Basic Studies on the Role of Softer Metallic Coatings in Ball Bearings

Suresha Gowda M. V, Ranganatha S, Vidyasagar H. N.

***Abstract:** The performance, reliability and load transferring capabilities of bearing elements are very important in industrial applications. The newer design of high speed machines demands better bearing system. The reliability is of primary importance in case of bearing elements used in aerospace industries. Exhaustive studies have been carried out by different researchers under two extreme conditions. One is using a fluid as lubricants which do not bear shear loads. The other extreme were using hard coatings which bears enormous amount of shear loads. In the present investigation an attempt has been made to understand the kinematics of deformation of coatings which are not as hard as conventional coatings. Casehardened carbon steel balls were coated with tin, zinc and nickel by electroplating technique. The thickness of the coating was maintained at 25 µm. Four ball test rig was used to simulate the field conditions. The experiments were conducted without lubricants. The normal loads were 100N, 300N and 500N respectively and run for a period of 5 minutes. The frictional load and normal load were monitored and co-efficient of friction was estimated. The wear scar was studied under scanning electron microscope. The co-efficient of friction was found to be dependent on normal load and type of coating material. The co-efficient of friction was found to be minimum of value 0.28 for a maximum normal load of 500N for tin coating. The morphology of wear scar studied in scanning electron microscope explains the dependency of co-efficient of friction on normal load and different coating materials.*

***Keywords:** Rolling contact fatigue, four ball tester, Coatings.*

I. INTRODUCTION

The life of machine element which transfers load and motion are very important. In specific the performance of journal bearings is of more industrial importance since these elements are used in machineries which run at very high speed and in hostile environment. The roller bearings are intermediate between the rotor and housing of the bearing. They accommodate the velocity and displacement between the static bearing and high velocity rotor. The performance of the roller is important from the point of reliability, accommodating shear loads, transferring the compressive loads and economy of the product. Attempts have been made to improve the life of these elements using different kinds of lubricants. Studies have been carried out using different lubricating materials and different lubricating domains. The domain studied are fully developed, mixed and boundary regimes [1].

Revised Version Manuscript Received on January 27, 2016.

Suresha Gowda M .V, Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore, Karnataka, India.

Dr. Ranganatha S, Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore, Karnataka, India.

Dr. Vidyasagar H . N, Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore, Karnataka, India.

Attempts also have been made to provide hard coatings to improve the performance and reliability of the bearing element. The different coatings techniques employed were The results showed that lubrication regime had a significant effect on performance of bearings. The lubricants depending on the regime were found to lead different types of failure [2]. thermal spraying (TS), physical vapor deposition (PVD) and chemical vapor deposition (CVD). Faraday [3] developed the PVD process. Titanium coatings were deposited using the PVD process for improving the wear resistance. The deposition process resulted in discontinuities such as pore, thermal stress induced cracks and oxylamide oxide lamellas are in completely molten particles. These defects were reported to be depending on process parameters involved in spraying [4-7]. Different authors tried to understand the performance of thermally coated bearing elements [8-11]. They found that improved microstructure and fracture toughness resulted in better performance of the rolling elements. Attempts have been made to study the effect of different coating materials [12]. Thermally sprayed ceramic coating and metal coatings were tested in the laboratory. The results indicated metal coatings perform well compared to ceramic coatings. The failure mechanisms reveal formations of blisters which lead to coating delamination. Mixed carbide coatings were also tried. The mixed carbides resulted in better performance. Aluminum oxide coatings were also tried but they were found to be inferior compared to carbide, titanium based coatings. Role of coating thickness were also studied [13-16]. The thickness of the coating was found to change the delamination from interfacial to cohesive. The coatings were imparted at high temperature, which led to thermal stresses [17-19]. The stresses were found to be tensile in some methods and compressive in other methods. Studies have been carried out to understand the failure mechanisms. The mechanisms were found to be dependent on defects with in the coatings, microstructure of the coatings and density of the coatings [20-27]. Suresh Gowda et al. [28], conducted experiments in four ball test rig for identifying the role of materials on deformation and damages, they found that the hardness of the material and normal loads control the deformation and damages of load bearing elements. The literatures revealed that attempts to accommodate the discontinuity in displacement and velocity are addressed by two approaches. One being the liquid lubricant which resists no shear stresses and transfer the compressive loads. The second approach is to give a coating which will have sufficiently larger shear strength which prevents the loss of material. In the present investigation an attempt has been made to understand the contribution of coating s which are not as stronger as conventional coatings but to some extent resist the shear

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stress unlike liquid lubricants which do not resists shear loads.

II. EXPERIMENTAL DETAILS

A. Material

The casehardened carbon steel balls were coated with nickel, tin and zinc. The coatings have been carried out by standard electroplating technique. The thickness of the plating was maintained at 25 µm. The chemical composition of ball material is shown in Table.1.

Table. 1 Chemical composition of the test balls.

Material	%C	%Si	%Mn	%P	%S	%Cr
Case hardened carbon steel	0.08-0.13	0.10-0.35	0.3-0.6	0.04	0.05	-

The dimension and physical properties of ball material is shown in Table. 2.

Table. 2 Dimension and physical properties of test balls.

Property	Case hardened carbon steel
Diameter (mm)	12.7
Surface roughness *R*a (µm)	0.024
Hardness (HRC)	60
Modulus of elasticity(GPa)	200
Poisson ratio	0.3

The yield strength of different coating materials are shown in Table. 3

Table. 3 Yield strength of different coating materials.

Material	Yield strength (MPa)
Tin	9-14
Nickel	14-35
Zinc	200

Experiments were conducted without lubricant using four ball test rig as per ASTM (D 4172) standards. The schematic diagram of test rig is shown in **Fig.1.** The test rig was loaded with four balls, three at the bottom and one on top. All the balls were washed with acetone and dried to maintain the surfaces free from impurities. The bottom three balls were held firmly in a ball pot without lubricant under test and pressed against the top ball. The top ball was made to rotate at the desired speed while the bottom three balls were pressed against it.

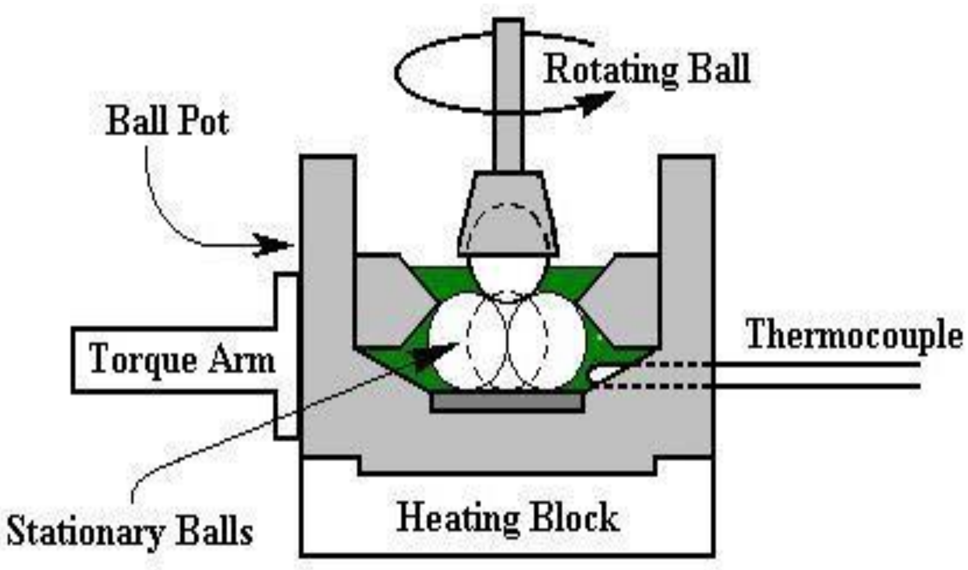

Fig.1 Schematic Diagram of Four Ball Test Rig

B. Test Procedure

A normal load of 1kg (100N) was applied and experiments were conducted by rotating the upper ball at a speed of 500 rpm. The experiments were conducted for running over 5 minutes. The ambient temperature was maintained at 75º C. The same procedure was repeated for loads of 3kg and 5kgs. The normal load, frictional force and co-efficient of friction were monitored and recorded on a personal computer. The balls after test were carefully taken out of the test rig and the wear scar which is due to deformation of material of the balls was studied under scanning electron microscope.

III. RESULTS AND DISCUSSIONS

The typical plots showing dependency of co-efficient of friction with time for experiments where casehardened carbon steel and balls coated with nickel, tin and zinc were shown in Fig.2.

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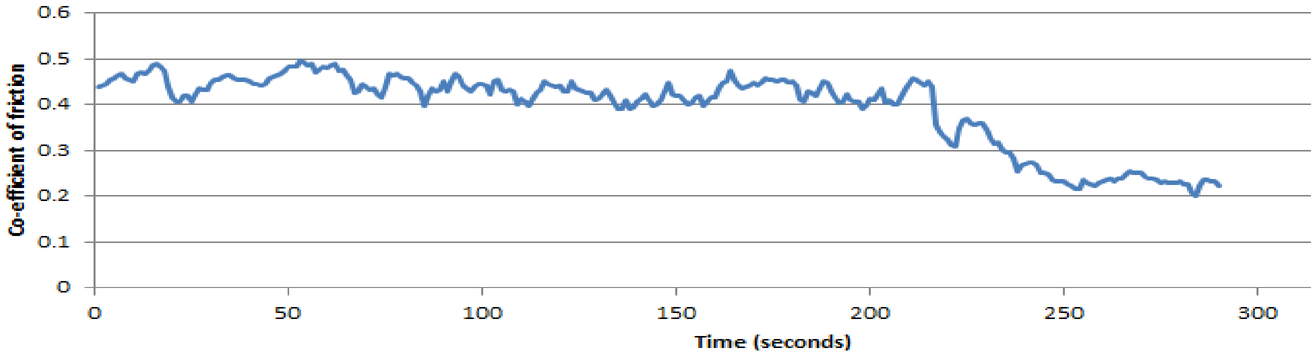


Fig. 2(a) Dependency of co-efficient of friction with time. Material; Casehardened carbon steel (uncoated) Load; 500N.

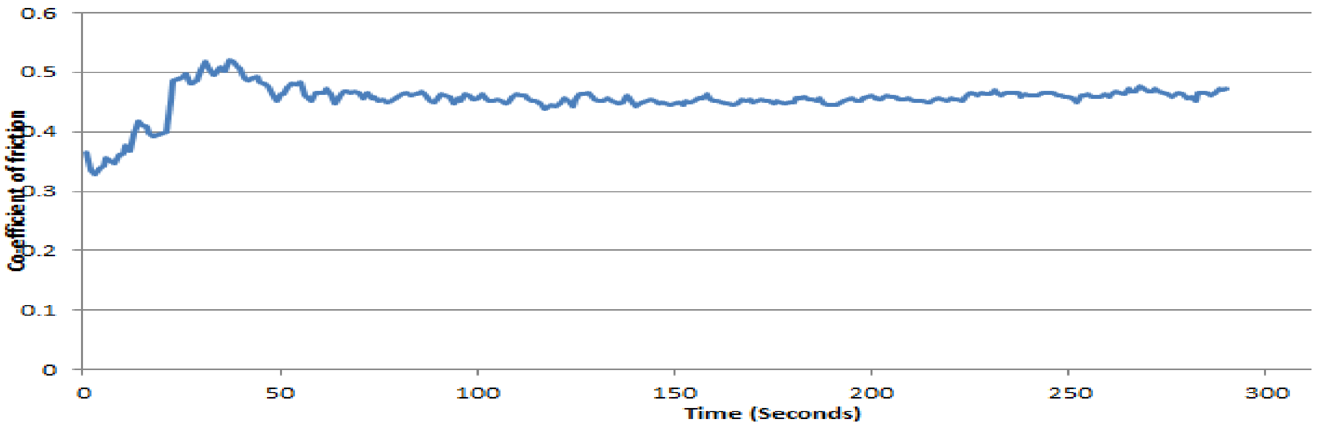


Fig. 2 (b) Dependency of co-efficient of friction with time. Material; Casehardened carbon steel (Nickel coated) Load; 500N.

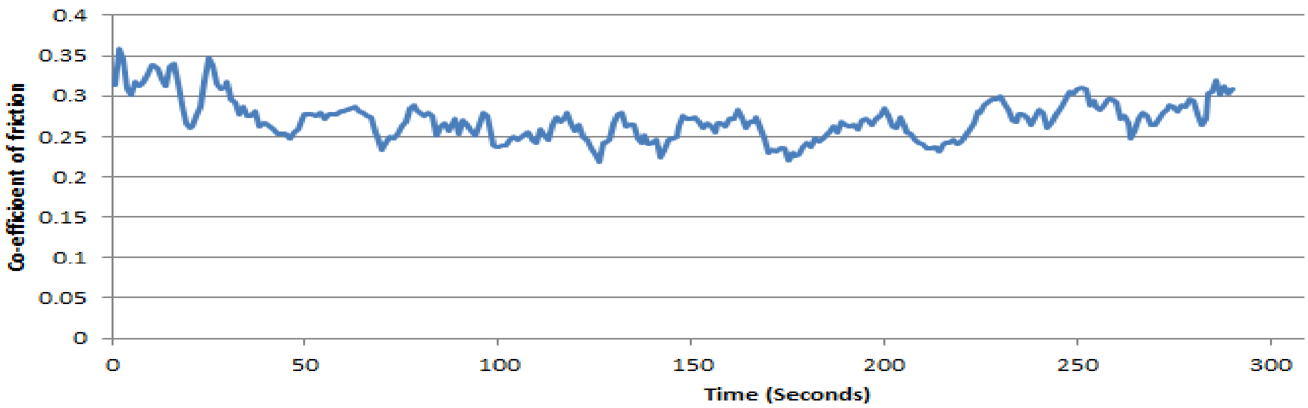


Fig. 2(c) Dependency of co-efficient of friction with time. Material; Casehardened carbon steel (Tin coated) Load; 500N.

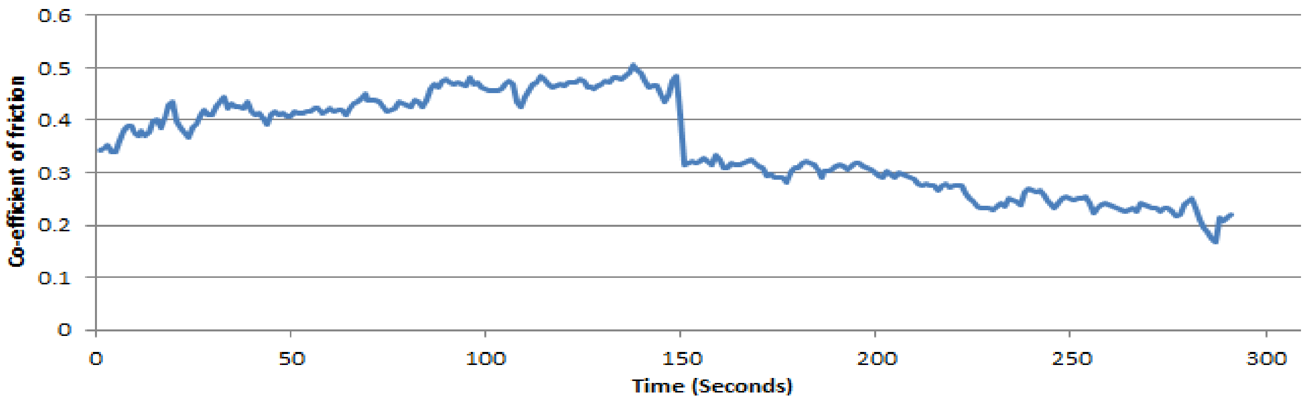


Fig. 2(d) Dependency of co-efficient of friction with time. Material; Casehardened carbon steel (Zinc coated)

Load; 500N.

It is observed from Fig.2 that co-efficient of friction for casehardened carbon steel was found to be steady after 20 seconds for a load of 500N. The steady state for coated casehardened carbon steel balls was reached approximately after 30 sec. The time required to reach steady state is called running in time. The co-efficient of friction in Fig.2 (a), (b) and (c) stabilizes with respect to time except 2(d). This deviation in co-efficient of friction graph with time is attributed to total failure of coating and exposure of substrate. The average co-efficient of friction and the corresponding loads are shown in Table.4.

Table.4. Applied load and co-efficient of friction for casehardened carbon steel balls (Uncoated) and coated with nickel (Ni), tin (Sn) and zinc (Zn).

Applied load (N)	Co-efficient of friction			
	Uncoated	Nickel coated	Tin coated	Zinc coated
100	0.79	0.69	0.76	0.87
300	0.56	0.48	0.36	0.55
500	0.44	0.46	0.28	0.43

Average co-efficient of friction in case of casehardened carbon steel ball (uncoated) is 0.79, 0.56 and 0.44 for loads 100N, 300N and 500N. The average co-efficient of friction in case of casehardened carbon steel ball coated with nickel is 0.69, 0.48 and 0.46 for loads 100N, 300N and 500N. The average co-efficient of friction in case of casehardened carbon steel ball coated with tin is 0.76, 0.36 and 0.28 for loads 100N, 300N and 500N. The average co-efficient of friction in case of casehardened carbon steel ball coated with zinc is 0.87, 0.55 and 0.43 for loads 100N, 300N and 500N.The average co-efficient of friction has been found to decrease, when load was increased. A plot depicting the variation of co-efficient of friction with normal load for case hardened carbon steel balls (uncoated) and coated with nickel (Ni), tin (Sn) and zinc (Zn) are shown in Fig.3.

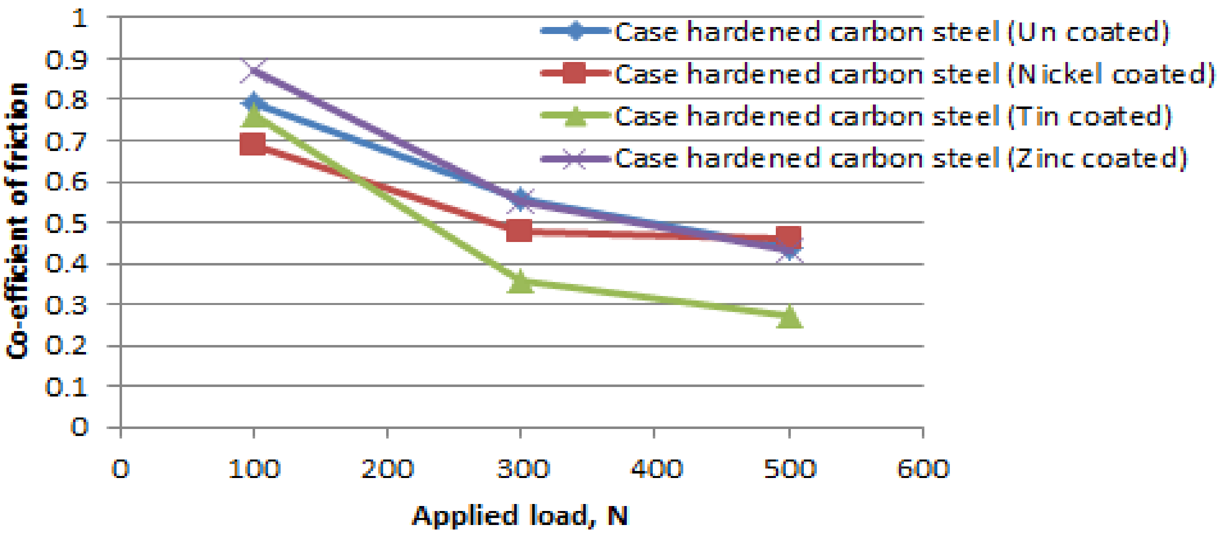


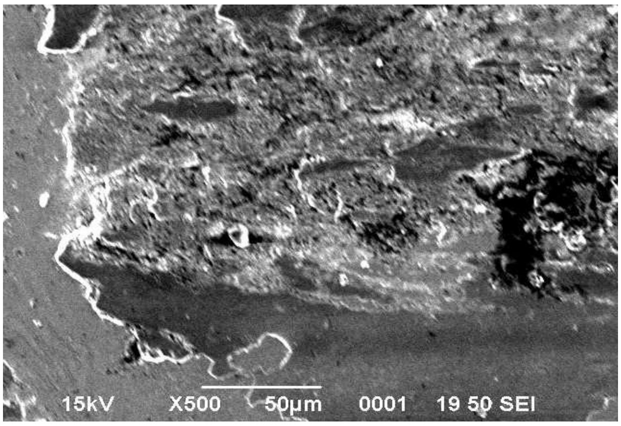
Fig.3 Co-efficient of friction with applied load for casehardened carbon steel balls (uncoated) and coated with nickel (Ni), tin (Sn) and zinc (Zn).

The co-efficient of fiction with normal load for casehardened carbon steel balls (uncoated) and coated with nickel (Ni), tin (Sn) and zinc (Zn) are shown in Fig.3.The graph with diamond symbol represents the dependency of co-efficient of fiction with normal load for uncoated casehardened carbon steel. The co-efficient of fiction was 0.79 at 100N, 0.56 at 300N and 0.44 at 500N. The graph with square symbol represents the dependency of co-efficient of fiction with normal load for nickel coated casehardened carbon steel. The co-efficient of fiction was 0.69 at 100N, 0.48 at 300N and 0.46 at 500N. The graph with triangle symbol represents the dependency of co-efficient of fiction with normal load for tin coated casehardened carbon steel. The co-efficient of fiction was 0.76 at 100N, 0.36 at 300N and 0.28 at 500N. The graph with × symbol represents the dependency of co-efficient of fiction with normal load for zinc coated case hardened carbon steel. The co-efficient of fiction was 0.87 at 100N, 0.55 at 300N and 0.43 at 500N. The graph shows that for tin coated balls, the co-efficient of fiction was found to decrease at a greater rate with increase in normal load. This observation could be attributed to the least yield stress for tin compared to other coating materials of nickel and zinc. In general the co-efficient of fiction was found to decrease with increase in normal load.

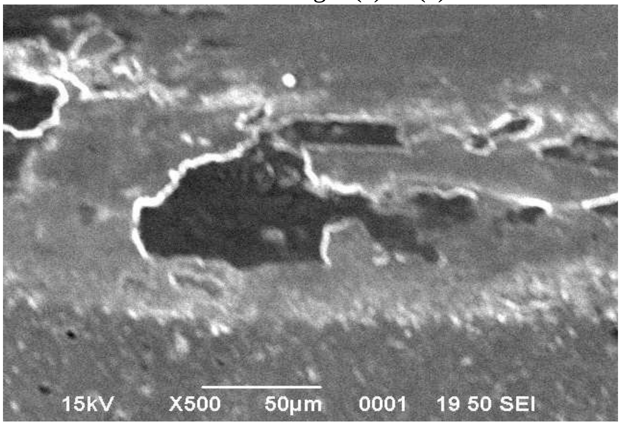
For understanding the dependency of co-efficient of fiction on normal load, systematic studies of wear scar were carried out in scanning electron microscope.

A. Scanning electron micrographic studies on wear scar

The wear scar which was a result of both deformation and failure was studied in scanning electron microscope. The scanning electron micrographs of wear scar for casehardened carbon steel ball (uncoated) studied in scanning electron microscope for a normal load of 100N, 300N and 500N are shown in Fig.4 (a) to (c).



(a) Wear scar on lower ball
Load; 100N Magnification; 500X



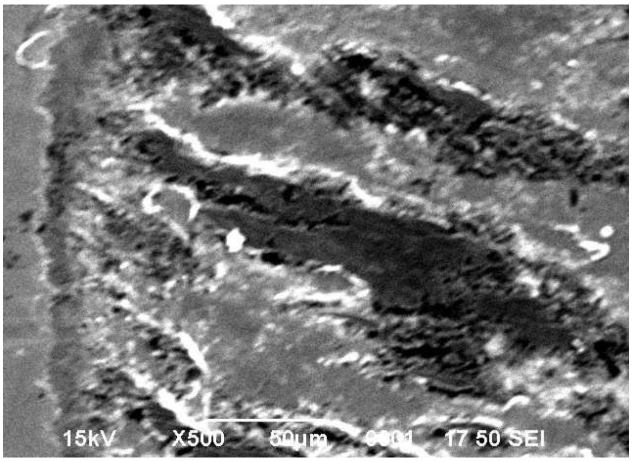
(b) Wear scar on lower ball
Load; 300N Magnification; 500X

(c) Wear scar on upper ball
Load; 500N Magnification; 500X

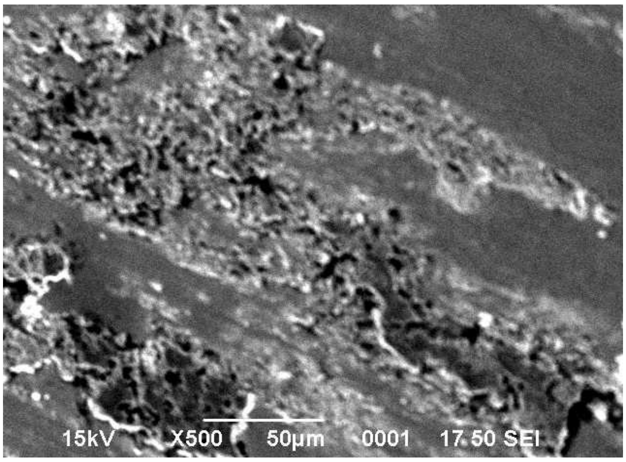
Fig.4 (a) to (c) Scanning electron micrographs of wear scar–casehardened carbon steel ball (Uncoated)

Micrograph in Fig 4(a) shows that the deformation and damage of the surface is more irregular. Micrograph 4(b) and (c) shows the deformation is more regular and uniform. This difference in deformation morphology is explains the variation in co-efficient of fiction with load.

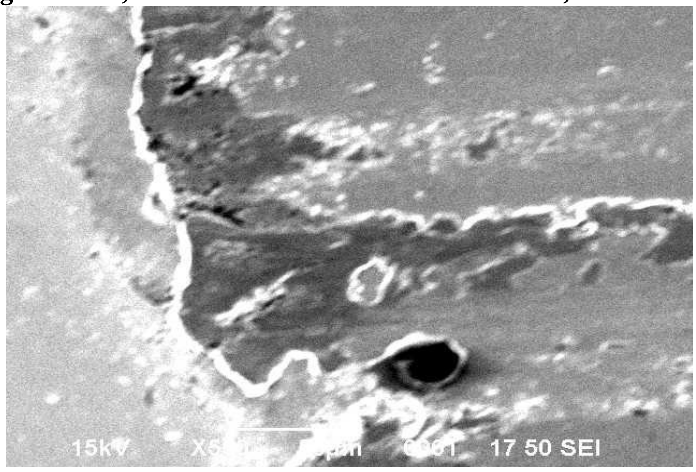
The scanning electron micrographs of wear scar for casehardened carbon steel ball with nickel coated studied in scanning electron microscope for a normal load of 100N, 300N and 500N are shown in Fig.5 (a) to (c).



(a) Wear scar on lower ball
Load; 100N Magnification; 500X



(b) Wear scar on lower ball
Load; 300N Magnification; 500X

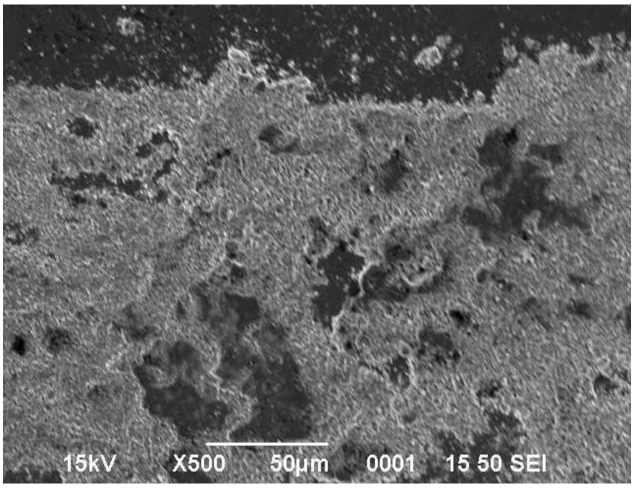


(c) Wear scar on lower ball
Load; 500N Magnification; 500X

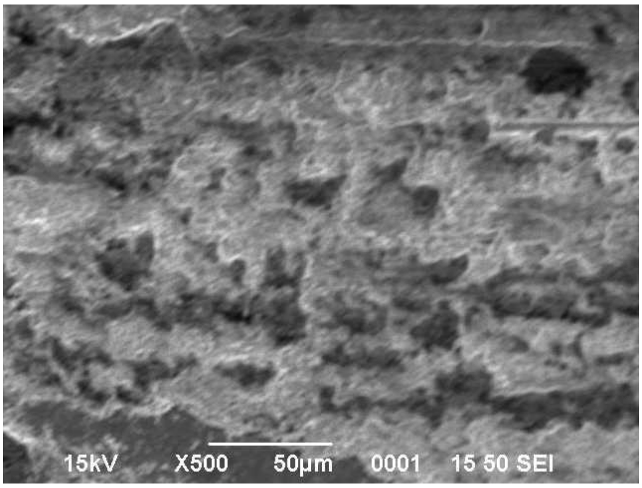
Fig.5 (a) to (c) Scanning electron micrographs of wear scar–casehardened carbon steel ball (Nickel coated)

Fig 5(a) shows the wear scar for a load of 100N. The deformation and damages in the micrograph are found to be severe compared to deformation and damages in micrograph 5(b) and (c) which are respectively for load 300N and 500N.

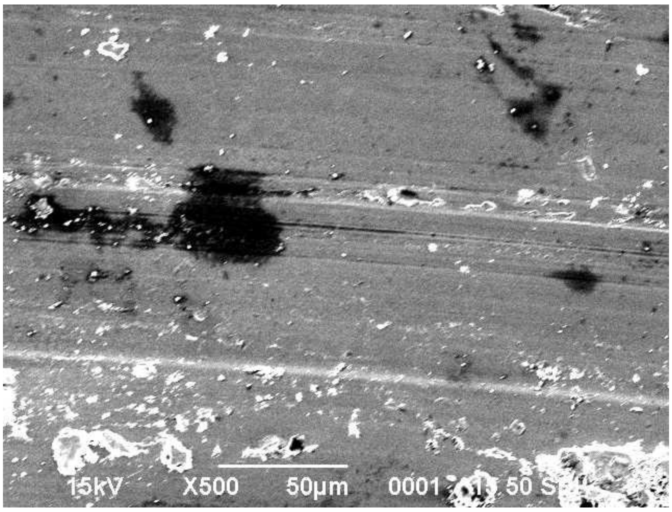
The scanning electron micrographs of wear scar for casehardened carbon steel ball with tin coated studied in scanning electron microscope for a normal load of 100N, 300N and 500N are shown in Fig.6 (a) to (c).



(a) Wear scar on lower ball
Load; 100N Magnification; 500X



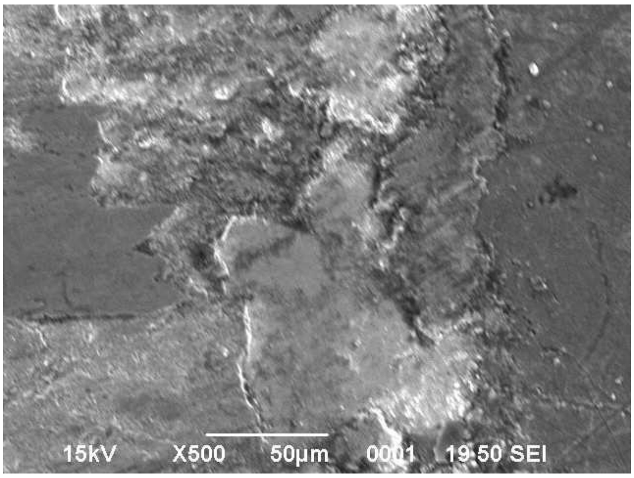
(b) Wear scar on lower ball
Load; 300N Magnification; 500X



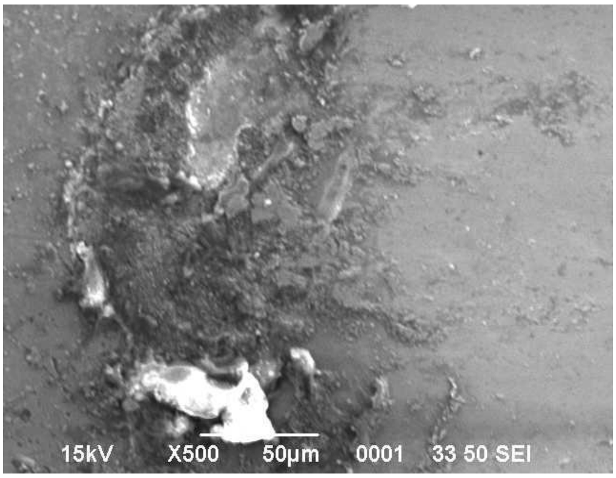
(c) Wear scar on lower ball
Load; 500N Magnification; 500X

Fig.6 (a) to (c) Scanning electron micrographs of wear scar–casehardened carbon steel ball (Tin coated)

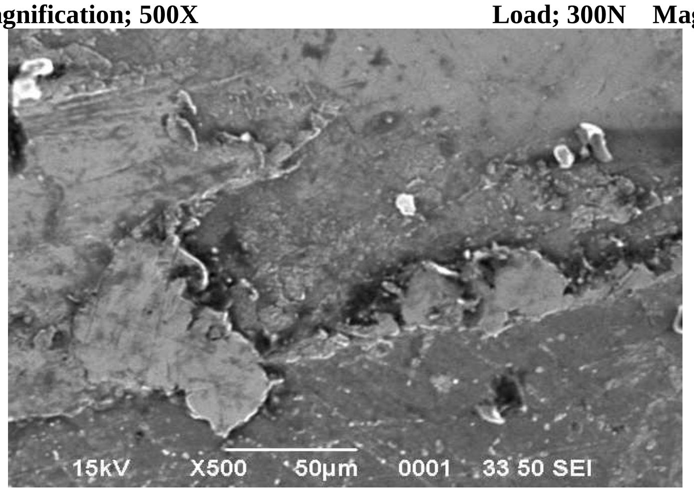
Fig 6(a) shows the wear scar for a load of 100N. The deformation and damage was found to be very severe compared to micrograph 6(c) which is for a load of 500N. Micrograph 6(b) shows regular pattern of damage and deformation compared to damages and deformation in micrograph 6(a). Micrograph 6(c) shows the total failure of the coating and exposure to substrate. The scanning electron micrographs of wear scar for casehardened carbon steel ball with zinc coated studied in scanning electron microscope for a normal load of 100N, 300N and 500N are shown in Fig.7 (a) to (c).



(a) Wear scar on lower ball
Load; 100N Magnification; 500X



(b) Wear scar on lower ball
Load; 300N Magnification; 500X



(c) Wear scar on lower ball
Load; 500N Magnification; 500X

Fig.7 (a) to (c) Scanning electron micrographs of wear scar–casehardened carbon steel ball (Zinc coated)

Fig 7(a) shows the wear scar for a load of 100N. The deformation and damage was found to be very severe compared to micrograph 7(c) which is for a load of 500N. Micrograph 7(b) shows damage and deformation of more regular compared to damages and deformation in micrograph 7(a). Micrograph 7(c) shows the total failure of the coating and exposure to substrate. These variations in morphology of wear scar revealed in scanning electron micrographs explain the dependency of co-efficient of fiction with load and coating materials.

IV. CONCLUSIONS

1. The co-efficient of fiction within the range of experimental normal loads was found to depend on normal load.
2. As normal load increases, the co-efficient of fiction was found to decrease.
3. The co-efficient of fiction was found to dependent on coating materials at a given normal load.
4. The co-efficient of fiction was found to be influenced based on strength of the coating material.
5. It was found that the tin coated ball experiments resulted in minimum co-efficient of fiction at maximum load.
6. The Non-Columb friction law observed in the result is attributed to the morphology of wear scar which was studied in scanning electron microscope.

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Suresha Gowda M. V., Graduated in BE (Mechanical Engineering), completed ME (Machine Design) and pursuing research in the Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore. Working as an Assistant Professor in the Department of Mechanical Engineering, S.J.C. Institute of Technology, Chick ballapur, Karnataka.

Dr. Ranganatha S., Graduated in BSc (MU), BE (Metallurgy), ME (Mechanical) and PhD from IISc. Bangalore. Working as Professor in the Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore, Karnataka.

Dr. Vidyasagar H. N., Graduated in BE (Mechanical Engineering), completed M.Tech (Advanced Manufacturing Engineering) and PhD from UVCE Bangalore. Working as an Associate Professor in the Department of Mechanical Engineering, University Visweswaraya College of Engineering, Bangalore, Karnataka.