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# Studies on the Effect of Ferrite Phase on Tribological Properties of a Plain Carbon Steel

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***Abstract :*** *In the present paper wear behaviour of plain carbon steel having ferrite phases under dry sliding condition has been investigated. Plain carbon steel material S1079 E.D.D. containing 0.13% C, 0.25% Si and 0.62% Mn in the form of rods were selected. These rods were used to produce the wear test pin specimens. After heat treatment process, studies on the microstructure of the wear test pin specimens were carried out. Compositions, morphologies and microstructures of worn surfaces were characterized by scanning electron microscope (SEM), energy dispersive spectroscopy analysis (EDS) and optical microscopy. It was observed that in ferritic phase both oxidative and laminative wear mechanisms dominated. A critical sliding speed of 3m/s sliding speed was observed in case of ferritic phase. In case of ferrite phase the volumetric wear rate was more for lower sliding speed-higher normal pressure and higher sliding speed-higher normal pressure combinations.*

***Keywords:*** *Volumetric wear, ferrite, sliding speed and normal pressure.*

## INTRODUCTION

One of the very large number of variables which can affect wear mechanisms and wear rates. Data obtained with one set of conditions may become useless while considering other conditions, because different processes may become important and wear rates can change by orders of magnitude with relatively small changes in experimental variables. The conditions responsible for transitions in wear mechanisms and the wear rate are complex [1]. Surface condition having important role in the process of wear is the friction coefficient which decreases with increase in the sliding speed and normal pressure [2]. Oxides that form the stable scale depend on alloy composition, alloy inter diffusion coefficients, oxygen solubility, diffusivity in the alloy, growth rates of various oxides, mechanical properties of the scale and the oxidation conditions [3]. Investigation of the fundamental delamination mechanisms of sliding wear with respect to phenomena show that when two sliding surfaces come in contact, normal and tangential loads are transmitted through the contact points by adhesive and ploughing actions ploughing through it [4]. Investigations of the plastic deformation of an elasto-plastic surface layer under the influence of normal and tangential loads exerted by a hard asperity reveal that, qualitatively the plastic deformation occurs in such a manner that the shear strain component in planes, perpendicular to the surface accumulates incrementally each time a hard asperity passes over the surface [5]. The analysis shows that the stress intensity factors reach maximum values at a finite distance below the surface, indicating that the cracks located at this depth will propagate faster than those located elsewhere. In the study of the effect of normal load on friction coefficient it was observed that the friction coefficient increases, almost linearly, with normal load and is contrary to the contact potential which presents a minimum with increasing normal load. In general, increasing normal load as well as increasing sliding speed resulted in a decrease in the coefficient of friction (μ) [6]. Heat is generated due to the sliding of two surfaces against each other due to the friction, which is absorbed by the two surfaces in different proportions. Temperature increase at the local points influence the rate of wear and decides the wear mechanism [7].

For the tribological properties study, commercial grade steel was used as shown in Table 1. Wear characteristics of these samples were investigated after the heat treatment process. Wear samples of size 30 mm length and 10mm diameter in the form of pins were used. These samples were covered with cast iron chips to avoid oxidation and subjected to heating above 840°C in a muffle furnace. After soaking for a period of 1h, the samples were then allowed to cool down in the furnace itself. Samples were then polished for microstructure study. Microstructure of the sample was recorded as shown in the Fig. 1

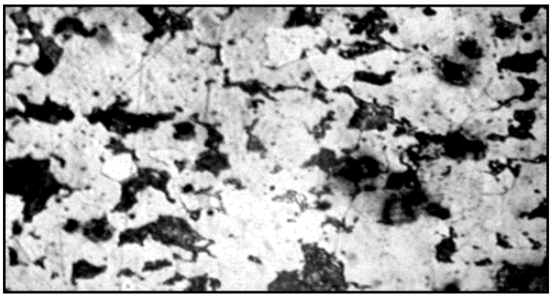

Fig.1 0.13 % Carbon steel, <10 % Pearlite, >90 % Ferrite annealed after heating at 840$^0$C

WEAR TEST

The wear tests were carried using a pin on disc wear testing machine. Both the surfaces of the pins were cleaned with acetone and the test were carried out at different sliding speeds of 1, 3, 5 and 7m/s with corresponding loads at 1, 3, 5 and 7kg respectively. Dry sliding wear test was carried out using a hardened counter face of a polished disk of EN-32 with a hardness of HRC 62- 65 at a relative humidity of 50-70 % at a room temperature of 32°C. Weight losses of pins were recorded using an electronic balance having an accuracy of 10-7 Kg at different interval of time.

METALLOGRAPHIC STUDIES

The test samples before the wear studies were prepared for metallographic examination by polishing using different grades of polish papers of 4/0, 6/0 and then wet polishing was carried out using wet alumina paste of sub-micron grade. Further, for etching of the wear test specimens after polishing 2% nital solution was used. After the wear test, worn out pin samples were coated with gold oxide to overcome the effect of oxidation and then studied under the optical and SEM microscopes. The micro hardness of the wear tested samples using Vickers hardness machine was measured using a load of 0.005kg. Surface roughness of the worn out pin specimen was recorded using surface roughness tester of Mitutoyo Precision SJ-210.

RESULTS AND DISCUSSIONS

Wear tests were first performed at a normal pressure from 0.1249 to 0.8743MPa with varying sliding speed from 1 to 7m/s for 10,000 meters. The volumetric wear rate was calculated from the expression volume loss per unit sliding distance (mm$^3$/ mm)

*Volumetric wear rate: Effect of normal pressure for constant sliding speed*

As seen in Fig. 2, for the sliding speed of 1m/s, the volumetric wear rate increases and accordingly then decreases with further increase in the normal pressure. Initially volumetric wear rate is low and increases with the increase in the volumetric wear rate. With further increase in the normal pressure the volumetric wear rate falls down because the volume loss is inversely proportional to the hardness as per the Archard's equation. During wear test under the influence of normal pressure on the specimens, the stress field of dislocation density originates i.e. with further increase in the normal pressure volumetric wear rate decreases [7].

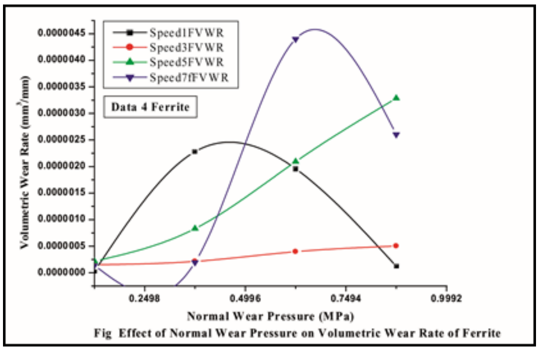


Fig. 2 Effect of Normal Wear Pressure on Volumetric Wear Rate of Ferrite

Further, under low sliding speed of 1m/s, the amount of heat generated between the sliding surfaces is quite low. Whatever the heat is generated will be carried out through the pin due to conduction. Also with increase in the normal pressure intimate contact between the wearing surfaces is more. Hence, with increase in the normal pressure amount of surface deformation is more which leads to work hardening. Due to this work hardening, surface hardness of the wearing pin increases, which results in reduction in volumetric wear rate. For the sliding speed of 3m/s the volumetric wear rate steadily increases with increase in the normal pressure. For the sliding speed of 5m/s, volumetric wear rate increases steeply with the normal pressure. For the sliding speed of 7m/s, initially the volumetric wear rate increases very fast, later at higher normal pressure of 0.8743MPa it decreases [8]. In case of ductile material with ferrite structure the wear takes place mainly by shear mode. Hence the wear increases only at the higher normal pressure, where frictional load could exceed the normal pressure causing the rise in frictional temperature leading to work hardening and easy removal of material due to embrittlement.

*Friction force: Effect of normal pressure for constant sliding speed*

From the Fig. 3 it is observed that the frictional force increases with increase in normal pressure. With increase in the normal pressure the intimate contact between the wearing surfaces and the sliding disc increases. Due to this increase in the contact area the frictional force increases with increase in the normal pressure.

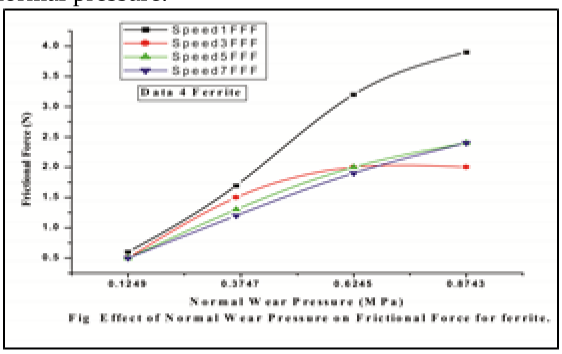


Fig. 3 Effect of Normal Wear Pressure on Frictional Force for ferrite

The frictional force steeply increases with an increase in the normal pressure. Presence of bigger size micro welds increases the frictional force as seen in Figs. 4(a-d). At the sliding speed of 3m/s frictional force is almost low and remains the same with increase in the normal pressure. It is seen that under sliding speed of 3m/s oxide film is generated between the wearing surfaces. Further it is also observed that at the sliding speeds of 5 and 7m/s frictional force steadily increases with the increase in the normal pressure. Under these sliding speeds oxide films break away permitting intimate contact between the wearing surfaces. As the normal pressure increases the area of intimate contact will increase and the frictional force will increase steadily with increase in the normal pressure as seen in Fig. 5(a-b)

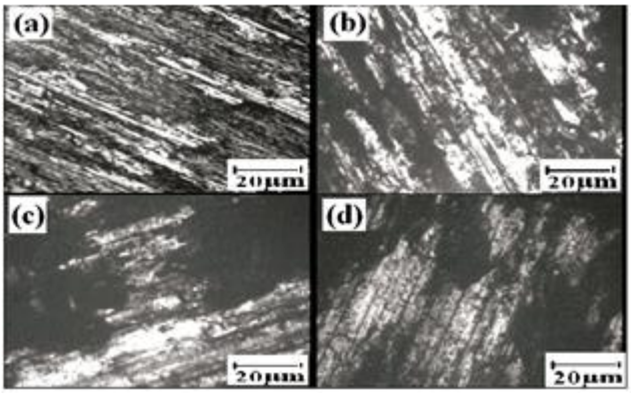


Fig.4 (a) Ferrite phase sliding speed 1m/sec, 212RPM, 0.1249 MPa normal pressure,
(b) Ferrite phase sliding speed 1m/sec, 212RPM, 0.3747MPanormal pressure,
(c) Ferrite phase sliding speed 1m/sec, 212RPM, 0.6245 MPa normal pressure, 167Min
(d) Ferrite phase sliding speed 1m/sec, 212RPM, 0.8743 MPa normal pressure of 1m/s,

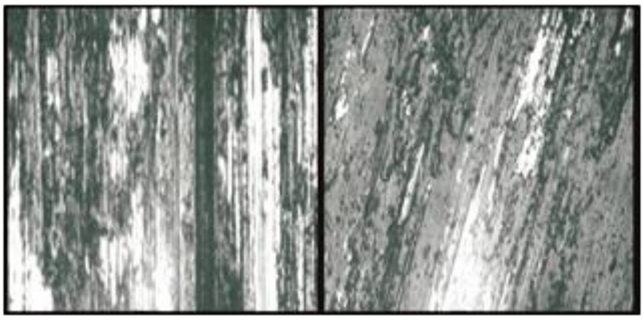

Fig.5 (a) Ferrite phase sliding speed 7 m/sec, 1484RPM, 0.1249 MPa normal pressure,
(b) Ferrite phase sliding speed 7 m/sec, 1484RPM, 0.3747 MPa normal pressure

*Volumetric wear rate: Effect of sliding speed for constant normal pressure*

Fig. 6 represents the three wear regions viz mild wear regime, transition wear regime and severe wear regime. Very low volumetric wear rates are observed in tests at the sliding speed of 3m/s regardless of normal pressure. This indicates that at this sliding speed the volumetric wear rate is independent of the sliding speed. Fig. shows the variation of volumetric wear rate for specimens treated differently at different normal pressures and sliding speeds. It can be seen that these pin specimens show a lower volumetric wear rate at the lower normal pressure and sliding speed. However, the wear rate increases rapidly with an increase in sliding speed beyond a certain test normal pressure.

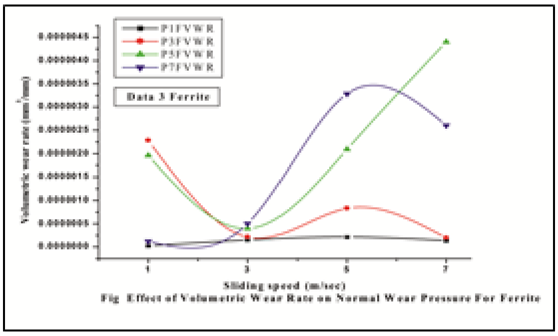


Fig 6 Effect of Normal Wear Pressure on Volumetric Wear Rate of Ferrite

Obviously, the wear mechanism of steel has a transition from mild wear to severe wear. It will be known from the analysis that the mild wear is oxidation dominated wear and the severe wear is plasticity dominated wear i.e. adhesion and delamination. It is understood that, volumetric wear rate is minimum at the sliding speed of 3m/s for all the normal pressures. Before and after the sliding speed of 3 m/s the volumetric wear rate is more when compared with that at the sliding speed of 3 m/s. At the sliding speed of 3 m/s the oxidative wear mechanism is observed.

*Friction force: Effect of sliding speed for constant normal Pressure*

From Fig. 7 it is observed that frictional force is reduced with the increase in the sliding speed for almost all normal pressures.

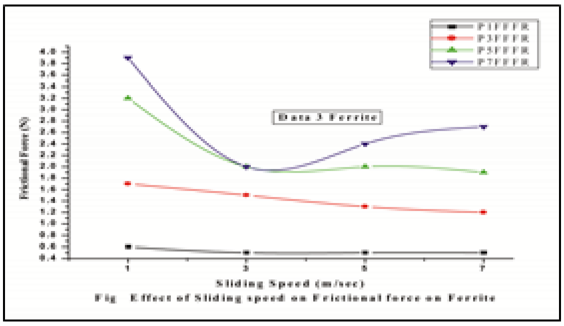


Fig. 7 Effect of sliding speed on frictional force

The frictional force increases with increase in the sliding speed because with increase in the sliding speed the reduction in residential time takes place which results in reduction in the growth of micro-welds. For the normal pressure of 0.8743MPa the frictional force reduces with the sliding speed up to 3m/s but increases further with increase in the sliding speed. Therefore the corresponding volumetric wear rate is low that is observed in the Figs. 4(a), 4(c). The micrograph also shows the chattering effect in the wear tracks, which may be due to the resistance offered by the material to the wear and also due to the welding effect on the debris that are formed.

Energy Dispersion Spectroscopy (EDS) Test

The EDS results interpreted in the figures with varying sliding speeds and normal pressures show that iron element was identified with no trace of oxygen in point 1.

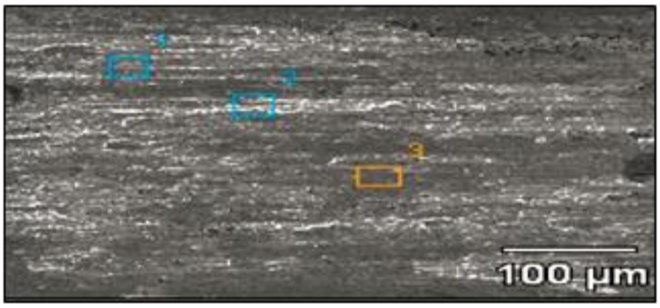


Fig.8 212 RPM, 0.1249 MPa

However a strong oxygen peak was recognized in point 2. It is clear that these points have oxygen rich compounds or tribo-oxides. At low normal pressure and low sliding speed ferrite phase forms oxides of Fe, Ferrite phase very high concentrations of both manganese and iron oxides form at high normal pressure and high sliding speed.

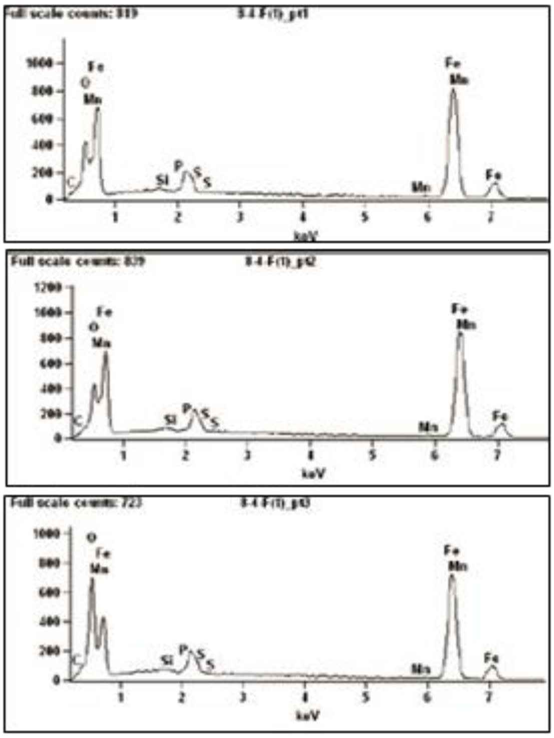

Fig. 9 (a-c) 212 RPM, 0.1249 MPa, for point 1, 2 & 3

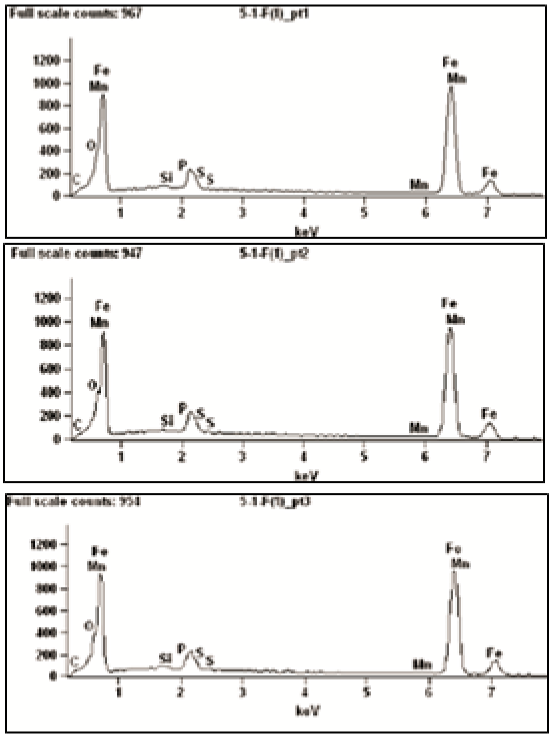

Fig. 10 1484 RPM, 0.8743MPa

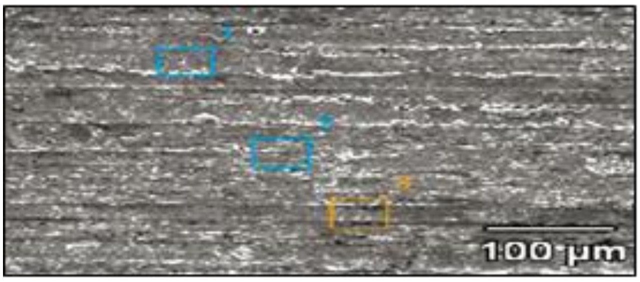


Fig. 11 1484 RPM, 0.8743MPa

## CONCLUSIONS

1. Ferrite phase wears negligibly at low sliding speed and low normal pressure conditions.
2. Frictional force increases with the normal pressure.
3. Laminative and delaminative mechanism is observed under high normal pressures
4. For ferritic phase, at higher normal pressure and higher sliding speed, high concentrations of both Mn and Fe oxides form.

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