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Correlating microstructural features with wear resistance of dual phase steel

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Abstract

In order to explore the tribological potential of the dual phase (DP) steel as a wear resistant material, the wear characteristics of the dual phase (DP) steel have been investigated with varying amounts of martensite from 43 to 81 vol pct, developed by varying holding time at the intercritical annealing temperature of 780 °C. Dry sliding wear tests have been conducted on DP steels using a pin-on-disk machine under different normal loads of 61.3, 68.5, 75.7 and 82.6 N and at a constant sliding speed of 1.20 m/s. At these loads, the mechanism of wear is mainly delamination, which has been confirmed by SEM micrographs of the subsurface and wear debris of the samples. Wear and friction properties have been found to be improved with increasing martensite volume fraction in dual phase steels.

Keywords: Wear; Friction; Delamination; Dual phase steel

1. Introduction

Dual phase (DP) steels consist of hard martensite islands embedded in a relatively soft and ductile matrix of ferrite. They have recently emerged as a potential engineering material system for automobile and other engineering applications [1]. Low carbon dual phase steels have found application in fabricating pipe-lines for transportation of mineral slurry and other wear resistant applications [2]. In a recent study they have also been found to hold good potential for use as farm implements where strength and wear resistance become of a great concern [3]. The tribology of dual phase steels has not yet been explored extensively, and only a few studies have been reported [2–7]. Wayne and Rice [4] have shown the dependence of wear on microstructure and have concluded that the duplex microstructure of DP steel offers higher wear resistance than that observed in a steel with spheroidal carbides. It has also been indicated that the wear resistance of dual phase steels increases with increasing volume fraction of martensite [5,6]. Sawa and Rigney [7] have found that the wear behavior of DP steel also depends strongly on martensite shape, size, and distribution of its martensite. The work reported is part of a study carried out on DP steels containing different martensite volume fractions to determine its effect on the wear behavior of these steels.

2. Experimental

Cylindrical pin samples (30 mm in height and 6 mm in diameter) of a plain carbon steel having C, 0.21 wt.%; Mn, 1.18 wt.%; Si, 0.26 wt.%; P, 0.035 wt.%; S, 0.032 wt.% were used for the current investigation. The samples were intercritically heat treated to develop dual phase structures having four different martensite volume fractions [8]. Intercritical heat treatment, i.e., annealing of a steel between its critical temperatures, Ae_1 and Ae_3, was conducted in a vertical tube furnace at 780 °C for 6.5, 7.5, 9 and 20 min followed by water quenching. Volume fractions of martensite in dual phase steels have been determined by the point-counting method [9]. Macrohardness of these samples was measured at loads of 30 kg, using calibrated standard hardness testing machines.

Dry sliding was carried out at a relative humidity of 55 to 75 pct at room temperature (25 °C) against the counterface of a hardened and polished disk made of AISI 52100 steel with HRC 62 to 65 hardness. Pin height losses were automatically measured by a pin-on-disk machine (manual tribometer: type TRM250) at different intervals of distance: Initially, the sample height was measured four times after every 200 m, then three times after every 400 m and finally three times after every

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800 m. Thus the total distance of sliding was 4400 m. Samples of DP steels were tested at loads of 61.3, 68.5, 75.7 and 82.6 N and at a fixed sliding speed of 1.20 m/s. Each test at a given load and sliding velocity was repeated three times with identical new samples on fresh disk surface, and the data for average volume loss after each interval of time were used for the analysis of wear rate.

The subsurface and wear debris of the specimens were examined under PHILIPS XL30 scanning electron microscope (SEM).

3. Results and discussion

3.1. Characterization of pin samples

The microstructures of dual phase steels DP1, DP2, DP3 and DP4 have white etching martensite and dark regions of ferrite as shown in Fig. 1(a) to (d). The volume fractions of martensite DP1, DP2, DP3 and DP4 steels, as estimated by a point-counting technique, are approximately 0.43, 0.53, 0.72 and 0.81 respectively. The macrohardness of DP steels with increasing volume fraction of martensite in DP1, DP2, DP3 and DP4 is 201 HB, 233 HB, 271 HB and 311 HB respectively.

3.2. Friction and wear characteristics

The variation of cumulative wear volume with sliding distance under different normal loads and at a fixed sliding velocity of 1.20 m/s is shown in Fig. 2 for DP1 steel. A similar variation has been observed

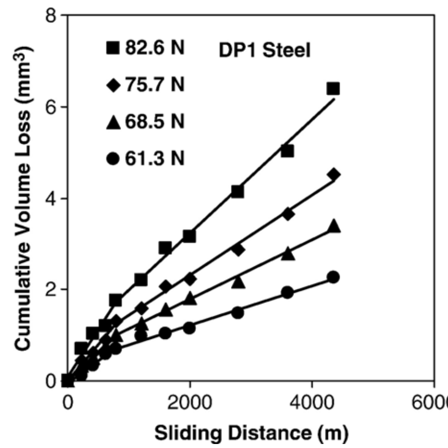

Fig. 2. Cumulative volume loss vs sliding distance at different loads in DP1 containing 43 vol pct martensite.

for DP2, DP3 and DP4 steel. The data has been analyzed on a linear scale using two separated stages of wear behavior characterized by two linear segments. The change in slope has been observed after the first four experimental points, with the forth point common between both the linear segment. Both the lines have been determined by the linear least-squares fit. For all DP steels, the first linear segment (run-in) is found to be steeper compared to the second linear segment (steady state). Other researches have observed similar trends in steels [10–13].

The wear rate i.e. volume loss in wear per unit sliding distance at a given load, has been determined from the slope of the linear least-

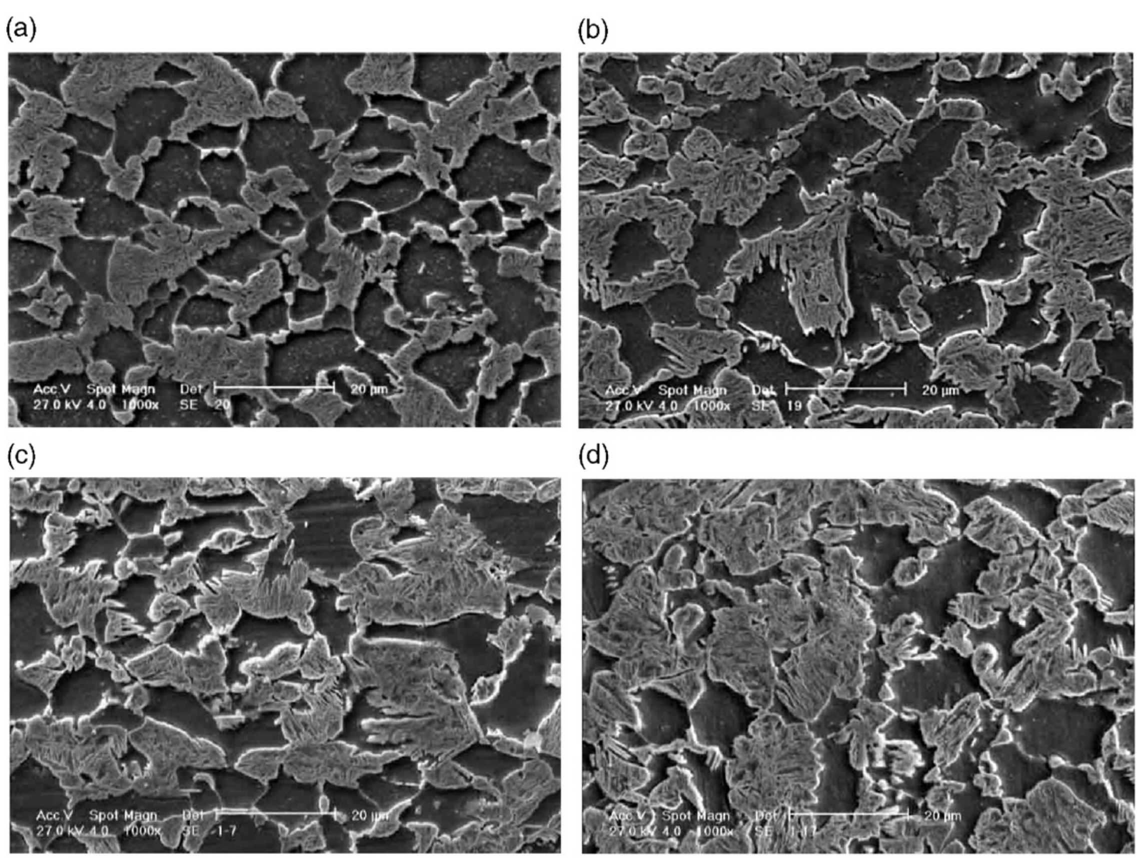

Fig. 1. Microstructure of dual phase steels (a) DP1, (b) DP2, (c) DP3 and (d) DP4, with dark grey regions of ferrite and light grey regions of martensite (etchant 2% nital).