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Role of Hardness on Abrasive Wear Modes in a Three Body Wear

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Abstract- In thermal power plants, fluid slurry conveying and other industrial applications where material is conveyed, the hard materials will be in-contact with parts of conveyors. The surfaces of piping and pumps surfaces come in contact with hard particles. The mill components like grinding ring, grinding balls and other components of the mill are exposed to different hard particles. In all the above the common feature is 'two bodies' which are in contact while transferring load and displacement from one object to other object. Apart from many are also exist, relative motions between the two objects. This type of loading and dynamic conditions gives rise to elastic, inelastic and surface damage of both the objects. This causes damage of machinery equipment which affects the efficiency of a machine and in extreme conditions leading to breakdown of machines. In the present investigations experiments have been conducted to understand basic wear mechanisms that will be prevailing when hardness of the material varies. For simulating the field conditions rubber wheel abrader test is used for conducting experiments. Mild steel (130.9 BHN heat resistant steel (155.6 BHN) High carbon high chromium steel (158.2 BHN) and cast iron (159.3 BHN) were used as target materials. Commercially available sand was used as abrader. Experiments were conducted with two normal loads 53.2 N and 102.4 N. The speed was maintained at 200 rpm. The time of test has 6 minutes, the flow rate was 100 grams/min. The wear loss was estimated and found that wear loss for mild steel and heat resistant steel are comparable which are 0.41 and 0.29 at a load of 53.2 N and 0.82 and 0.57 at a load of 102.4 N. The wear loss was estimated and found that wear loss for high carbon high chromium steel and cast iron of 0.08 and 0.04 at a load of 52.3 N and 0.16 and 0.06 at a load of 102.4 N which is again comparable.

Keywords: - 130.9 BHN heat resistant steel (155.6 BHN) High carbon high chromium steel (158.2 BHN) and cast iron (159.3 BHN), 102.4 N,

I. INTRODUCTION

Wear rates are reported over a wide range varying from 10^{-15} to 10^{-11} mm^3/Nm when operating conditions and materials selection varies [1- 7].

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This implies there is no unique way of designing the machine elements. Attempt have been made to quantify parameters which are used in design by constructing the maps [8, 9]. The wear volume and wear surface roughness are of different types which have been reported by [10, 11].Wear is basically classify into following mechanisms [12];

Adhesive wear: If the contact surfaces are very smooth and enough adhesive bonding stresses exists between two pairs which could be sufficient enough to resist the relative sliding displacement then adhesive wear takes place.

Fatigue wear: whenever the cyclic load occurs between two components which are under relative motion fatigue wear occurs.

Corrosive wear: whenever the relative motion occurs between two components especially corrosive liquids and gases reaction products give rise to corrosive wear.

Abrasive wear: whenever two contact surfaces interlocks due to their surface morphology, pouching takes place which leads to abrasive wear. Different models are develop to estimate the abrasive wear volume. One of the model estimate the wear volume loss V in terms of normal load 'W', length of sliding distance 'L', and hardness value 'H', is given in equation no 1[13].

$$V = \frac{1}{3}\frac{WL}{H} \quad \text{.............................. (1)}$$

The percentage of wear loss is estimated according to equation no 2 when tests were conducted in rubber wheel abrader according to ASTM G 65 specification.

$$\textit{Percentage in volume loss} = \frac{\text{Difference in weight}}{\text{Initial weight}} X\,100 \quad \text{.................. (2)}$$

Kozi kato conducted the experiment in vacuum and identified three different abrasive modes which are cutting mode, wedge forming mode and ploughing mode. These modes are shown in the Fig.1 [13]. Suresh gowda etal conducted experiments using four ball tester to study the role of material on deformation and failure modes and fond that material influenced the mode of failure [14].

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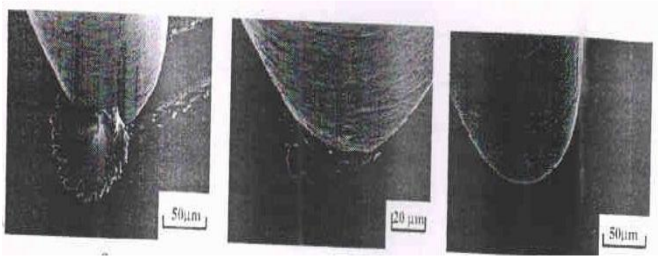

A B C

Fig.1 Three different modes of abrasive wear observed by SEM: Cutting mode (A), Steel pin on brass plate; Wedge forming mode (B), steel pin on stainless steel plate; Ploughing mode (C), Steel pin on brass plate

The literature survey indicates a general relationship between wear loss and hardness of the materials. An attempt has been made to find symmetrically how wear loss and hardness are related by conducting the test using rubber wheel abrader by choosing target material of different hardness.

II. EXPERIMENTAL PROCEDURE

Experiments were conducted using rubber wheel sand abrader. Mild steel (MS), Heat resistant steel (HRS) high carbon high chromium steel (HCHC) & Cast iron (CI) were used to prepare the target specimen. The brinell hardness of different materials as target are shown in the Table1.

Table 1. Brinell hardness of different materials.

S L. No.	Specimen	Brinell hardness number (kg/mm^2)
1	Mild steel	130.9
2	Heat resistant Steel	155.6
3	High carbon high chromium steel	158.2
4	Cast iron	159.3

The dimensions of the machined specimen are shown in Fig.2.

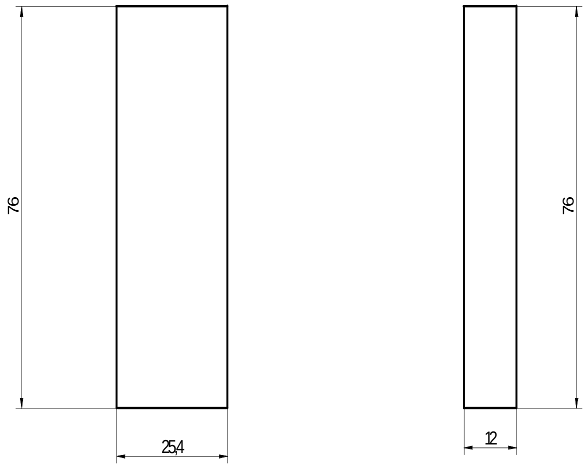

Fig. 2. Dimensions of target specimen

Commercially available silica sand was procured & further processed by washing, drying and sieving. The dry sand analyzed for sand distribution according to ISO 3310/1. The schematic view of rubber wheel abrader test rig is shown in Fig 3.

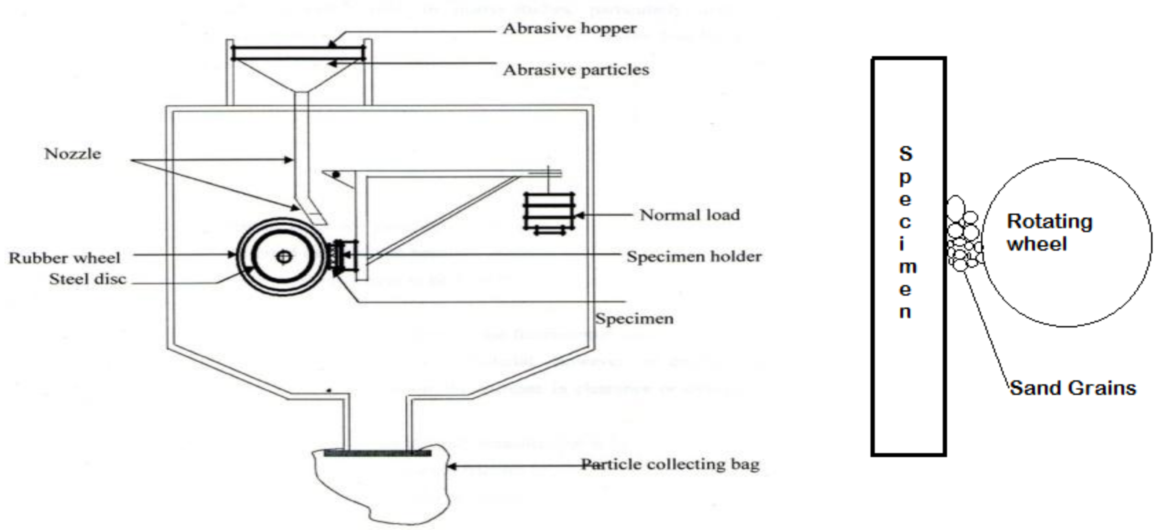

Fig.3. Dry sand wheel abrader

The loading lever was relived from specimen contact and following initial setting was carried out. The target material which is shown in the fig 1 is fixed to the specimen holder of the test rig.The process sand was filled in the hopper and by trial anderror the flow rate was adjusted to 100gms/min. The speed of the rubber wheel was maintained at 200 rpm. This speed has further confirmed using stroboscope. After the initial setting, the loading lever was set to impart the load on the specimen.

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The combination of loads, test duration are given in Table 2. The test target specimens were weight before and after test for estimating volume loss using equation no 2.

Table 2: Experimental parameters.

S. No.	Load in N	Speed in rpm	Sand flow rate in gms/min
01	102.4	200	100
02	53.2	200	100

The test specimens after experiment were studied in scanning electron microscope for understanding wear mechanisms.

III. RESULTS AND DISCUSSIONS

The volume loss for Mild Steel, Heat resistant steel, high carbon High Chromium steel and Cast iron are estimated using equation number 1 by finding out the weight of the target test sample before and after experiments. The volume loss for different materials are shown in Table 3.

Table 3: Volume loss of Different Materials

S. No.	Material	Percentage of volume loss for a load 53.2 N	Percentage of volume loss for a load 102.4 N
01	Mild Steel	0.41	0.82
02	Heat resistant steel	0.29	0.57
03	High carbon high chromium steel	0.08	0.16
04	Cast iron	0.04	0 .06

The volume loss for different materials and different loads are shown in the bar chart Fig.4.

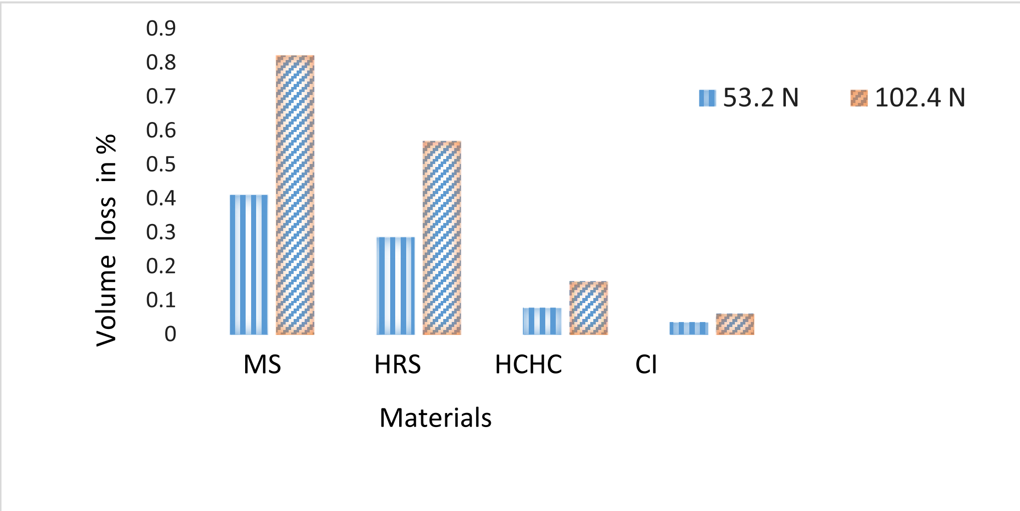

Fig. 4. Bar graph of volume loss for different normal loads.

The volume loss for cast iron is 0.04 at a normal load of 53.22 N and 0.06 at a normal load of 102.46 N. The volume loss for high carbon high chromium steel is 0.08 at a normal load of 53.22 N and 0.16 at a normal load of 102.46N. The volume loss for heat resistant steel is 0.29 at a normal load of 53.22 N and 0.57 at a normal load of 102.46 N. The volume loss for mild steel is 0.41 at a normal load of 53.22 N and 0.82 at a normal load of 102.46 N. The volume loss is found to be minimum for cast iron and maximum for mild steel. The volume loss is plotted versus hardness of different materials and shown in the Fig.5.

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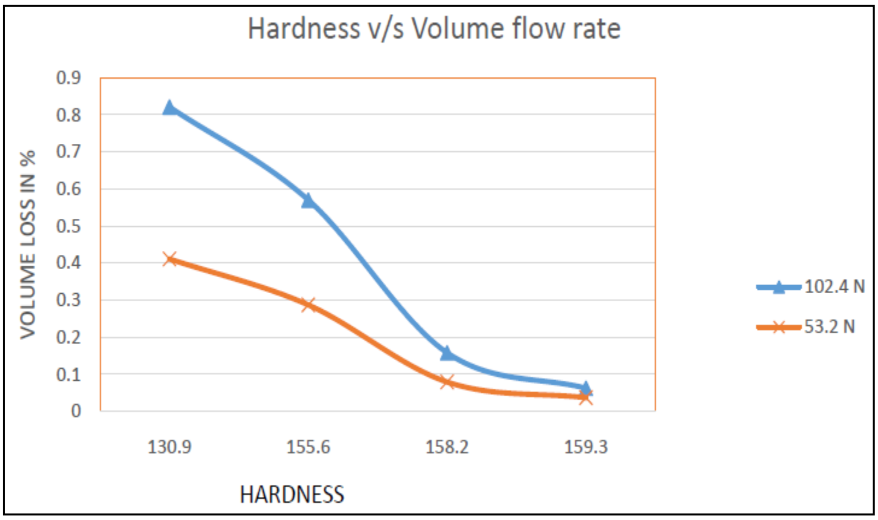
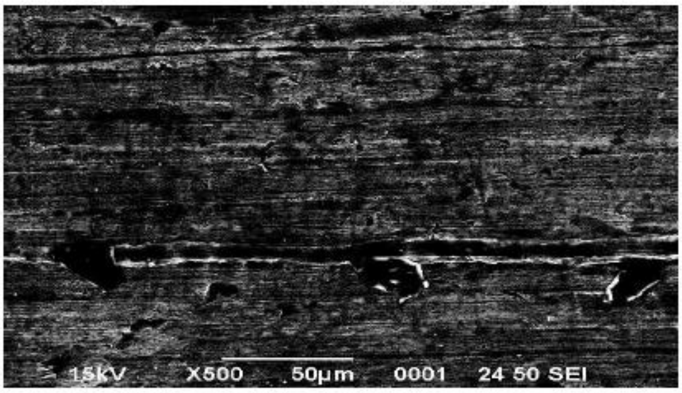


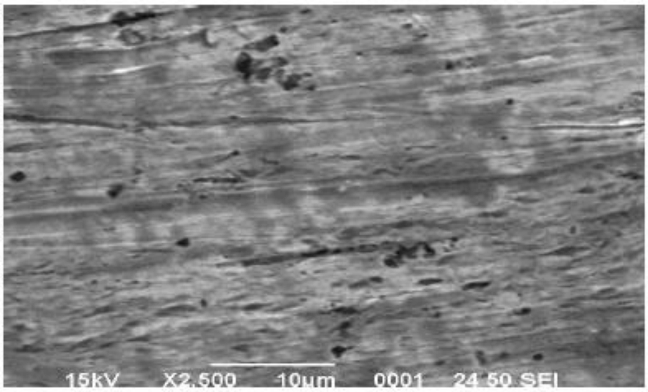
Fig.5. Dependency of volume loss with hardness for different loads.

The maximum volume loss was found to be 0.8 when normal load was 102.4 N and hardness was 130.9 (mild steel) BHN. The minimum volume loss was found to be 0.6when normal load was 102.4 N and hardness was 159.3 (cast iron) BHN. In case of mild steel, volume loss was found to be 0.4 when normal load changed from 102.4 N to 53.2 N.

The volume loss is found to be sensitive for normal load at lower hardness. This sensitiveness of volume loss with hardness is found to reduce as hardness increases and eventually found to be insensitive to the normal load at higher hardness within the experimental conditions. For understanding the dependency of volume loss under different loading conditions with change in material (hardness) scanning electron micrographic studies is carried out on tested samples. The photograph studied in SEM is shown in Fig.4 to 8.



(a)
Material: Mild steel
Load: 53.2 N
Magnification: 500 X



(b)
Material: Mild steel
Load: 53.2 N
Magnification: 2500 X

Fig.6 (a) & (b) SEM Micrograph of Wear scar-Mild steel.

Micrograph 6(a) is the worn out surface of the target specimen for a load53.2 N. The magnification of micrograph is 500. The micrograph shows deep groove at the middle. This deep groove has a raised and well defined ridges. These ridges shows large amount of plastic deformation and at places the ridges are torn out. The groove does not run completely and end at mid-way. There are many grooves which are not well defined and one such is found at the top. These grooves are not as clear as one which is at mid. Micrograph 6 (b) shows the worn surface of mild steel at magnification 2500. The micrograph shows grooves without any ridges. The magnified view appears smoother.

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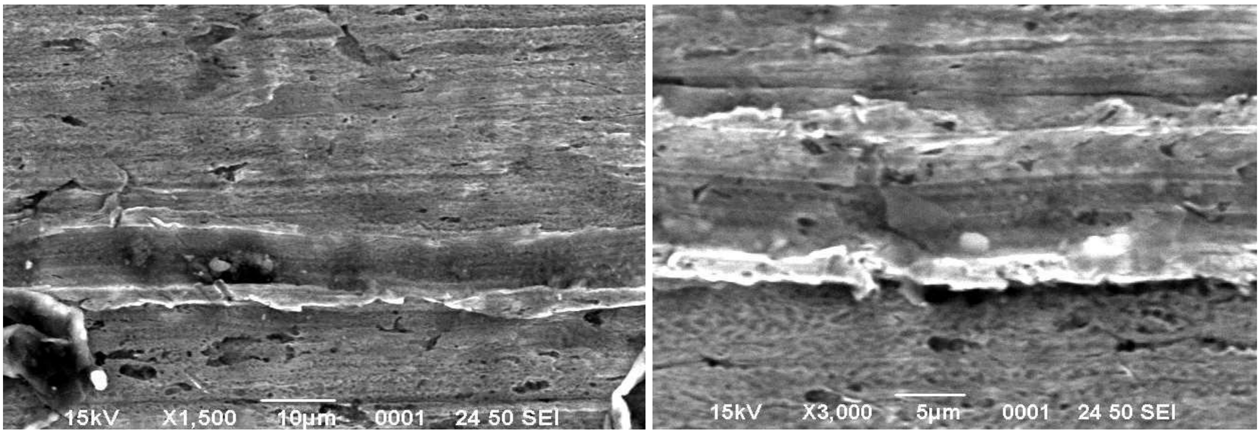
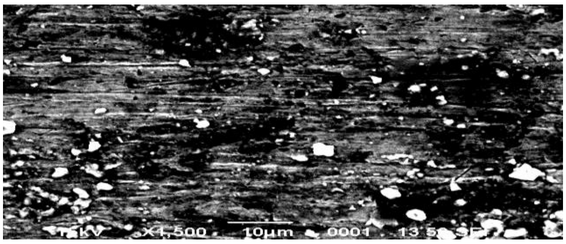


(a)
Material: Mild steel
Load: 102.4 N
Magnification: 1500 X

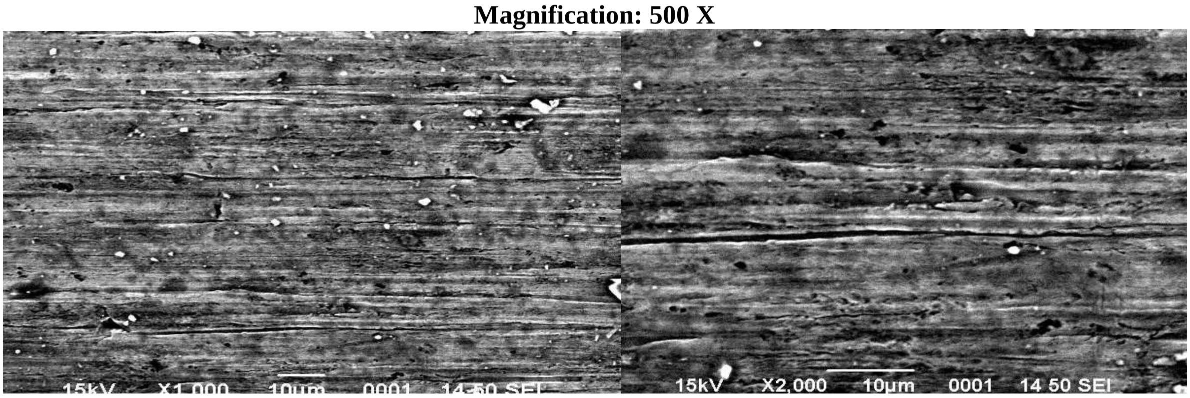
(b)
Material: Mild steel
Load: 102.4 N
Magnification: 3000 X

Fig.7 (a) & (b) SEM Micrograph of Wear scar-Mild Steel.

Micrograph 7 (a) is the worn out surface of the target specimen for a load of 102.4 N. The magnification of micrograph is 1500. There is a deep groove at the middle. The groove does not have well raised ridges as in case of micrograph 6 (a). At the right side of groove torn out material at the ridge is found. Micrograph 7 (b) is the worn out surface of the target specimen for a load of 102.4 N. The magnification of micrograph is 3000. Here two grooves are found which are adjacent to each other. The ridge which is common to both the grooves is found to be smoother and not well raised. The ridge at the bottom portion of the photograph is raised to a smaller extent and also it is torn out at many places. In general the micrograph 7 is more smoother compared to 6 (a). The features of worn surfaces shown in Fig 6 and 7 indicate the severe cutting mode of abrasive wear.



(a)
Material: Heat resistant steel
Load: 53.2 N
Magnification: 500 X



(a)
Material: Heat resistant steel
Load: 102.4 N
Magnification: 1000 X

(b)
Material: Heat resistant steel
Load: 102.4 N
Magnification: 2000 X

Fig.8 (a), (b) & (c) SEM micrograph of wear scar-Heat resistant steel.

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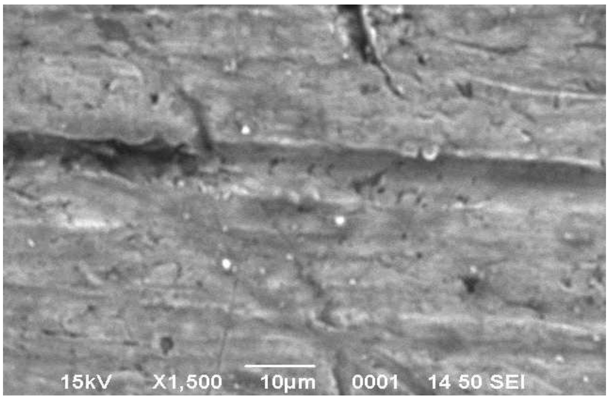
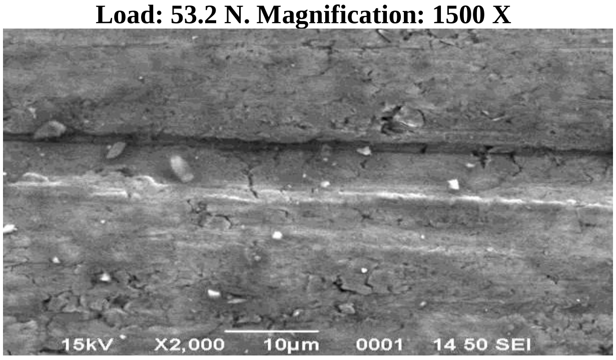
Micrograph 8 (a) is the worn out surface of the target specimen for a load of 53.2 N. The magnification of micrograph is 1500. The surface is not smooth, many grooves are found in the entire area and not well defined. Micrograph 8 (b) is the worn out surface of the target specimen for a load of 102.4 N. The magnification of micrograph is 1000. The surface is not smooth and worn grooves are not well defined. Micrograph 8 (c) is the worn out surface of the target specimen for a load of 102.4 N. The magnification of micrograph is 2000. At higher magnification few well defined grooves are found at the middle of the micrograph and not well defined grooves found at other areas of micrograph. The features in micrograph 8 indicates the mild cutting mode of the abrasive wear.



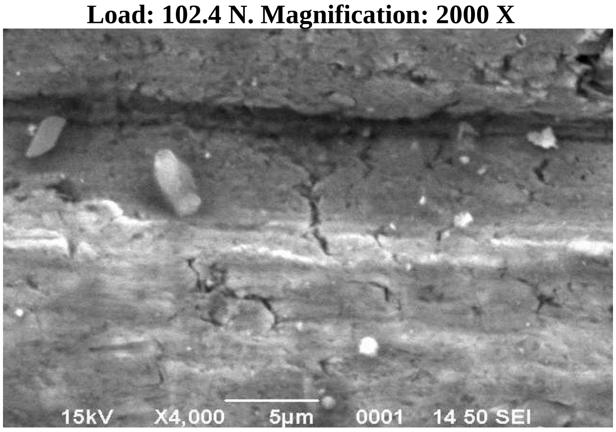
(a)

Material: High carbon high chromium Steel
Load: 53.2 N. Magnification: 1500 X



(b)

Material: High carbon high chromium Steel
Load: 102.4 N. Magnification: 2000 X

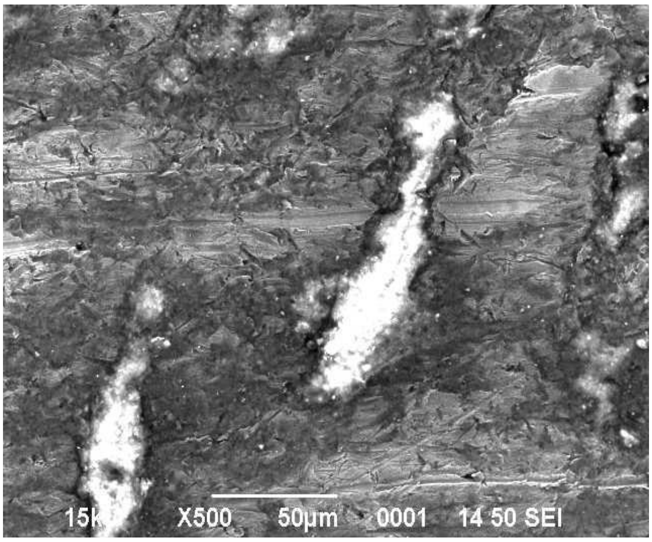


(c)

Material: High carbon high chromium Steel
Load: 102.4 N. Magnification: 3000 X

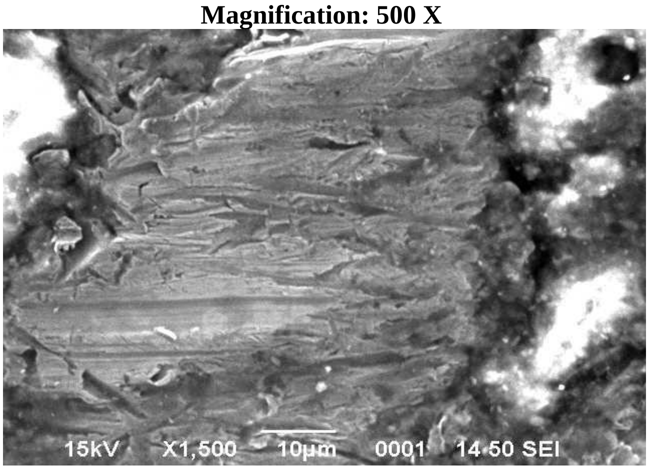
Fig.9 (a), (b) & (c) SEM micrograph of wear scar-High carbon high chromium steel

The photograph studied in SEM for the high carbon high chromium steel (HCHC) at a load of 53.2 N and 102.4 N as shown in the Fig 9. Micrograph (a) shows worn-out area of high carbon high chromium steel at a load of 53.2 N. The magnification of micrograph is 1500. The surface is smooth with a well-defined groove at the middle of the photograph. There is no ridges found with the groove. Micrograph (b) shows worn-out area of high carbon high chromium steel at a load of 102.4 N. The magnification of micrograph is 2000. There is a well-defined groove without ridge at the middle of the photograph. Cracks are observed in the groove. The depth of the groove is more than the groove in micrograph (a). Micrograph (c) is the magnified view of the micrograph (b). There appears to be cracks in the groove. In order to confirm the appearance of the crack, micrograph (b) is magnified and seen in micrograph (c). The micrograph (c) clearly shows the existence of crack in the groove. The features in micrograph indicates the wedging mode of abrasive wear.



(a)

Material: Cast iron
Load: 53.2 N
Magnification: 500 X



(b)

Material: Cast iron
Load: 102.4 N
Magnification: 1500 X

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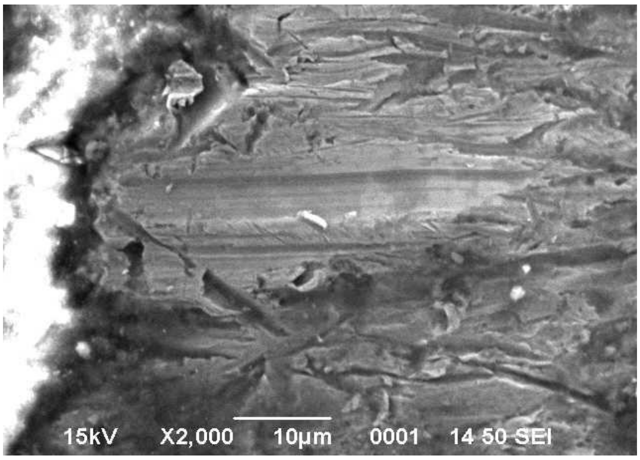

(c)

Material: Cast iron

Load: 102.4 N

Magnification: 2000 X

Fig.10. (a), (b) & (c) SEM micrograph of wear scar- Cast iron.

The photograph studied in SEM for the cast iron (CI) at a load of 53.2 N and 102.4 N as shown in the Fig 10. Micrograph (a) shows worn-out area of cast iron at a load of 53.2 N. The magnification is 500. The micrograph shows shallow grooves without ridges. These grooves are at the center and right side of the photograph. Micrograph (b) shows the worn-out area of CI at a load of 102.4 N. The magnification of micrograph is 1500. There is well definedone groove at the middle of the photograph. Micrograph (c) shows the different location of worn surface at a load of 102.4 N. The magnification of micrograph is 2000. The micrograph does not show any groove or other surface damages. The feature in micrograph 8 indicates the wedge forming mode of abrasive wear.

Micrographs in Fig 6 and 7 are for mild steel whose hardness is 130.9 BHN which is lowest compared to other metals which have been subjected to abrasion test. The volume loss for mild steel at both loads were maximum and are 0.41 and 0.82 at a loads of 53.2 N and 102.4 N. Comparing the micrographs of mild steel with heat resistant steel, high carbon high chromium steel and cast iron; the mode of wear is basically formation of deep grooves and well defined ridges which are characteristics features of cutting mode of abrasive wear. These ridges are further removed by the abrasive material. The material removal is consisting of two modes; number one is cutting mode of abrasive wear and mode two is where ridges were removed by subsequent abrasive material explaining the larger volume loss when compared to heat resistant steel, high carbon high chromium steel and cast iron.

Micrographs in Fig 8 are for heat resistant steel whose hardness is 155.6 BHN. Which is more than mild steel and less than high carbon high chromium steel and cast iron. The volume loss for heat resistant steel is 0.29 and 0.57 respectively at loads of 53.2 N and 102.4 N. These losses are more than mild steel and less than high carbon high chromium steel and cast iron. Comparing the SEM photographs with others the micrographs are similar to mild steel except the absence of well raised ridges. The mode of wear is cutting mode.

Micrographs in Fig 9 are for high carbon high chromium steel whose hardness is 158.2 BHN which is more than mild steel and heat resistant steel and less than cast iron. The volume loss is 0.08 and 0.16 at loads of 53.2 N and 102.4 N which is less than mild steel and high resistant steel and more than cast iron. The micrograph shows the plastic deformation morphology which is entirely different from mild steel and heat resistant steel. The mode of wear is different from modes found in mild steel and heat resistant steel. Here the metal is removed by forming a shallow groove. There is no formation of ridges. This mode is characteristics of wedge formation.

Micrographs in Fig 10 are for Cast iron whose hardness is 159.3 BHN which is more than Mild steel Hear resistant steel but comparable with High carbon high chromium steel. The volume loss is 0.04 and 0.06 at loads of 53.2 N and 102.4 N which is less than mild steel and heat resistant steel but comparable with High carbon high chromium steel. The micrograph shows the wear mechanism which is similar to high carbon high chromium steel. This mode is characteristics of wedge formation

IV. CONCLUSIONS

1. The wear was abrasive with different modes.
2. The wear was cutting mode of abrasive wear in case of mild steel and heat resistant steel.
3. The wear was wedge formation mode of abrasive wear in case of High carbon high chromium steel and cast iron.
4. Mild steel (130.9 BHN) showed maximum loss compared to heat resistant steel (155.6 BHN) High carbon high chromium steel (158.2 BHN) and cast iron (159.3 BHN).
5. Volume loss of Heat resistant steel is almost comparable with mild steel but more when compared to High carbon high chromium steel and cast iron.
6. Wear loss of High carbon high chromium steel and cast iron are comparable.
7. Wear loss of High carbon high chromium steel and cast iron are very less compared to mild steel and Heat resistant steel.

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