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EFFECT OF MICROSTRUCTURE ON ABRASIVE WEAR BEHAVIOUR

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In the current study, abrasive wear resistance of two distinct microstructures, namely pearlite and martensite with a similar hardness level was studied. A two-body abrasive environment was simulated in a pin-on-disc tribometer (ASTM G99), by subjecting the metallic surface (i.e. microstructure) against silicon carbide abrasive particles. Pearlite (multi-phase) revealed better abrasion resistance than martensite (single-phase) with respect to abrasive wear characteristics. Abrasion induced microstructural changes were analysed through sub-surface and topographical investigations. To summarize, the multi-phase microstructure (ferrite and cementite lamellae in pearlitic microstructure) was more efficient in combating abrasion than the single-phase microstructure (i.e. martensite).
Keywords: Abrasive wear, microstructure, tribometer and specific wear rate.

INTRODUCTION

Abrasive wear involves undesirable material removal phenomenon, when hard particles abrade against a relatively smooth material surface and move relative to it. It contributes to nearly 50% of industrial wear thereby, leading to significant costs for the replacement of worn out machineries [1-2]. A two-body sliding abrasive system is quite dynamic and it is largely based on the energy balance principle. During abrasion, frictional energy is dissipated towards the abrading metallic surface. Therefore, the abrasion resistance of a material is governed by the quantum of frictional energy consumption by the microstructure. However, this frictional energy consumption varies for different microstructure due to their distinct microstructural constituents [2-5].

Furthermore, abrasion induces morphological changes in layers beneath the abraded surface (i.e. sub-surface layer) that differs from the bulk microstructure. Nevertheless, the properties of the microstructural constituents such as hardness, fracture toughness etc., greatly determine their mode of material removal during abrasion [6-8]. Therefore, the investigation of sub-surface layers becomes a primary objective for understanding the abrasion behaviour of the microstructure. In other words, the characteristics of the microstructural constituents play a crucial role in evaluating the abrasion resistance of a material.

The current study focussed on the abrasive wear behaviour of two distinct microstructures, namely pearlite and martensite with a similar hardness level. Sub-surface and topographical investigations have been done to analyse the extent of deformation during abrasion. The outcome of this study can greatly aid us in understanding the effect of microstructure in abrasive wear behaviour.

EXPERIMENTAL SECTION

The steel alloys used in the current study consisted of two different alloys (Table 1). Steel A was austenitized at 900°C for 5 min, followed by rapid water quenching to obtain a fully martensitic microstructure. Steel B had a fully pearlitic microstructure in the as-received condition. The samples were prepared using standard metallographic technique for the microstructural characterization.

Table 1. Chemical composition of the steels (in weight %)

Alloys	C	Si	Mn	Cr	Mo	Ni	Al	Co
Steel A	0.844	0.27	0.67	0.02	0.006	0.04	0.002	0.004
Steel B	0.046	0.264	1.84	0.0078	0.251	0.0087	0.0702	0.0066

The abrasive wear analysis of the microstructures was studied using a high temperature tribometer. The tests were conducted in an unlubricated condition with a constant speed of 200 mm/s, load of 9 N and sliding distance of 300,000 mm. By subjecting the stationary pin (i.e. microstructure) to abrade against the abrasive disc simulated a two body abrasive environment. Before each test, the pin was cleaned in ethanol, to measure the weight loss after the wear test. The topography of the abraded surfaces was analysed using an optical profilometer to investigate the groove characteristics. Two-dimensional colour images were rendered using a point selection technique, by scanning over the abraded surfaces.

RESULTS AND DISCUSSION

The fully martensitic microstructure produced in steel A consisted of highly dislocated laths having a hardness of 355±3 $HV_{0.01N}$ (Fig. 1b). The as-received fully pearlitic microstructure in steel B contained ferrite and cementite lamellae with a hardness of 326±2 $HV_{0.01N}$ (Fig. 1a). The interlamellar spacing and cementite thickness was approximately 0.1 µm and 0.3-0.4 µm, respectively. Despite having a similar hardness level, the microstructural characteristics had a significant influence on the abrasive wear behaviour. The following sections describe the impact of these microstructures on the characteristics of abrasive wear.

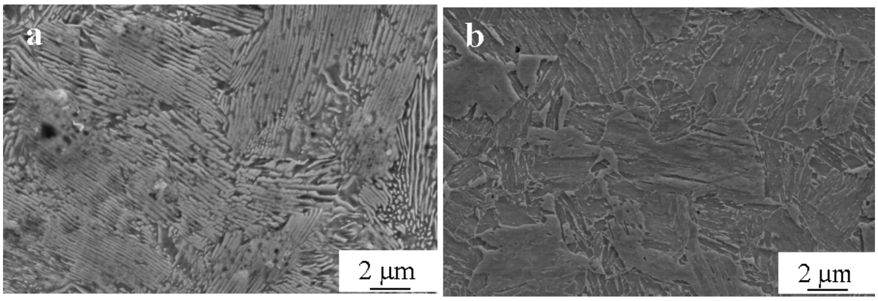

Fig. 1. Microstructural characterization: a) Steel A – pearlite and b) Steel B – martensite

The specific wear rate of the microstructures subjected to a silicon carbide abrasive environment (i.e. particle size of ~ 58 µm) was studied (Fig. 2). If the specific wear rate of pearlite was defined as unity, then the relative wear rate of martensite was found to be 2.59. Pearlitic microstructure with a slightly lesser hardness (i.e. 326±2 $HV_{0.01N}$) displayed better abrasion resistance than martensite. Literature reports that multi-phase microstructures with a combination of brittle and ductile phases are more efficient in combating abrasion than a single phase microstructure [9]. A brittle phase offers more resistance towards abrading action of the particles, meanwhile, the ductile phase reduces the cracking or failure nature in the matrix. This theory accounts for the superior abrasion resistance of pearlite microstructure [10].

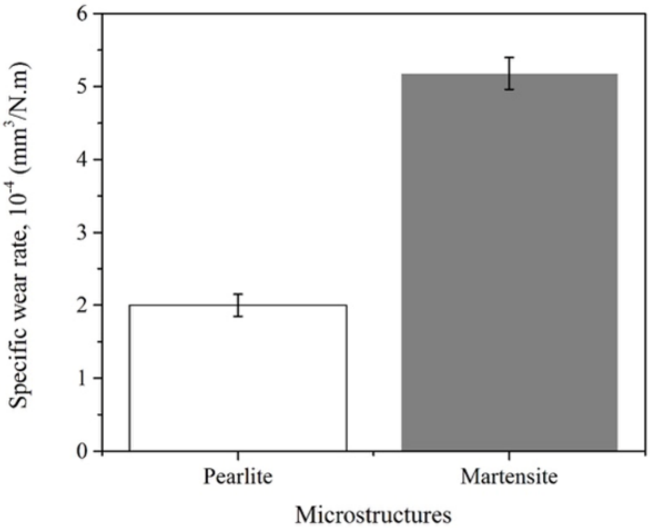

Fig. 2. Specific wear rate of microstructures subjected to a silicon carbide abrasive environment

Topographic analysis through differential colour profile represented the groove nature and the amount of material removed in the microstructures. Pearlite displayed deep and narrow grooves, with some discontinuity in the form of pits (as shown by arrows, Fig. 3a). The hard nature of the cementite lamellae offers more resistance towards the grooving nature, leading to non-uniform narrow grooves. On the other hand, the grooves were wide and shallow in case of the martensite microstructure (Fig. 3b), where heavy material loss was observed. This could be attributed towards the brittle nature of the laths, which are quite vulnerable during the high strain levels of abrasion.

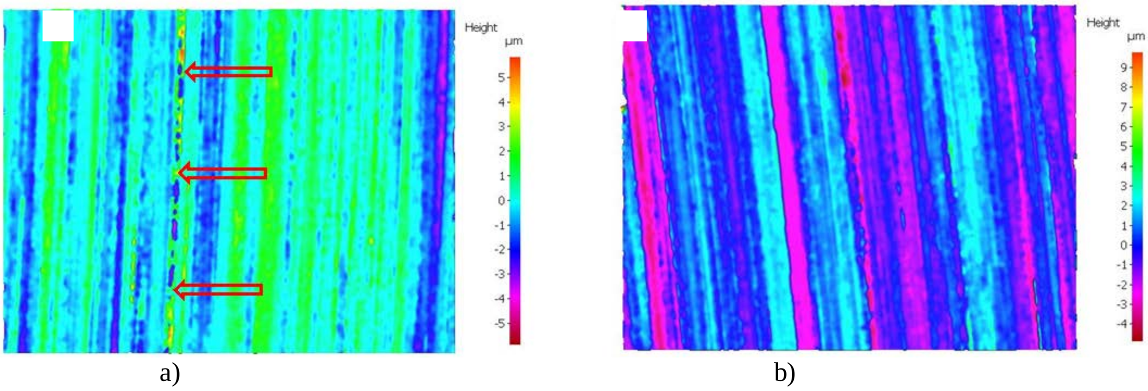

Fig. 3. Topographical analysis of the abraded surfaces: a) pearlite and b) martensite. Note: The scale is different for each microstructure.

Abrasion induced microstructural changes was observed through the sub-surface characterization of the microstructures. In general, the layer beneath the abraded surface was strikingly different from that of the bulk microstructure (Fig. 4). Pearlite displayed significantly high level deformation than martensite. This could be due to the presence of ductile ferrite phase that favours the phenomenon of plastic realignment of its constituents (i.e. ferrite and cementite, Figs. 4a and b). The significant amount of hardness increment (i.e. 43%) on their abraded surface, indicated their extent of work hardening capability. Conversely, martensite revealed a featureless, white, non-etching sub-surface layer (Figs. 4c and d). The brittle nature of the martensitic laths has resulted in very little plastic deformation [11] leading to the formation of such highly dislocated sub-surface layer with negligible work hardening (i.e. 3%). The post wear analysis once again proves the distinct abrasive response of the two different microstructures.

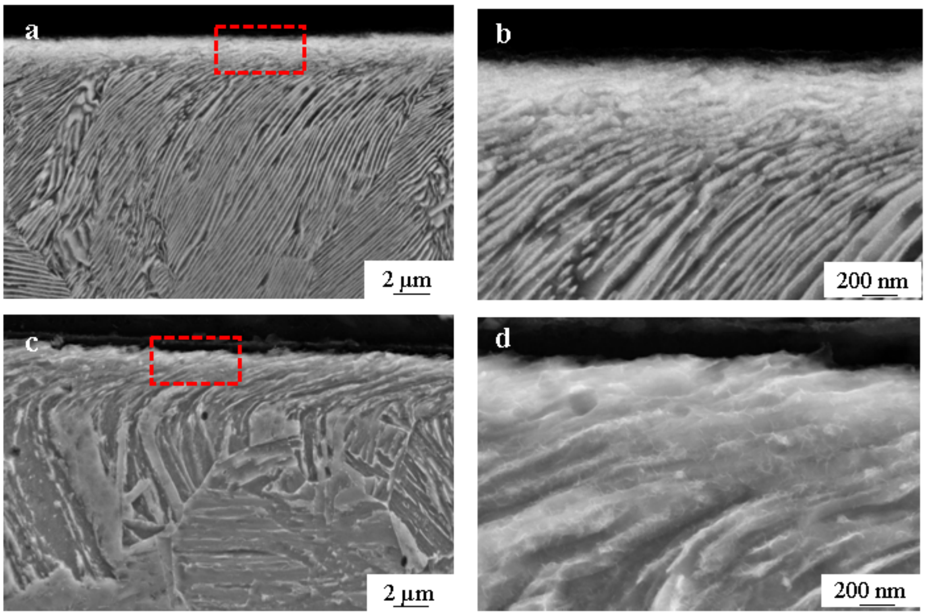

Fig. 4. Sub-surface characteristics of microstructures: Pearlite (a and b) and martensite (c and d)

The current observations suggest that the unique abrasion behaviour of the microstructures is clearly influenced by its constituents. The combination of ductile ferrite phase and the hard cementite lamellae in pearlite offers better abrasion resistance than the single brittle martensitic phase. This is mainly due to the fact that ductile phase offers support to the load bearing brittle phase. Therefore, such multi-phase microstructure matrix can effectively combat abrasion phenomenon.

CONCLUSIONS

The following conclusions can be drawn from the current study:

1. The unique abrasion behaviour of the microstructures showed the impact of microstructural constituents on abrasion phenomenon.

2. The amount of material removed was based on the distinct groove characteristics of the microstructures.

3. The sub-surface deformations were critical in determining the abrasion resistance of the microstructures.

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