Inelastic Behavior of En 31 Steel Metallic Surface Subjected to Hard Body

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Abstract. In machineries of thermal power plants elements such as coal conveying systems, grinding balls, slurry carrying systems involves transfer of load and displacements. In all these machineries every element is subjected to the hard body such as particles from coal and slurry cause continuous wear results with abrasive wear. Due to this abrasive wear there is inelastic and damage of both the objects was takes place. Since many elements of all these machineries were made from En category steels this study was focused on En 31 steel. In the present study rubber wheel abrader was used to conduct the experiments. 106 microns, 212 microns and 425 microns graded abrader was used for conducting the test. En category steel i.e. En 31 was used as target material for the studies. The sand flow rate of 95 grams/minute was maintained. The weight loss was calculated and found that 0.004, 0.012 and 0.021, for an abrader size of 106 microns following with 0.005, 0.012 and 0.020 & 0.007, 0.022 and 0.023 for an abrader size 425 microns. For all these three tests a normal load of 11.37 N, 35.31 N, and 58.85 N was applied. Scanning electron microscope (SEM) was used to study the morphological analysis. There is light influence on volume loss due to the influence of abrader. Weight loss of the material does not solely depend on increasing in abrader size. Inelastic deformation and wear modes are seen as subject to mechanical properties of the target material. Disfigurement highlights describe the volume loss of the wear.

1. Introduction

In thermal power plants the machineries like coal conveying systems, coal handling systems, fluid and slurry handling systems, ash handling systems, many elements were made from En category steels. EN category steel offer excellent properties like wear resistance, toughness properties at low temperatures, good elastic modulus, High strength properties enable them to use in shafts, punches, drills, dies, mining equipments, ploughing elements of agriculture. In all these applications the common feature is two rubbing surfaces. Due to continuous operations involved there will be the transfer of displacements and motions. Transfer of displacements and loads causes the failure of machine elements leading to permanent machine breakdowns and efficiencies. During continuous rubbing a third body i.e. dirt or sand particles are present between the contact surfaces. As continuous relative motion takes place the third body will rubbing over the surface tends to abrade the surface, so that causing ploughing the surface. Due to this material was displaced from contact surface, so that weight losing will take place leads to element failure. Hence to design the elements of the machineries, it is the strong thrust needed to understand the mechanisms of wear in all the directions. It is also strong necessity required to understand the nature of wear as how it behaves with respect to load and nature i.e abrasive, adhesive and so on [1, 12].
**Abrasive wear:** whenever two contact surfaces interlocks due to their surface morphology, ploughing takes place which leads to abrasive wear. The mechanism is shown in figure 1(a)

![Figure 1. Schematic image adhesive wear mode.](image)

**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. The mechanism is shown in figure 1 (b).

From the model developed they determined that in three types of abrasive wear modes the grooves were formed as a result of abrasive particle and there is a plastic flow of the material by creating the groove having ridges on both sides. They found experimental and theoretical estimates of morphology of deformation in ploughing, cutting and wedge formation [3]. **Kayaba and Kato** [4] developed a model for predicting adhesive wear proposing various models of wear. The size of the wear particle predicted does not simply equal to the size of contact. The complexity of wear marvel was evaluated by characterizing boundaries like wear modes and wear rates. The complication of wear phenomenon was quantified by defining parameters like wear modes and wear rates. **Jonas Allebert** et al [5] tried to understand the influence of overlay welded high chromium white iron and quenched, tempered low alloy carbon steels. The test results showed that the wear of the material was dependent on abrasive size. **Seth** et al [6] made an attempt to understand the wear behavior of steel which were coated by thermally sprayed aluminum-titanium alloy coatings. The test results showed that wear performance of coating with aluminum and titanium was comparable within the weight percentage. **Beata Bialobrzeska & Piotr Kostencki** [7] conducted laboratory and field experiments to study the wear behavior of selected low alloy boron steels. They identified the two pre dominative wear modes which were micro-cutting and micro-ploughing. **Victor Gomez** et al [8] attempted in identifying effect of size of abrasive particles on wear. The test results indicated that the mass fraction of two different sized powders had a bearing on wear modes of the micro-scale level & wear rate was not found to have a direct relation with mass fraction. **Vytenis jankauskas** et al [9] made an attempt to characterize wear behavior of manually arc welded hard facings with low carbon and stainless steel matrix. They found the experimental results that improvement in wear resistance when tungsten carbide content was an order of 42 to 48%. **Hernandez** et al [10] made an attempt to understand role of temperature on abrasive of boron steel and hot forming tool steels. The wear rate was found to remain either a constant or improved as the temperature increases up to 400ºC.. The wear rate was found to increase with increase in temperature above 400ºC. **Bin Hwang** et al [11] studied the role of tensile properties on abrasive wear of steel saw wires. The two body wear was found to be influenced by tensile strength and micro-hardness of test materials. Whereas wear loss of three body wear was found to be influenced by elongation or ductility. The point of the work introduced in this paper was to give the tool to foreseeing versatile and inelastic characteristic of En 31 steel when exposed to abrasion wear.
2. Experimentation
Experimentation was done by using dry sand abrader test rig. Dry sand wheel abrader confirms ASTM G-65 standards. The schematic view of dry sand abrader was shown in figure 2.

![Figure 2. Schematic view of dry sand abrasion test rig.](image)

Three levels of different loads, varying size of abraders, constant speed, constant speed and flow rate was followed during entire test. The test parameters followed during the experimentation was tabulated and shown in table 1.

| Sl no | Abrader type  | Abrader size in microns | Normal Load in N | Wheel velocity in rpm | Test time in minutes |
|-------|---------------|-------------------------|------------------|-----------------------|---------------------|
| 01    | Graded Sand   | 106                     | 12               | 200                   | 8                   |
| 02    | Graded Sand   | 212                     | 35               | 200                   | 8                   |
| 03    | Graded Sand   | 425                     | 59               | 200                   | 8                   |

The test includes loading the target specimen in the slot provided in the test rig. Calculating the leverage loss the normal load was found for three different levels. The normal load was applied so that the chlorobutyle rubber wheel having contact with the target specimen. The wheel has been allowed to rotate at a speed of 200 revolutions per minute. The standard size sand abrader was sieved and filled to the hopper of the test rig. The sand flow rate of 100 grams/minute was maintained during the test. The test has been conducted for 8 minutes. After the test the target specimen was weighed and test result was recorded. Before the experiment also the target specimen was weighed. Weight loss of the target specimen was recorded by taking initial and final weight of the specimen.

3. Results and Discussions
The weight loss for target material was calculated by weighing before and after experimentation and weight difference of target test sample with normal load and abrader sizes was tabulated table 2.

| Sl. no | Abrader size in microns | Load in N | Volume loss in mm³ |
|--------|-------------------------|-----------|-------------------|
| 1      | 106                     | 12        | 0.004             |
|        |                         | 35        | 0.012             |
|        |                         | 59        | 0.021             |
| 2      | 212                     | 12        | 0.005             |
|        |                         | 35        | 0.012             |
|        |                         | 59        | 0.020             |
| 3      | 425                     | 12        | 0.007             |
|        |                         | 35        | 0.022             |
|        |                         | 59        | 0.023             |

Weight loss the specimen was calculating by taking initial weight and final weight of the specimen by before and after conduction of experiments. The weight loss calculated was tabulated in the table 2. The weight loss of 0.004,
0.0021 and 0.021 was found for the normal load of 11.77 N, 35.31 N and 58.85 N and abrader size of 106 microns. Similarly, weight loss of 0.005, 0.012 and 0.020 was found for the same normal load and abrader size of 212 microns. And the weight loss of 0.007, 0.022 and 0.023 was found for the same normal load and abrader size of 425 microns.

The variation of volume loss of the target specimen subjected to three different sand abraders was plotted in the graph and as shown in the figure.3.

Figure 3. Variation of volume loss for different normal loads.

Figure 3 shows the dependency of volume loss of target material for three different sized abraders. The curve with blue color belongs to volume loss of target specimen when the grain size of the abrader is 106 microns. Weight loss of 0.004, 0.012 and 0.021 was takes place when the normal loads 12 N, 35 N and 59 N respectively. The curve with red color belongs to volume loss of target specimen when the grain size of the abrader is 212 microns. Weight loss of 0.005, 0.012 and 0.020 was takes place when the normal loads 12 N, 35 N and 59 N respectively. The curve with green color belongs to volume loss of target specimen when the grain size of the abrader is 425 microns. Weight loss of 0.007, 0.022 and 0.023 was takes place when the normal loads 12 N, 35 N and 59 N respectively. From the results it was found that there is no much influence of weight loss at the selected normal load levels except the weight loss takes place at a normal load 35.31 N and abrader size 425 microns.

The variation of weight loss of the target specimen subjected to three different normal load levels was plotted in the graph and as shown in the figure.3.

Figure 4. Variation of volume loss for different sized abraders.

From the figure the blue curve shows the weight loss of the target specimen when the normal load was 12 N. The weight loss takes place for this normal load was 0.004, 0.012 and 0.021 subjected to three abrader sizes of 106 microns, 212 microns and 425 microns. The red curve shows the weight loss of the target specimen when the
normal load was 35 N. The weight loss takes place for this normal load was 0.005, 0.012 and 0.020 subjected to three abrader sizes of 106 microns, 212 microns and 425 microns. The green curve shows the weight loss of the target specimen when the normal load was 59 N. The weight loss takes place for this normal load was 0.005, 0.012 and 0.020 subjected to three abrader sizes of 106 microns, 212 microns and 425 microns.

In order to understand the deformation morphology of the abraded specimens a scanning electron micrographic study was carried out and discussed below.

Figure 5 shows scanning electron micrographs when the target specimen was subjected to a normal load of 11.77 N and three abrader sizes.

![Figure 5](image1.png)

**Figure 5.** SEM micrographs of wear scar- for normal load of 11.77 N, abrader size 106 microns(a), 212 microns (b) & 425 microns(c) with a magnification of 500 X

Micrographs shown in figure 5 (a) & figure 5 (b) have one groove but these grooves were not well defined. The scratches were found in both micrographs 5 (a) and 5 (b). But theses scratches are also not defined clearly. Many number of grooves were found in micrograph shown in figure 5 (c), but not well defined.

Figure 6 shows micrographs scanned by scanning electron microscope (SEM), when the target specimen was subjected to a normal load of 35.31 N and three different abrader sizes.

![Figure 6](image2.png)

**Figure 6.** SEM micrographs of wear scar- for normal load of 35.31 N, abrader size 106 microns(a), 212 microns (b) & 425 microns(c) with a magnification of 500 X

Two number of grooves were found in micrographs shown in figure 6 (a) and figure 6 (c). No well defined grooves were found but many scratches were found in micrograph in figure 6 (b).

Figure 7 shows micrographs scanned by scanning electron microscope (SEM), when the target specimen was subjected to a normal load of 58.85 N and three different abrader sizes.

![Figure 7](image3.png)

**Figure 7.** SEM micrographs of wear scar- for normal load of 58.85 N, abrader size 106 microns(a), 212 microns (b) & 425 microns(c) with a magnification of 500 X

There are two grooves each one at micrograph shown in figure 7 (a) and figure 7 (c) along with little no scratches. In micrograph shown in figure 7 (b) no well-defined grooves were found but more number of well-defined scratches were found.
In order to better understanding the variation of weight loss with different normal loads has been shown in figure 8 to figure 13. The wear scars were scanned by scanning electron microscope.

Micrographic study of wear scars when target specimen was subjected to different normal load levels and abrader size of 106 microns has been shown in figure 8.

![Figure 8. SEM micrographs of wear scar- for abrader size of 106 microns, normal load 11.77 N (a) 35.31 N (b) & 58.85 N (c) with a magnification of 500 X](image)

Micrographs shown in figure 8 (b) and figure 8(c) have more density of scratches without any grooves where as micrographs shown in figure 8 (a) has very less density of scratches without any grooves.

Micrographic study of wear scars when target specimen was subjected to different normal load levels and abrader size of 212 microns has been shown in figure 9.

![Figure 9. SEM micrographs of wear scar- for abrader size of 212 microns, normal load 11.77 N (a) 35.31 N (b) & 58.85 N (c) with a magnification of 500 X](image)

All the micrographs shown in figure 9 (a), 9 (b) and 9 (c) do not have any grooves but many scratches are found.

Micrographic study of wear scars when target specimen was subjected to different normal load levels and abrader size of 425 microns has been shown in figure 10.

![Figure 10. SEM micrographs of wear scar- for abrader size of 425 microns, normal load 11.77 N (a) 35.31 N (b) & 58.85 N (c) with a magnification of 500 X](image)

Micrographs shown in figure 10 (a) shows grooves of different intensities running across the length. Micrographs shown in figure 10 (b) & 10 (c) does not shows any cleared grooves but micrographs shown in figure 10 (b) & 10 (c) are comparable.

Micrographic study at lower magnification which is at 500 x could not reveal the feature which could explain the weight loss on variations in abrader sizes. A further study was carried out at magnification level of 1500 X to understand the in detail inelastic deformation of the target specimen.
Micrographic study of wear scars when target specimen was subjected to a normal load of 11.77 N and three different abraders has been shown in figure 11.

![Micrographs](image1)

**Figure 11.** SEM micrographs of wear scar—normal load of 11.77 N, abrader size 106 microns (a), 212 microns (b) & 425 microns (c) with a magnification of 1500 X.

Micrograph shown in figure 11 (a) and figure 11 (b) show very few not well defined and shorter in size grooves. These two micrographs are comparable. Micrograph showed in figure 11 (c) shows well defined bigger grooves with mild cut ridges. Micrograph shown in figure 11 (c) is different from micrograph shown in figure 11 (a) and shown in figure 11 (b).

Figure 12 shows the scanning electron micrographs study of wear track on EN 31 at a normal load 35.31 N and different grades of abraders.

![Micrographs](image2)

**Figure 12.** SEM micrographs of wear scar—normal load of 35.31 N, abrader size 106 microns (a), 212 microns (b) & 425 microns (c) with a magnification of 1500 X.

Micrographs shown in figure 12 (a) shows a narrow and discontinuous groove running across the length. Micrographs shown in figure 12 (b) shows non continuous, shallow and number of grooves compared to features observed in micrograph shown in figure 12 (a). Micrograph shown in figure 12 (c) shows groove which is wider, deeper with not well defined ridges running across the length. At few places partially chipped metallic material is observed.

Figure 13 shows the scanning electron micrographs study of wear track on EN 31 at a normal load 58.85 N and different grades of abraders.

![Micrographs](image3)

**Figure 13.** SEM micrographs of wear scar—normal load of 58.85 N, abrader size 106 microns (a), 212 microns (b) & 425 microns (c) with a magnification of 1500 X.

Micrographs shown in figure 13 (a), 13 (b) and 13 (c) shows grooves which are running across the length. The groove features in figure 13 (b) and figure 13 (c) are comparable whereas grooves in micrograph shown in figure 13 (a) is different from grooves found in micrograph 13 (b) and micrograph 13 (c). The groove found in micrograph 13 (a) is shallow but little wider.
4. Conclusions
The wear was found to be consequence of deformation. No such inelastic deformation was found due to the influence of abrader size. Significant deformation was found by the impact of normal load. The wear was found with different modes and well defined mode was not found. The deformation features characterize the wear volume losses. The grain sizes of the abrader are found to have little influence on volume loss when compared to the wear loss with normal load. It is required to carry out the study for the materials which exhibit different microstructural features. It is necessary to correlate the study with the developed theoretical model with different instant of loads.

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