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Effects of microstructure and experimental parameters on high stress abrasive wear behaviour of a 0.19 wt% C dual phase steel

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Abstract

The present investigation is aimed at understanding the influence of the size and quantity of ferrite plus martensite on mechanical and abrasive wear properties in a 0.19 wt% C dual phase steel. The results indicate that the mechanical properties like strength, ductility and impact, as well as abrasion resistance of the samples are greatly influenced by the material and test conditions. For example, the samples involving prior annealing showed higher ductility but less strength over the normalized specimens. Also, the increasing intercritical annealing temperature led to superior strength associated with reduced ductility. The wear rate increased with load and abrasive size due to a larger depth of cut made by the abrasive medium. The wear rate decreased as sliding distance increased. The steel subjected to prior normalizing treatment attained superior wear resistance to that of the one subjected to prior annealing treatment. The wear rate also decreased with increasing intercritical annealing temperature from 765 to 805 °C with an exception that the steel treated at 805 °C exhibited wear rate comparable to the one treated at 765 °C when tested against coarser size (40 μm) abrasive.

Keywords: Dual phase steel; Microstructure–property correlations; High stress abrasive wear property

1. Introduction

Steels containing ferrite and martensite phases are known as dual phase steels [1]. Such steels have recently emerged as a potential engineering material system for automobile and other engineering applications because of their high strength-to-weight ratio and good formability characteristics [1–3]. Further, dual phase steels have much better deformability than any other high strength steel of equivalent tensile strength [4,5]. Dual phase steels are produced by subjecting low carbon steel samples to intercritical annealing between the critical temperature Ae_1 and Ae_3, i.e. in the two phase (ferrite + austenite) region, for a specific duration followed by ice water quenching [6]. The Ae_3 temperature very much depends on the contents of carbon and other alloying elements present in the steel [1]. In this case, austenite transforms to martensite while ferrite remains unchanged [1].

Mechanical and abrasive wear properties of steels have been reported to depend upon their microstructure and chemical composition [1–13]. The type, content and amount of various phases greatly control the mechanical and abrasive wear properties of steels [6–13]. It has also been reported that mechanical properties of dual phase steels are greatly influenced by microstructural changes brought about by different heat treatment cycles [14–21].

Some work has been carried out to understand the influence of changes in the microstructure of low carbon steels brought about by different heat treatment cycles on the low stress abrasive wear behaviour of steel [24]. Based on the literature survey, it can be clearly said that no information exists on the effect of microstructural alterations in terms of varying quantities and sizes of martensite and ferrite on mechanical and high stress abrasive wear behaviour of a dual phase steel. The study could help to assess the working capability of the steels in different engineering applications specially for automobile applications and decide appropriate heat treatment cycles to generate desired combinations of microstructure, thereby

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leading to superior mechanical and abrasive wear properties.

In view of the above, the present investigation was aimed at studying the influence of variation in the size and content of ferrite and martensite on the mechanical and abrasive wear properties of a 0.19 wt% C steel at various loads, abrasive sizes and sliding distances.

2. Experimental technique

2.1. Sample preparation and heat treatment

A low carbon steel (C—0.19, Si—0.014, Mn—0.58, P and S—0.03, Fe remainder) plate of 12 mm thickness was selected for performing the experiments. Samples for abrasion tests (45 mm × 40 mm × 6 mm), microstructural studies (size: 20 mm × 15 mm × 6 mm), and tensile and impact tests (12 mm × 12 mm × 105 mm) were cut from the steel plate and subjected to various heat treatments in a vertical tubular furnace.

The heat treatment cycles involved subjecting the steel samples to annealing (furnace cooling) and normalizing (air cooling) treatments after austenitizing at 890 °C for 1 h. The annealed samples were further subjected to intercritical annealing at 765 °C for 1 h while the normalized samples were subjected to intercritical annealing at 765 and 805 °C for 1 h. The idea of this mode of heat treatment was to produce varying quantities of (ferrite + martensite) of different grain sizes in the samples. Table 1 shows the heat treatment cycles adopted in this investigation.

Heat treated samples were then machined to final dimension for conducting two body (high stress) abrasion tests (40 mm × 35 mm × 4 mm), hardness measurements (size: 15 mm × 15 mm × 4 mm), and tensile and impact tests. These samples were finally polished using standard metallographic technique prior to their abrasion tests and hardness measurements.

2.2. Microscopy and hardness measurement

The samples were polished using standard metallographic techniques and etched with 2% nital (98% C_2H_5OH + 2% concentrated HNO_3). The etched specimens were mounted on a brass stud, sputtered with gold and examined using scanning electron microscope (SEM). The volume fraction of different phases (i.e. ferrite and martensite) of the samples was measured using point count technique. An average of 50 phase fields has been considered in this study. Hardness of the samples was measured using a Brinell Cum Vicker's Hardness Tester at an applied load of 30 kg. An average of five observations was considered in this study. The range of variation in hardness values was observed to be ±3%.

2.3. Impact tests

Specimens of 10 mm × 10 mm cross section and 55 mm length were cut for performing impact tests using a Charpy impact testing machine. A 45° V notch having 0.2 mm fillet radius and a depth of 2 mm was made at the mid point along the length of the samples.

The energy absorbed was directly measured from the scale in Joules. An average of three observations has been reported in this case.

2.4. Tensile tests

The tensile tests were performed on standard specimens of gauge diameter 6 mm and gauge length 24 mm at a strain rate of $10^{-3}\,s^{-1}$. A Hounsfield make 20 T microprocessor based universal testing machine was used for performing the tensile tests.

2.5. Abrasive wear tests

High-stress (two-body) abrasion tests were performed on metallographically polished rectangular specimens (size: 40 mm × 35 mm × 4 mm) using a abrasion tester [22]. The abrasive (SiC) particles embedded on emery paper were fixed on a 50 mm diameter and 12 mm thick aluminium wheel. The samples were pressed against the abrasive medium with the help of a cantilever loading mechanism. The specimen experienced to-and-fro motion against the abrasive particles while the abrasive wheel also changed its position by the time the specimen completed one cycle (corresponding to a sliding distance of 0.0625 m). This enabled the samples to encounter fresh abrasive particles (in each cycle) prior to traversing 400 cycles (corresponding

Table 1
Phases formed in the steel after various heat treatments

S. no.	Type of treatment	Heat treatment cycles	Volume fraction of phases present
1	Annealing	Austenitization at 890 °C for 1 h followed by furnace cooling	Ferrite (79.3) + pearlite (20.7)
2	Normalizing	Austenitization at 890 °C for 1 h followed by air cooling	Ferrite (78.8) + pearlite (21.2)
3	Treatment (TA1)	Annealing (as stated in S. no. 1) + intercritical annealing (holding at 765 °C for 1 h followed by ice water quenching)	Ferrite (69.9) + martensite (30.1)
4	Treatment (TN1)	Normalizing (as stated in S. no. 2) + intercritical annealing (holding at 765 °C for 1 h followed by ice water quenching)	Ferrite (60.8) + martensite (39.2)
5	Treatment (TN2)	Normalizing (as stated in S. no. 2) + intercritical annealing (holding at 805 °C for 1 h followed by ice water quenching)	Ferrite (42.9) + martensite (57.1)