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Wear Behavior of Spherodized Cementite in Hyper Eutectoid Plain Carbon Steel

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Abstract: Pin-on-disc unlubricated wear tests for 1.5% carbon steel were conducted under operational conditions of load between 0.0625 & 0.749 MPa and speed between 1 & 4 m/s. All wear tests were conducted for the distance travel of 5000 meters. This work is based on the effect of microstructure on wear rate. Different microstructures have been developed like combinations of pearlite and cementite by annealing, almost 100 percent cementite by quenching and spheriozided cementite by interment forging. SEM and XRD micrographs have been studied to understand the wear mechanisms. It is observed that spherodized cementite shown least volumetric wear rate than other developed microstructures.

Key words: Hyper eutectoid steel, Spherodized cementite, Wear rate, SEM, XRD.

1. INTRODUCTION

Steels represent the most important group of engineering materials as they have the widest diversity of applications of any of the engineering materials. Generally, carbon is the most important element profoundly affecting the mechanical properties of the steels. Increasing the carbon content of steels increases the hardness and strength[1]. Hyper Eutectoid steels are mainly used for the manufacture of working structures or devices of bulldozers, loader – dozen, fork lift & rolling mills. Common mode of failure among these materials is due to wear. Hence a study regarding the wear rate of these materials is important from a practical standpoint.

From the literature conclusions it is evident that the wear behaviour of steels with different carbon compositions has been studied extensively but there is relatively lesser focus on the wear behaviour of hypereutectoid steel considering the different phases present in it. The different phases are namely pearlite, cementite, matensite and spherodite cementite. . The physical properties of these phases are entirely different. The wear behaviour changes abruptly with the change in phases. An essential constitutes still designing of the microstructures of hypereutectoid steels in such a way to achieve the required properties.

2. EXPERIMENTAL DETAILS

1.5% carbon steel is selected to understand the wear behaviour and wear mechanisms. The chemical composition of 1.5 % carbon of the hypereutectoid steel shown in table 2.1.

Table 2.1: The chemical composition of 1.5 % carbon hyper eutectoid steel.

% C	% Si	% Mn	% P	% S	% Cr	% Mo
1.45	0.285	0.369	0.0071	0.305	2.30	0.0010

The steel sample was subjected to different heat treatment process to attain different microstructures. Initially three specimens were annealed under the charcoal cover for avoiding decarburization and developed the equilibrium pearlite and cementite phases [2]. One of the specimens was heated again at 1000°C and soaked for one hour for homogenization and quenched in water to get almost 100% martensite microstructure. Another specimen again heated to a temperature 750°C and forged with hammer on the anvil. After forging again heated to a temperature 750°C and soaked for 2 hours and again forged with hammer on anvil. This procedure is repeated till cementite is spherodized in the ferritic matrix. So, it is developed three microstructure specimens like combination of pearlite and cementite by annealing, almost 100 % martensite by quenching and spherodized cementite by forging and heating repeatedly.

After developing the microstructures, each specimen was under taken for wear test for the fixed sliding distance of 5000 meters under the operational conditions mentioned below.

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Table 2.2 Wear testing parameters

Sl.No	Load (Kg)	Normal Pressure (MPa)	Speed (m/s)	Rpm (N)	Time (Minutes)	Distance cover (m)
1	0.5	0.0624	1	174	83.6	5027
2	2	0.2498	2	347	41.7	5001
3	4	0.4996	3	521	27.17	4892
4	6	0.7492	4	695	20.83	5003

Wear test

Dry sliding wear test was carried out using a hardened counter face of a polished disc of EN-32 with a hardness of HRC 62-65 at a relative humidity of 50-70% at a room temperature of 32^{0}C. A pin-on-disc type wear testing machine manufactured by DUCOM, Bengaluru (India) was used here. A pin specimen of hyper-eutectoid steel is pressed against a rotating disc specimen of carbon steel for machine structure use [4]. Wear tests were carried out a the normal pressures of 0.062, 0.2498, 0.4996 & 0.7492 MPa with the sliding speed of 1, 2, 3 and 4 m/s for a sliding distance of 5,00 meters. The volume wear rate was calculated from the expression volume loss per unit sliding distance (mm^3/m). a schematic diagram of wear testing machine is shown if Fig. 2.1

Fig.2.1 Pin-on-disc wear testing machine Microtructure figures

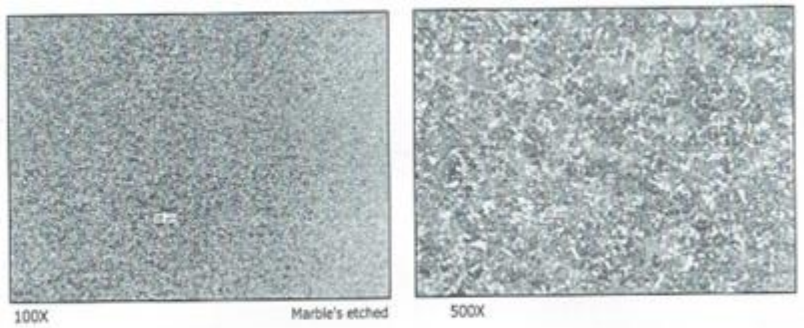

Fig. 2.2 From the micrograph of annealed specimen, it is observed that the spheriozed cementite is dispensed in the matrix of ferrite and pearlite. The corresponding hardness of the specimen is 27 HR$_{.}$

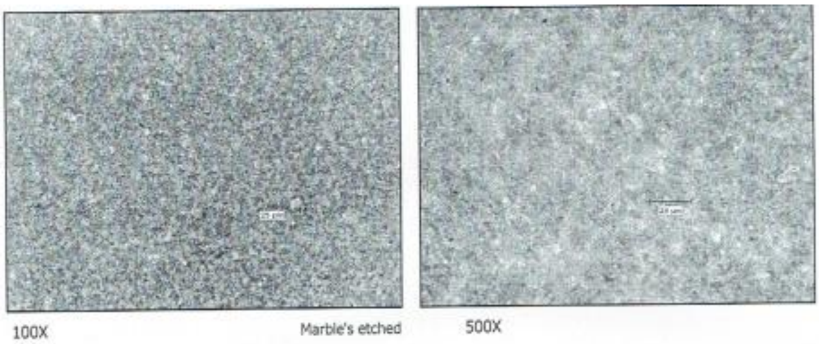

Fig. 2.3 From the micrograph of forged specimen, it is observed that the spheriozed cementite is uniformly dispensed in the matrix of ferrite. The corresponding hardness of the specimen is 22 HR$_{c.}$

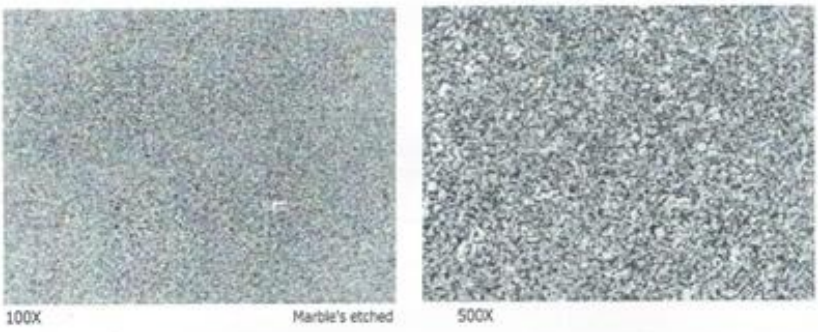

Fig. 2.4 From the micrograph of quenched specimen, it is observed that the microstructure consists of angular and fine globular carbides uniformly dispensed in the matrix tempered martensite. The corresponding hardness of the specimen is 62 $HR_{c.}$

3. RESULTS AND DISCUSSIONS

Graphs

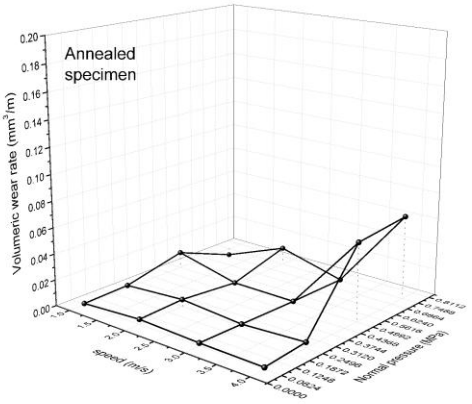

Fig. 3.1 Effect of normal pressure and speed on volumetric wear rate for annealed specimen.

From the figure 3.1 it is observed that volumetric wear rate is almost minimum and same under the low normal pressures of 0.0624 and 0.2498 MPa with increase in the speed [3]. Whereas under the high normal pressure of 0.4996 and 0.7492 MPa, the volumetric wear rate is increase almost with increase in the speed. But under high normal pressuer and sliding speed the volumetric wear rate is increased drastically. Annealed specimen is a combination of pearlite and cementite. The corresponding hardness of the microstructure is 27 $HR_{c.}$ Under low normal pressures of 0.0624 and 0.2498 MPa, the volumetric wear rate is almost constant with increase in the speed. During wearing, with increase in the normal pressure the plastic deformation of the wearing surface will increase. Due to this plastic deformation of the wearing surface, the hardness of the worn out surface will also increase [6]. As per Archard wear equation, volume loss is directly proportional to the normal load and inversely proportional to the hardness of the surface. Hence, with increase in the load i.e., with increase in the normal pressure the corresponding hardness will also increase hence, the ration remains almost same therefore the wear rate also becomes almost the same. But under the high normal pressure and speed, the volumetric wear rate is high. During wearing, due to Increase in the normal pressure the hardness of the wearing surface will increase at the same time, frictional temperature generates at the wearing surface [7]. Due to this increase in the frictional temperature the corresponding surface hardness may decrease. Hence, due to this decreased in the surface hardness the volumetric wear rate is increased.

From the Fig. 3.2 it is observed that volumetric wear rate is almost same under all operational conditions of normal pressure and speed, but except at the high normal pressure of 0.7492 MPa and speed of 4 m/s. it is forged specimen which has spheriozed cementite uniformly dispensed in the matrix of ferrite [5]. The corresponding hardness of the microstructure is 22 HR. Cementite is a hardest phase which has embedded in the softer matrix of ferrite. During wearing initially softer matrix of ferrite wears faster than the spherodized cementite. Later the cementite comes in contact with the sliding disc. The cementite is a hardest phase which wears very slowly. Also spherodized cementite is embedded in the softer matrix of ferrite. During wearing the impact loads caused by the vibrations of rotating disc are absorbed by the softer matrix of ferrite. It means the softer matrix of ferrite gives cushioning effect to the hard phase of

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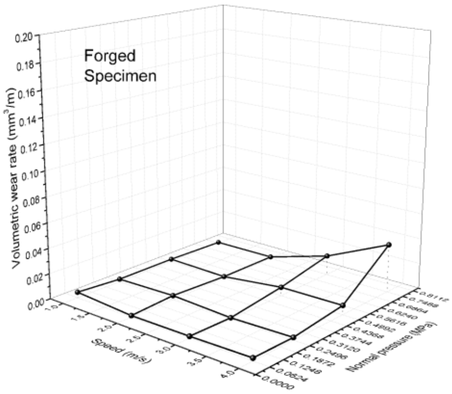

. Fig. 3.2 Effect of normal pressure and speed on volumetric wear rate for forged specimen

spheriozed cementite. Due to the cushioning effect the volumetric wear rate almost minimum [8]. But under the high operational conditions volumetric wear rate is little increased, this is due to the increase in the frictional temperature. Even though the hardness of the microstructure is lesser than the hardness of the annealed specimen, the wear rate is lesser than the annealed specimen.

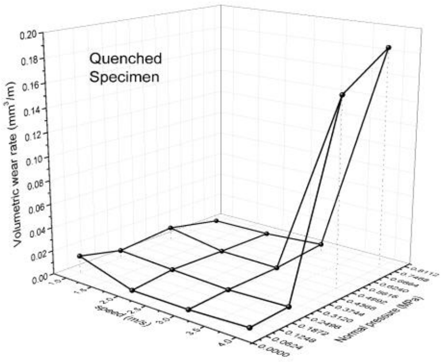

Fig. 3.3 Effect of normal pressure and speed on volumetric wear rate for quenched specimen

From the figure 3.3, it is observed that, volumetric wear rate is almost minimum under low operation conditions, whereas under high operational conditions, volumetric wear rate is high which is higher than the annealed and foraged specimen [10]. The microstructure of the specimen consists of angular and fine globular carbides uniformly dispensed in the matrix tempered martensite. The corresponding hardness of the specimen is 62 HR$_{c.}$ Martensite is hard and defective in nature [9]. Which has number of micro cracks in the phase. Under low operations conditions, the volumetric wear rate is low due to its high hardness value of 62 HR. Whereas under high operational conditions, due to the high thrust force due to the high normal pressure,

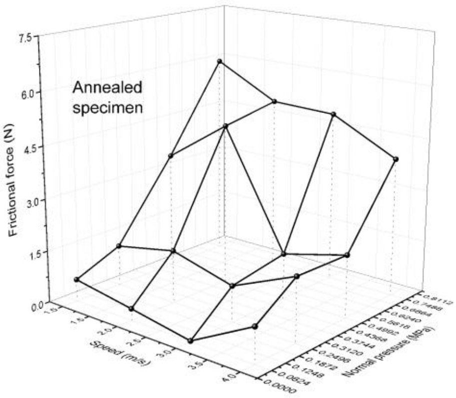

Fig. 3.4 Effect of normal pressure and speed on Frictional force for annealed specimen.

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From the figure 3.4 it is observed that frictional force is increased with the normal pressure and the same is almost decreased with the sliding speed[11]. With increase in the normal pressure the contractibility in area between the wearing pin with the sliding disc will increase and this results in increase in the frictional force. Whereas the same is almost decreased with the sliding speed. With increase in the sliding speed the residential time between the asperities is reduced with results in decrease in the rate of growth of the micro weld. Hence, low force is required to break the small micro welds.

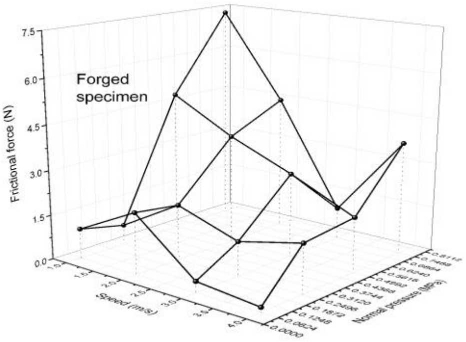


Fig. 3.5 Effect of normal pressure and speed on frictional force for forged specimen.

From the figure 3.5 it is observed the nature of graphs as it is for annealed. This is a forged specimen, from the micro graphs it is understood that, spheriozed cementite is uniformly dispensed in the matrix of ferrite. The corresponding hardness of the specimen is 22 $HR_{c.}$ whereas hardness of the annealed specimen is 27 HRc [12]. Even though it is forged specimen, cementite is dispersed in the softer matrix of ferrite, where as for annealed specimen, cementite is dispersed in the peralitic matrix. Therefore hardness of the forged specimen is softer than the annealed specimen, due to its softness; the frictional force is lifted up when compared with the annealed specimen.

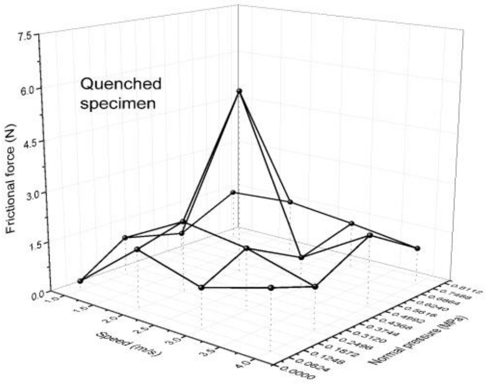
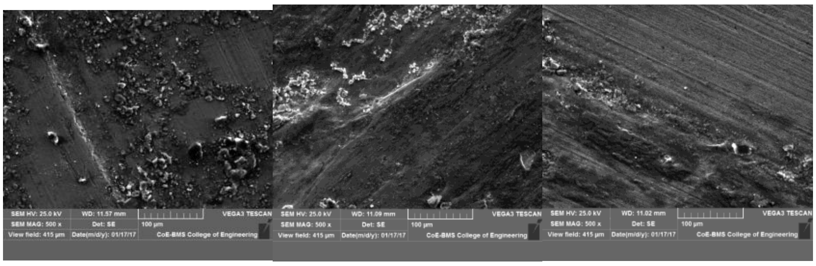


Fig. 3.6 Effect of normal pressure and speed on Frictional force for quenched specimen

Figure 3.6 is observed the almost same nature of graph but almost all values are suppressed. This is quenched specimen and corresponding hardness of the specimen is 62HRc. Micrographs consists of angular and fine globular carbides uniformly dispensed in the matrix of tempered martensite [13]. This is not only harder than the other heat treated specimens, but also brittle than the other specimen. Due to its brittleness the frictional force is stepped down.

SCM



(a) (b) (c)

Fig. 3.7 SEM micrograph for (a) annealed, (b) forged and (c) quenched under the normal pressure of 0.75 MPa and sliding speed of 4 m/s.

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It is observed that volumetric wear rate is high for quenched and least for forged specimen. SEM micrographs have been taken under these operational conditions. Volumetric wear rate for forged specimen is least and from the SEM micrograph (b) it is observed the worn out surface is almost smooth and flat. Whereas volumetric wear rate is high for quenched is high. From the SEM micrograph (c) it is observed that almost abrasive wear mechanism is observed. Abrasive wear mechanism is severe were hence, the wear rate is high. For annealed specimen the volumetric wear rate is moderate and the SEM micrographs shows delaminative wear.

XRD: The forged specimens show the formation of oxide layer which tends to decrease the wear rate.

4. CONCLUSIONS

There is a direct proportionality of the volumetric wear rate with sliding distance and normal load.As the sliding distance and normal load increase there is a reduction in volumetric wear rate which means wear resistance is increased. Wear rate of quenched specimen is high compared to annealed and forged specimens [14]. The volumetric wear rate increases with increase in normal pressure. The volumetric wear rate is high during high operational conditions and it is low in low operational conditions [15]. The spherodite globular microstructure shows resistance to wear. Hence sperodization heat treatment process can be used to reduce wear in ultrahigh carbon steels.

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