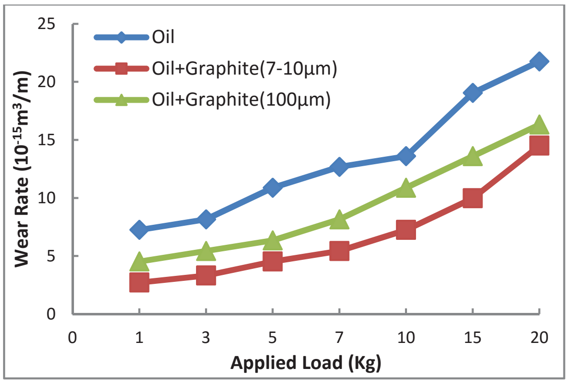

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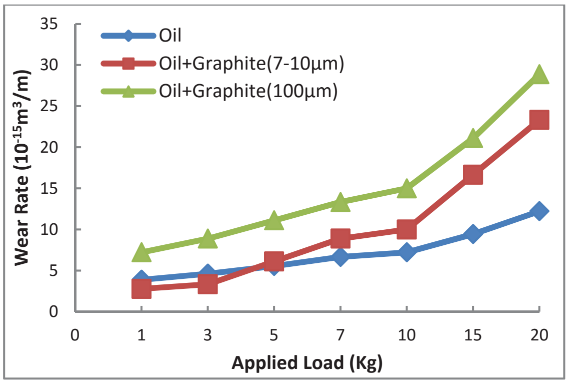
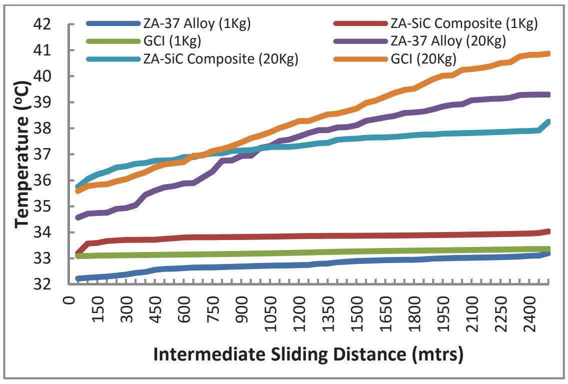


(c)

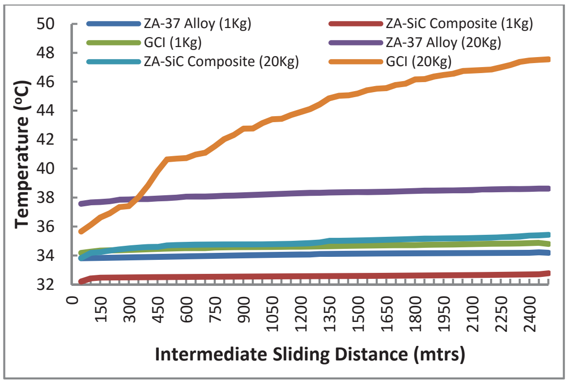
Fig. 4 Wear Rate of the samples plotted as a function of applied load in various lubricated environments for (a) Matrix Alloy (b) SiC Reinforced Composite and (c) Cast Iron

2) Frictional Heating

Temperature rise near the surface of the test material plotted as a function of Intermediate sliding distance in various lubricated environment at 1 Kg & 20 Kg Load are shown in Figs. 5 (a)-(c). The temperature increases linearly with the sliding distance irrespective of the load and test material. In oil lubricated condition, at higher load maximum friction heating is obtained by the grey cast iron followed by the matrix alloy and composite. However, at lower load maximum frictional heating is obtained by the composite and minimum by the Grey cast iron while matrix alloy shows intermediate response. In oil +5 wt% Graphite (7-10 µm) lubricated condition at higher load same pattern of behavior is obtained as in the case of oil lubricated condition however at lower load maximum frictional heating by the matrix alloy followed by the grey cast iron and composite. In oil +5 wt% Graphite (100 µm) lubricated condition at both higher and lower load maximum friction heating is obtained by the matrix alloy and minimum by the composite while grey cast iron attains intermediate behavior.



(a)



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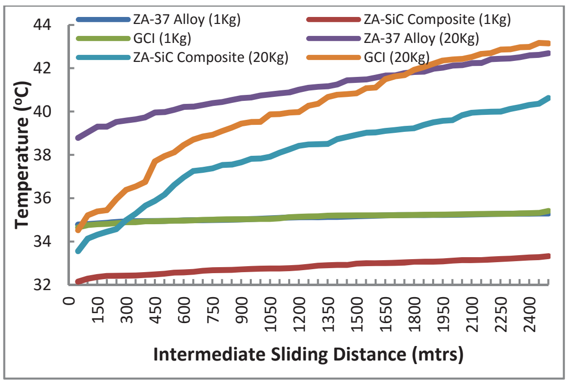
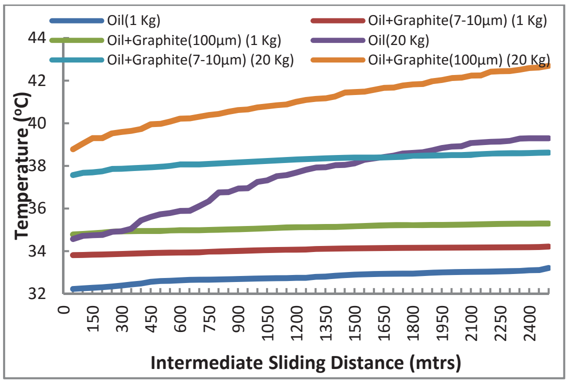


(c)

Fig. 5 Temperature rise of the samples plotted as a function of Intermediate sliding distance in (a) oil (b) oil + (7-10µm) size graphite and (c) oil + (100µm) size graphite lubricated environment at 1 Kg & 20 Kg Load



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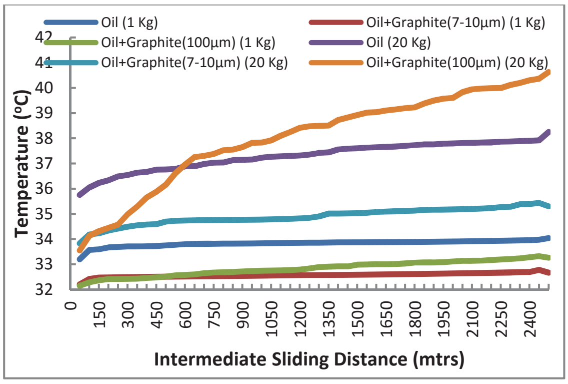

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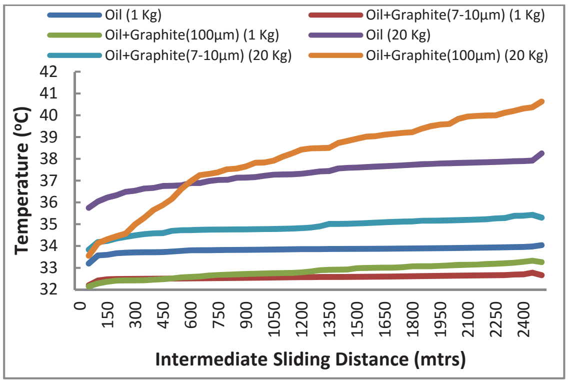
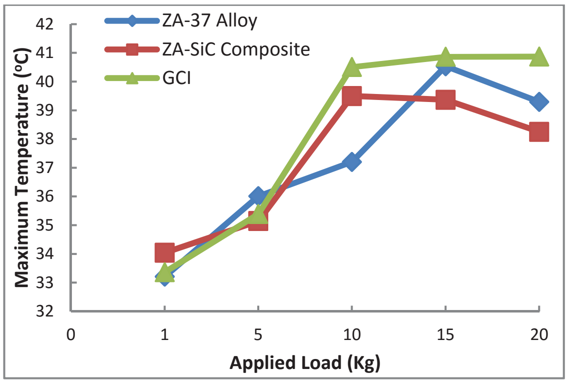


(c)

Fig. 6 Temperature rise of the samples plotted as a function of Intermediate sliding distance in various lubricated environments for (a) Matrix Alloy (b) SiC Reinforced Composite and (c) Cast Iron at 1 Kg and 20Kg load



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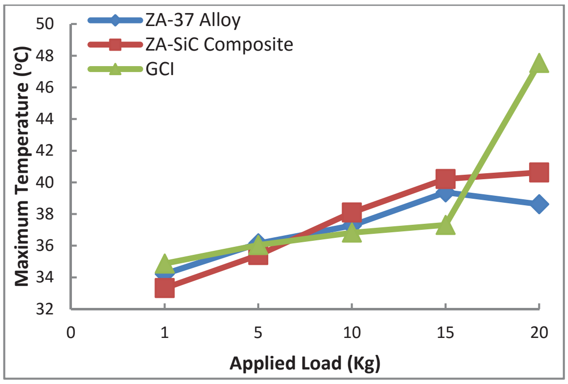

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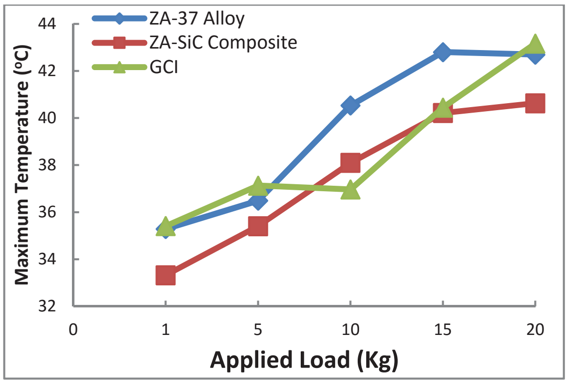


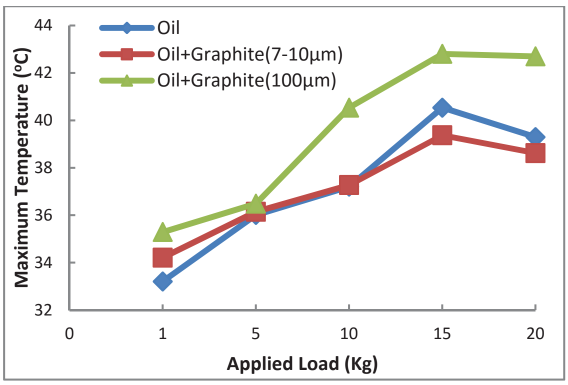
(c)

Fig. 7 Maximum temperature rise of the samples plotted as a function of applied load in (a) oil (b) oil + (7-10µm) size graphite and (c) oil + (100µm) size graphite lubricated environment

Fig. 6 represents the Temperature rise of the samples plotted as a function of Intermediate sliding distance in various lubricated environments for Matrix Alloy SiC Reinforced Composite and Cast Iron at 1 Kg and 20 Kg load. It may be noted that in case of matrix alloy at both the higher and lower load maximum frictional heating is obtained in the oil + 5 wt% Graphite (100 µm) lubricated condition followed by the oil +5 wt% Graphite (7-10 µm) and oil lubricated condition. However, in case of composite and cast iron at higher load maximum frictional heating is obtained in the case of oil + 5 wt% Graphite (100 µm) lubricated environment and minimum frictional heating is obtained in the case of oil +5 wt% Graphite (7-10 µm) lubricated condition while oil lubricated environment shows intermediate response. Moreover, at lower load reverse trend of frictional heating is obtained. In this case maximum frictional heating is obtained in case of oil lubricated environment followed by the oil + 5 wt% Graphite (100 µm) and oil +5 wt% Graphite (7-10 µm) lubricated condition. Maximum temperature rise near the surface of the test material plotted as function of applied load in various test environments are depicted in Figs. 6 and 7. The frictional heating initially increased with load however further increment in the load reduces the severity of the frictional heating. Moreover, frictional heating of all the test materials behaved in an identical manner.

3) Friction Coefficient

Friction coefficient of the samples as a function of sliding distance in various lubricated test environment at 1 kg and 20 kg load has been plotted in Figs. 9 and 10. The friction coefficient decreased with increasing sliding distance and applied load for all the test materials. At higher load (20 Kg) maximum friction coefficient is obtained in case of grey cast iron followed by the alloy and composite in all the lubricated test environments. However, in case of lower load a mixed trend of behavior is obtained. Moreover, Figs. 11 and 12 depicted the steady state friction coefficient curve plotted as a function of applied load in various test environments. The change of pattern of variation of friction coefficient is in peculiar manner. Although in general steady state friction coefficient initially decreased with the increase in applied load further increase in applied load increased the friction coefficient up to a certain extent then it finally reduced with the increase in applied load.



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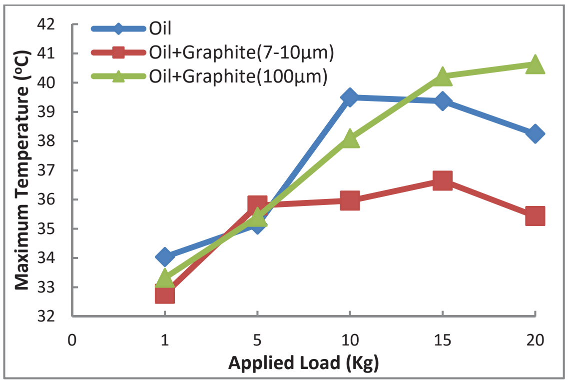

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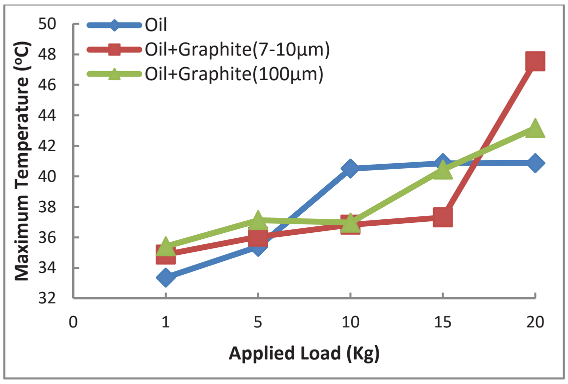

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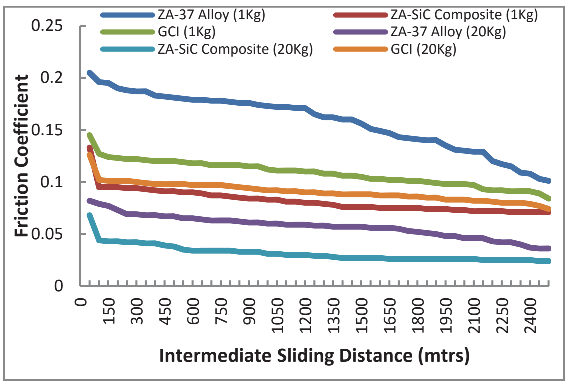
Fig. 8 Maximum temperature rise of the samples plotted as a function of applied load in various lubricated environments for (a) Matrix Alloy (b) SiC Reinforced Composite and (c) Cast Iron



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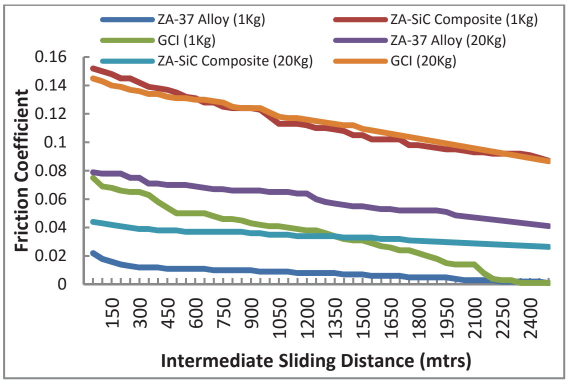

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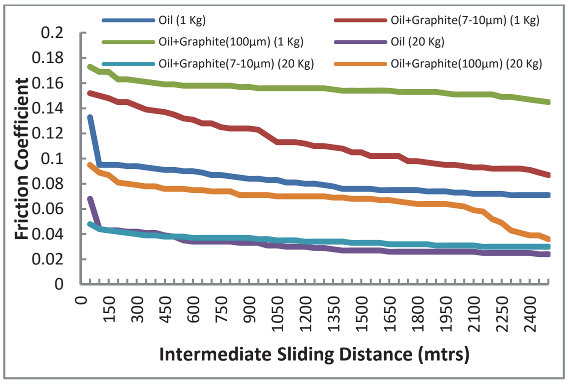

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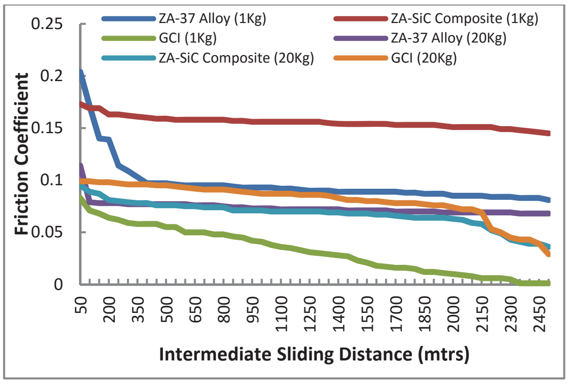

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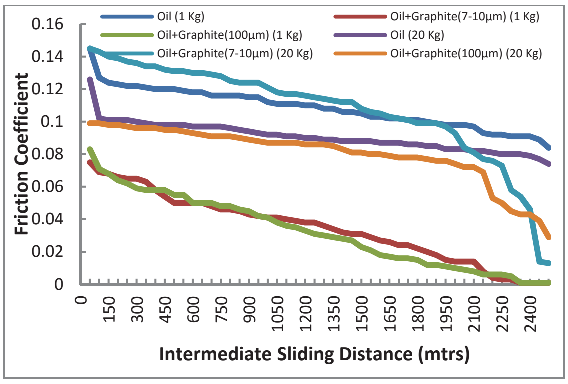
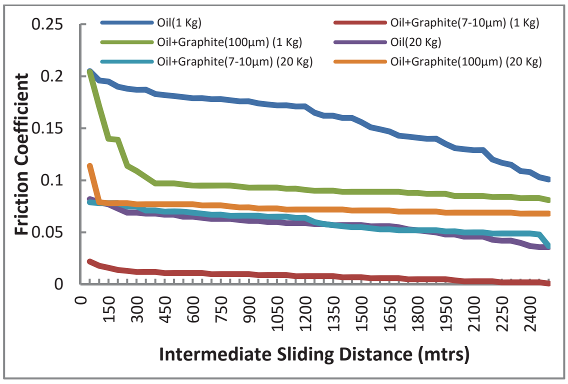


(c)

Fig. 9 Friction Coefficient of the samples plotted as a function of Intermediate sliding distance in (a) oil (b) oil + (7-10µm) size graphite and (c) oil + (100µm) size graphite lubricated environment at 1 Kg & 20 Kg Load

Fig. 10 Friction Coefficient of the samples plotted as a function of Intermediate sliding distance in various lubricated environments for (a) Matrix Alloy (b) SiC Reinforced Composite and (c) Cast Iron at 1 Kg and 20Kg load



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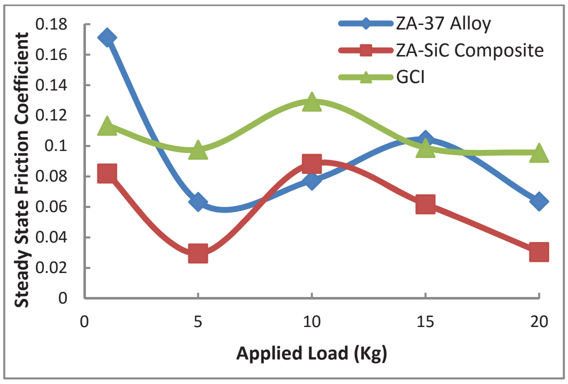

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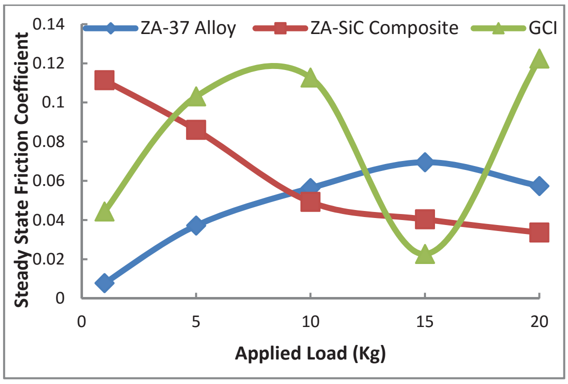

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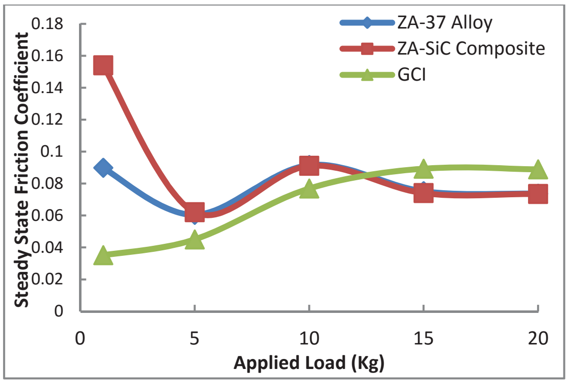
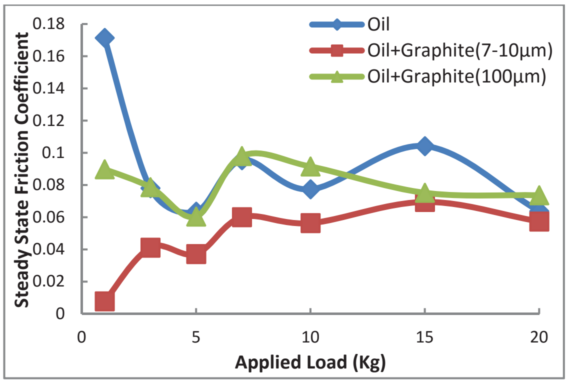
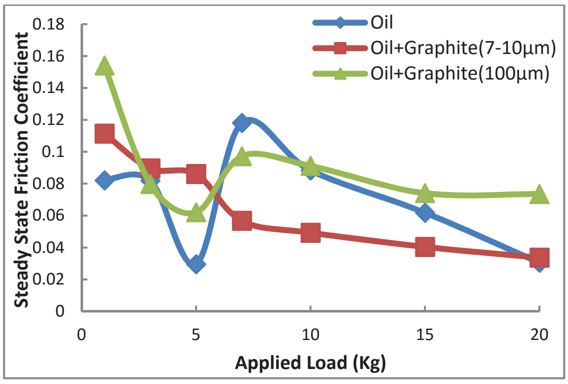


(c)

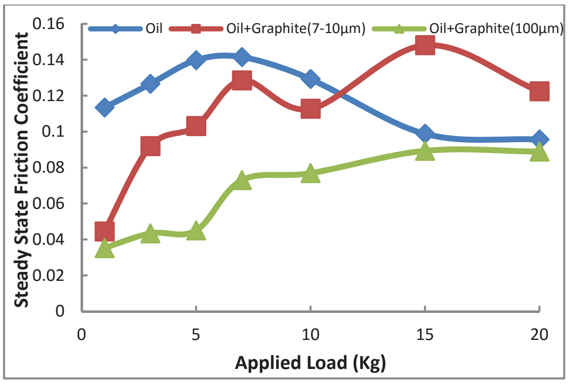
Fig. 11 Steady state friction coefficient of the samples plotted as a function of applied load in (a) oil (b) oil + (7-10μm) size graphite and (c) oil + (100μm) size graphite lubricated environment



(a)



(b)



(c)

Fig. 12 Steady State friction coefficient of the samples plotted as a function of applied load in various lubricated environments for (a) Matrix Alloy (b) SiC Reinforced Composite and (c) Cast Iron

IV. Discussion

From microstructural characteristics point of view, the (grey) cast iron comprised of pearlite with limited quantity of ferrite in the matrix along with flakes of graphite (Figs. 2 (c) & (d)). Ferrite is a soft and ductile phase while pearlite comprises of hard and long needle type cementite with sharp corners dispersed as lamellae in ferrite. Accordingly, the (cementite part of) pearlite offers load bearing characteristics but at the same time facilitates cracking tendency. Ferrite provides support and compatibility to the hard cementite while the cementite imparts thermal stability enabling the phase to carry load. Flakes of graphite provide solid lubrication and facilitate smearing [44] of the phase in between the contacting surface leading to good wear resistance. However, graphite/ matrix interfacial regions become favourable sites for the nucleation and propagation of microcrackes [45]. Microcracking tendency predominates at low operating temperatures while load bearing and lubricating tendency of the phases become more effective at higher operating temperatures (161).

The (zinc-based) matrix alloy contains α+η and ε phases (Fig. 2 (a)). The α phase being FCC has load bearing capability and deferability [27]-[37], [45]. The η phase has hexagonal structure with c/a ratio greater than that of an ideal

HCP crystal [46]. This enables the phase to provide solid lubrication characteristics. The somewhat hard ε phase offers wear resistance to the alloy system [47]. However, the (zinc-based) matrix alloy has low melting point in general causing the phases to play their positive rates at low operating temperatures. Reinforcing the alloy system with thermally stable micro-constituents through alloying with high melting elements and/or incorporation of hard ceramic particles improves its elevated temperature strength. Wear resistance under severe conditions also improves because of improved thermal stability while ambient temperature properties deteriorate over the matrix alloy due to enhanced cracking tendency introduced by the thermally stable micro-constituents [27]-[37].

Coming to the sliding wear tests, factors affecting the wear response of materials are applied load, sliding velocity, sliding distance and test environment. Applied load directly influences the wear rate i.e., higher the load greater the wear rate. Other variables such as distance and velocity do not have well defined effects on the wear response of materials [27]-[37]. As far as environmental (lubricated, oil / oil + graphite) effects are concerned, a lot of complexity exists [27]-37].

Normally the use of a lubricant improves the sliding wear characteristics of material because of the formation of a lubricating film consisting of a variety of reaction products. The introduction of a solid lubricant into the liquid / semi solid lubricant brings about a further improvement in wear behavior by increasing stability of the film. This is in view of the fact that the lubricant mixture should not loose adherence with the contacting surface and, at the same time, it should have enough lubricating characteristics. The question of loosing adherence arises when the mixture become too dry i.e. when the quantity of the solid lubricating phase in the mixture becomes too much to cause tearing-off of the thick and dry lubricating film. Subcritical quantity of the solid lubricating phase reduces the probability of forming a stable lubricating film on the contacting surfaces. Accordingly, either side of the content of the solid lubricant constituent phase in the lubricant mixture may deteriorate the wear response of materials.

Having discussed the role of various material and operating variables on wear behaviour, it would now be easier to better understand the observed wear response of the samples in this investigation.

The wear rate of the samples increased with the increasing in applied load irrespective of the test material. The sliding wear behavior of the alloy and composite improved in the presence solid lubricant to the oil in view of the formation of more stable and effective lubricating film(s). The addition of graphite to the oil lubricants increased the possibility of the formation of a more stable lubricating film causing further in the wear rate. However, this could be realized that for the (7-10 μm) size of graphite particle in the oil, minimum wear rate was obtained.

The wear response of the cast iron samples is superior than the (zinc-based) matrix alloy (and also than the composite in some cases) may be a result of a significant reduction in the cracking tendency of the former thereby favoring the smearing of graphite and formation of lubricating (graphite) films. This led to the best wear performance of the cast iron in oil lubricated conditions at lower load while at higher load there is a subsequent destruction of the lubricant film and enhanced the cracking tendency of the material thus the wear rate is higher than the composite. In the latter case, the composite material possessed a good combination of properties like strength, ductility, lubricating tendency and thermal stability [36], [37].

Increasing rate of frictional heating with test duration could be attributed to the increasing effective area of contact thereby reducing the severity of wear condition. A higher rate of temperature rises in some cases towards the end of the tests could be owing to the sticking /adhering tendency of the specimen material to the disc surface. More severe wear condition due to increasing applied load caused the rate of temperature increase to become higher. The matrix alloy exhibited the generation of least frictional heat due to its excellent lubricating tendency. The abrasion caused by the fragmented dispersoid SiC particles caused larger frictional heating than the matrix alloy [36], [37]. The cast iron suffered for maximum temperature increase irrespective of the test condition due to the abrasion caused by the fragmented cementite particles through their entrapment in between the contacting surfaces. Addition of graphite decreased the frictional heating through the formation of a still more stable lubricating film. The matrix alloy was most favorably affected in this case in view of the major constituent like η being solid lubricating in nature [46]. The frictional heating is not very much affected by the variation in the size of graphite particle.

The probability of more effective formation of a lubricant film caused the friction coefficient to decrease with increase in load. The lubricating and less cracking nature of the major phase η caused the friction coefficient of the matrix alloy to become the least. The abrasion caused through the entrapped dispersoid phase after fragmentation during wear led to higher friction coefficient of the composite than matrix alloy. The suppressed cracking tendency of the cast iron enhanced the solid lubrication characteristics of the graphite flakes in the cast iron. This, associated with the load bearing capability of the matrix microconstituents, like cementite (in pearlite). More effective formation of lubricating film in the presence of liquid /liquid + solid lubricant led to reduced friction coefficient. The suppressed cracking tendency resulting in increased efficiency of graphite film formation caused the friction coefficient to be the least at higher load in the case of cast iron while a lack of cracking tendency in the matrix alloy led to its reduced friction coefficient considerably under identical test conditions. Least friction coefficient in the event of adding optimum size of graphite particle in the lubricating oil could be attributed to the formation of most stable lubricating film.

An appraisal of the observations made in this study clearly suggests varying effects of parameters like cracking tendency, lubricating characteristics, thermal stability etc. of material constituents and experimental parameters like load and conditions (dry and lubricated). The overall effect of the parameters on the wear behaviour of the samples seems to be complex in nature. However, generally speaking, the presence of lubricant helps to improve the wear response. The addition of graphite particles to lubricating oil offers the best wear performance of material. Whatever is the case, parameters leading to suppressed cracking tendency and improved thermal stability and lubricating capability ultimately lead to the formation of most stable lubricating film and offer good wear response.

V. Conclusion

Based on the observations made in this study, following conclusions could be drawn:

1) The matrix alloy contained primary α, α+η and ∊ while the composite revealed the presence of the dispersed SiC particles in addition to the features of the matrix alloy. The cast iron showed the presence of pearlite with a small quantity of ferrite in the matrix. Graphite existed in the microstructure of the cast iron as flakes.
2) The hardness & density of the cast iron were highest amongst the three varieties of the samples. The density of the composite was the least while the zinc-based (matrix) alloy exhibited minimum hardness.
3) Wear Rate increased with applied load. The composite exhibited less wear rate than that of the matrix alloy and cast iron in all the test environments. The cast iron experienced minimum wear rate in oil, intermediate in oil +5% Graphite (7-10 µm) and maximum in oil +5% Graphite (100 µm) lubricated environment.
4) Testing the samples in oil plus graphite lubricated conditions led to less wear rate than that in oil alone. Addition of 5 wt% graphite (7-10 µm) to the oil lubricant led to minimum wear rate.
5) Frictional heating increased with load and test duration, the frictional heating increased at a higher rate initially followed by a lower rate of increase at longer test durations. The matrix alloy attained maximum heating while it was least for the composite in oil + graphite environment while in oil lubricated environment maximum heating is attained by the cast iron at higher load however at lower load composite attained maximum frictional heating.
6) The friction coefficient increased with test duration. The matrix alloy in general experienced maximum friction coefficient while that of the cast iron was the least. The composite attained intermediate values. The friction coefficient became greater with increasing load in the case of the composite whereas the trend reversed in the case of the matrix alloy and to some extent for the cast iron.
7) The steady state friction coefficient decreases with increase in load for all the material. It was noted that the maximum steady state friction coefficient attained by cast iron, while a mixed trend was noted in the case of the matrix alloy and composite. The addition of graphite to the lubricating oil further reduced the steady state friction coefficient. However, no definite trend of variation was noted.

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