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Wear resistance of structural steels having ultra-low carbon to high carbon concentration

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The tribological behavior of the different structural steels with carbon concentration ranging from 0.002 % to 0.7%, were evaluated through ball on disc wear testing method. Testing was carried out at three different loads i.e. 30N, 40N and 50N to understand the wear behavior at different loading conditions. The wear resistance of the Spheroidized high carbon steel (0.7%) is found to be lesser than that of steels containing pearlite microstructure i.e. Low carbon (0.19%) steel and Medium carbon (0.32%) steel. Enhanced strain hardening of the pearlite structure was held responsible for the increased wear resistance. As expected IF steel showed least wear resistance due to its softer ferrite content. The SEM images of the worn structures are correlated with the macroscopic wear resistance data.

***Keywords*:** Wear testing, IF steel, SEM micrographs, Worn structures

1. Introduction

Wear occurs when two surfaces come in contact with each other. Generally wear process involves the relative movements of the surfaces. Wear is basically a surface phenomenon, where the surface of the material gets removed continuously due to delamination of the surface layer because of various processes undergoing at the subsurface level [1]. The environmental condition along with the crack generation at the sub surface level has an important role to play during wear property evaluation [2]. Wear resistance of steels or any metals is correlated to various factors like microstructure, mechanical work history and composition. Extensive studies have been carried out to understand the generalized mechanism of wear occurring under various conditions. Mang et al. have attempted to describe wear behavior of metals through predictive mathematical equations [3]. But the aim of predicting wear with respect to few specific properties has been largely unsuccessful. This is concluded by Hurricks et al. that only the knowledge of composition and bulk mechanical properties of materials is not sufficient to understand wear behavior. Rather the knowledge of microstructure and the influence of microstructure over the wear properties carry equal importance [1].While a steel surface undergoes wear, various complex mechanisms like crack or void formation, pulling off colonies of pearlite, dissolution of carbides etc. come into play [4-5]. These properties affect the wear behavior of steels to a vast extent.

Therefore the present study aims to understand the effect of microstructure over the wear properties of the steels. The study therefore includes steels with only a single phase ferrite concentration to steel with Spheroidized cementite to understand the relation of wear with various features in the microstructure.

2. Experimental Procedure

Five different steels with varying carbon concentration were selected for the present study. The samples selected are Spheroidized high carbon steel (0.7% C), Medium carbon steel (0.32% C), Low carbon steel (0.19% C), Microalloyed steel (0.07% C) and IF steel (0.002% C). The wear testing for the samples were carried out in DUCOM ball on disc wear testing machine in dry condition.to study the wear behavior at different loading conditions, wear test was carried out at three normal loads i.e.

at 30N, 40N and 50N load respectively. Three samples with dimension 1cm×1cm×1cm were cut and metallographically prepared for the wear testing. For the testing a diamond indenter was holed against the specimen surface with a wear track diameter of 4 mm. The samples were rotated at a speed of 25 rpm for a time period of 15 minutes. Finally HITACHI SU3500 Scanning Electron Microscope (SEM) was used to observe the worn out surface of the steels.

3. Results & Discussion

The plots showing the wear rate in microns as a function of sliding distance for the steels selected in the study, are given in Fig. 1 (Fig. 1a-1e).

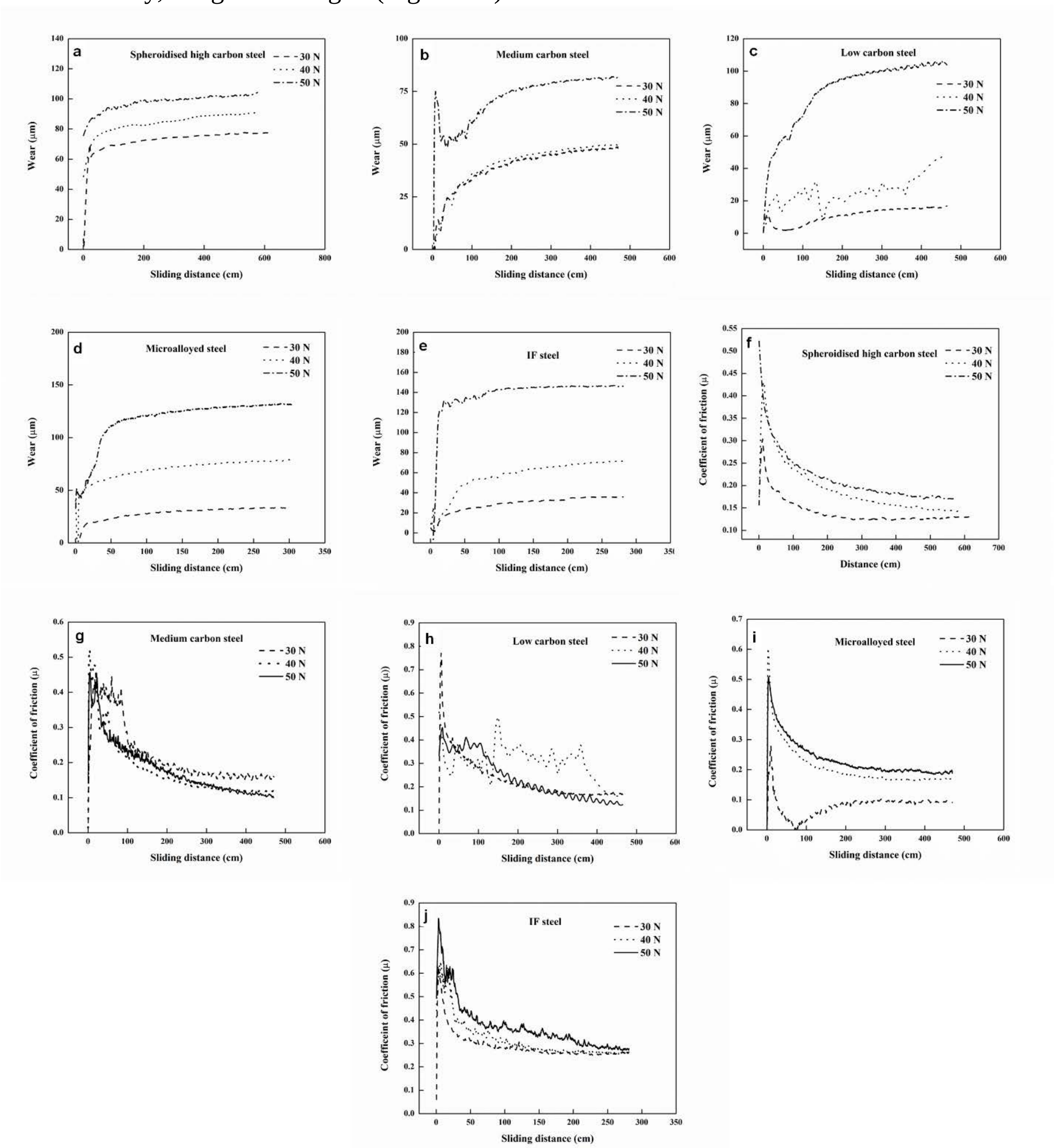

Fig. 1 Wear rate versus sliding distance for (a) Spheroidized high carbon steel, (b) Medium carbon steel, (c) Low carbon steel, (d) Microalloyed steel and (e) IF steel Variation of coefficient of friction value with sliding distance for (f) Spheroidized high carbon steel, (g) Medium carbon steel, (h) Low carbon steel, (i) Microalloyed steel and (j) IF steel.

For all specimen the amount of wear increases with wear load. It can be observed from the Fig. 1a – 1e that initially the wear rate is quite high which gets stabilized after a certain sliding distance. This is seen in all the specimens. Another conclusion that can directly be followed from the Fig. 1 is that the increase in wear rate with load for the specimens can't be said to be directly related with the carbon concentration. For Medium carbon steel the wear rate observed for 30N and 40N loads are quite similar, whereas a considerable amount of increase in wear rate can be detected at 50N load.

The amount of wear in the specimens is a strong function of the constituent phases inside the material. For IF steel and Microalloyed steel the wear rate show little difference at 30N and 40N loads. But at 50N IF steels wear rate is considerably higher than that of Microalloyed steel due to softer ferritic matrix in the former. Similar is the case with Low carbon and Medium carbon steels, where the wear amount and wear rate in Medium carbon steel is lower than that of Low carbon steel due to presence of higher fraction of pearlite in its microstructure. The wear rate vs distance plots at 30N and 40N load seem to be incorrect and disturbed. This might be the result of uneven sample surface encountered during testing.

In spite of having highest surface hardness, Spheroidized high carbon steel shows lower resistance to wear deformation than that of Low carbon and Medium carbon steel. This can be observed from the comparison of variation of wear rate with sliding distance for all samples given in the Fig. 1. The presence of softer ferritic matrix in Spheroidized high carbon steel explains the poor wear resistance of the above mentioned steel. This result agrees with previous studies carried out by Y. Wang et al., where steels with pearlitic microstructure showed higher wear resistance than that of the steel with Spheroidized microstructure [6].

The influence of surface hardness over the wear properties of the steels during sliding conditions are quite complex and it is difficult to directly relate the surface hardness of the materials directly with their wear properties [7]. Instead the thermal stability of the phases in the microstructure of the steels play an important role in this phenomenon. As with ongoing sliding contact wear process the temperature of the test piece increase, their surface hardness decrease. This might explain the observation of higher wear rate in steels with higher surface hardness [6].

The high wear resistance of the Medium carbon steel and Low carbon steel is attributed to the presence of lamellar pearlite in their microstructure. With successive wear of the surface, the surface layers work harden appreciably. As it is known that pearlite has excellent work hardening capability due to the orientation of carbides in lamellar form, the wear in pearlite becomes considerably smaller than structures with similar hardness or in some cases than structures with higher surface hardness [8]. The phase fraction of pearlite in the considered Medium carbon steel is nearly 50 %. This explains the highest wear resistance observed in the Medium carbon steel.

The similar concept of work hardening can be employed to explain the wear behavior observed in IF steel and Microalloyed steel. Both the IF steel and Microalloyed steel contain ferrite phase in their microstructures due to very less carbon content. The grain size in case of Microalloyed steel is quite smaller than that of the IF steel, which imparts greater strain hardening capability to the Microalloyed steel. It can be observed the wear resistance at smaller loads (30N and 40N) in both the steels are similar i.e. the degree of work hardening in both the steels is similar at lower loading conditions. But at 50N load fine grain microstructure of Microalloyed steel work hardens more and shows higher resistance to wear deformation.

Fig. 1(1f – 1j) shows the variation of coefficient of friction with sliding distance for each steel at different loads. A sharp decrease in the value of coefficient of friction with little initial fluctuation is the common feature in all the steels. The rapid decrease in the value of coefficient of friction implies the very fast increase in the wear resistance of steels by virtue of their own deformation i.e. work hardening.

The coefficient of friction value at lower loads of Low carbon steel shows a lot of fluctuation which may be the effect of carrying out test with an uneven specimen. The transition in coefficient of friction values with progressing wear test indicate towards the change of wear mechanism with time. It can be observed that the coefficient of friction values for all specimens increase slightly with increase in load from 30N to 40N, where as an appreciable inflation in coefficient of friction values is seen when transition of load occurred from 40N to 50N.

The wear resistance of the above steels can directly be related to the appearance and features on the worn out surfaces. Fig. 2 (Fig. 2a – 2h) show selective SEM images of the wear track at different loads for the samples. Fig. 2a shows the wear track of IF steel sample at a load of 50N. The evidence of micro cutting of the steel specimen can be found from this picture, which indicates abrasive wear has taken place in IF steel [9]. When a metal surface work hardens with time, then cracks form in the sub surface region. These cracks join together and eventually sheets of metal are separated from the surface exposed to wear. This is known as delamination [10]. Delamination and sub surface cracking can be observed in Microalloyed and Low carbon steels (Fig. 2c & 2d). This indicates considerable strain hardening occurring during wear of these steels, which in turn enhances their wear resistance.

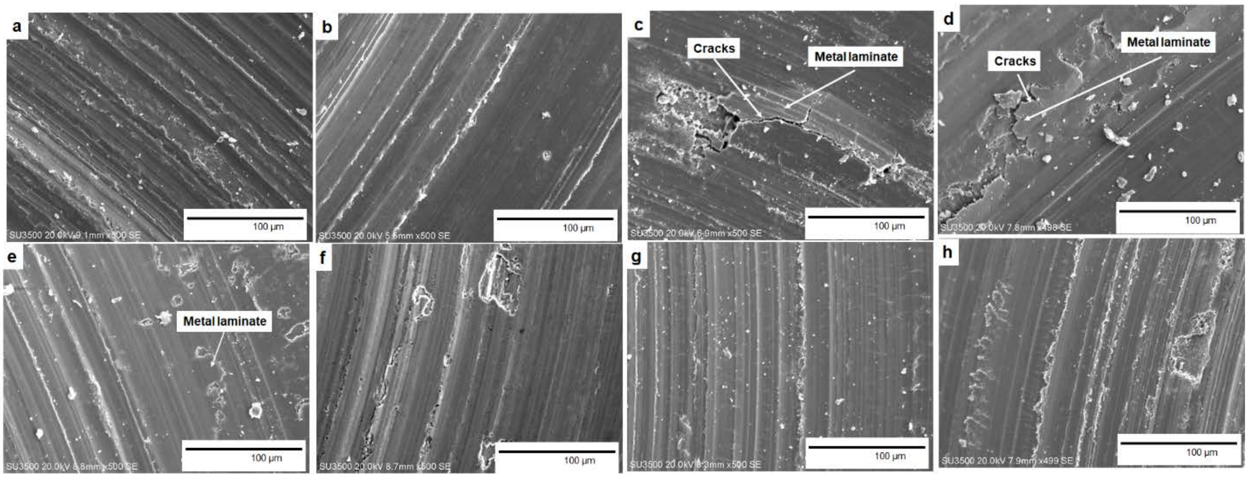

Fig. 2 SEM images of worn surface of (a) IF steel at 50N load, (b) Microalloyed steel at 30N load, (c) Microalloyed steel at 50N load and (d) Low carbon steel at 50N load. SEM images of worn out surface of (e) Medium carbon steel at 50N, (f) Spheroidized high carbon steel at 30N, (g) Spheroidized high carbon steel at 40N and (h) Spheroidized high carbon steel at 50N.

Spheroidized high carbon steel, in spite of its highest surface hardness show inferior wear resistance than that of the plane carbon steels having lesser carbon concentration. This conclusion can be strengthened from Fig. 2 (Fig. 2f. – 2h) Spheroidized high carbon steel specimen even at lower load i.e. at 30N load shows the removal of patches of metal from localized sites (Fig. 2f). In Spheroidized high carbon steel, hard cementite particles are uniformly distributed in the softer ferritic matrix. During sliding wear, the huge plastic deformation can cause the nucleation of cracks at the hard cementite particles [11-14]. This is responsible for more material loss from the Spheroidized structure and hence more wear rate. The removal of the material from surface of Spheroidized high carbon steel seems more prominent at the higher load (50N) as can be seen in Fig. 2h.

4. Conclusions

1. The wear of the steel samples with sliding distance was measured.At 50N load, Medium carbon steel showed highest wear resistance whereas IF steel showed the least.
2. The carbon concentration cannot directly be related to the wear resistance of the steels. The importance of microstructure of the surface exposed to wear is more towards determining the wear resistance than the composition.
3. The coefficient of friction values showed a rapid increase in value followed by a relatively stable regime. This indicates a change in wear mechanism or changes in surface condition of the steels while testing.
4. The features observed in the SEM micrograph of the worn surface of the samples at particular loads are related to the wear rate shown by the specimen at those particular loads.

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