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Erosive and abrasive wear performance of carbide free bainitic steels – comparison of field and laboratory experiments

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ABSTRACT

Carbide free bainitic (CFB) steels have been tested in two heat treated conditions and compared with currently used quenched and tempered (QT) steel in an industrial mining application subjected to erosive–abrasive wear. A conventional sliding abrasion and a new application oriented high-stress erosion wear tests were performed in laboratory. The results of the erosion and the field tests were compared. The microstructural changes were investigated by optical and scanning electron microscopy. The hardness and hardness profiles of the steels were measured. The results showed that in the laboratory tests, the abrasion and erosion wear rates of the CFB steels were 35% and 45% lower respectively in comparison to the QT steel. In the field test, the mass losses of the CFB steels were about 80% lower in comparison with the QT steel. The improved wear resistance of the CFB steel can be explained by its higher hardness and higher work hardening. The erosion wear test was able to simulate the work hardening effect and the wear mechanisms observed in the field test samples.

1. Introduction

The development of steels with ferritic-austenitic microstructures, often named carbide free bainite (CFB) produced by austempering of Si- and/or Al-rich steels, has led to an increased interest in investigating their wear resistance in different applications. Different laboratory tests have shown good wear resistance for the CFB steels when subjected to sliding wear [1–4] and rolling-sliding wear [5–6]. Initial erosion wear [7] as well as abrasion [8] wear tests of CFB steels have also shown promising results. The wear resistance of CFB steels is attributed to their fine ferritic laths surrounded by austenitic films. The very fine laths in the microstructure give high hardness. The stresses and strains caused by the wear can also transform the austenite in the microstructure to martensite to give an extra increase of the hardness in comparison with normal deformation hardening of a material surface. In addition, the lath structure at the surface is refined by the wear and the surface hardness is increased [3,4]. Due to excellent wear resistance of steels with CFB microstructure, they have shown to be suitable to be used in applications as rails [7,9], and cutter-knifes [10].

The excellent wear resistance of CFB steels together with their good toughness properties caused by the lack of carbides and martensite in the initial microstructure, are the main reasons for the testing of the CFB steels in the specific industrial mineral handling application in this work. The component in question is subjected to severe erosive and abrasive wear. Martensitic steels are also of interest but the application in which the field test was performed is also subjected to impact loads. The impact resistance of high hardness martensitic steels is limited. In addition, the need of developing a more application oriented wear test method for testing of these steels was recognized. The goal of the new test method was to simulate the real wear conditions and wear surface deformations in a mineral handling application better than the usual conventional testers, such as rubber wheel or abrasive paper test.

Based on previous excellent rolling–sliding laboratory results of a CFB steel [11] and the information presented in the literature, the aim of this work was to compare the wear resistance of a CFB steel with the quenched and tempered (QT) steel used in industrial equipment for sorting of iron ore. The bars used in this application are subjected to a combination of high-stress abrasion and erosion wear, which gives the possibility to study whether the CFB steels are suitable materials for also this kind of combination of different wear types.

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Furthermore, these steels were also subjected to both a conventional sliding abrasion wear test and a new application oriented high-stress erosion wear test in laboratory. The latter was designed to simulate dry erosion and abrasion wear in mining applications.

2. Materials, tests and analyzes

The materials tested were a QT steel and a high Si-alloyed CFB steel austenitized at 950 °C and austempered at two different temperatures; 270 and 300 °C. The QT steel was produced by conventional treatment by quenching from austenite to room temperature followed by tempering at 500–650 C to the target hardness. Table 1 presents the material properties for the steels. The hardness and Charpy-V impact energy values were measured from the both laboratory and field test samples. Ten hardness measurements with 1 kg load and three impact tests were performed on each steel. Other mechanical properties of CFB270 were measured in a previous work [12]. Tensile test has not been performed on CFB300 samples. The chemical composition of the steels was measured by optical emission spectroscopy (OES).

Sample preparation for characterizations was performed by grinding in several steps followed by stepwise polishing finished by silica suspension “Mastermet”. Nital (3%) solution was used as etchant. Optical microscopy (OM) and scanning electron microscopy (SEM) were used to characterize the microstructure. X-ray analyses was performed by Siemens PANalytical EMPYREAN diffractometer with monochromatic CuKα radiation with 40 kV and 45 mA. The software HighScore Plus was used to analyze the XRD-data. The surface roughness was measured by Wyko NT1100 profilometer. The wear surfaces and their cross-sections were characterized by SEM in order to determine the wear mechanisms and compare deformation depths at the wear surfaces.

Table 1
Test materials and their properties.

Material	QT	CFB270	CFB300
Hardness [HV_1]	310 ± 10	601 ± 14	506 ± 17
KV [J]	97 ± 4	16 ± 2	19 ± 2
$R_{p0.2}$ [N/mm^2]	800	1650	
R_m [N/mm^2]	900	2050	
A_5 [%]	10 min	16	
C [%]	0.35	1.0	
Si [%]	0.31	2.5	
Mn [%]	0.72	0.75	
Cr [%]	1.35	1.0	
Ni [%]	1.36		
Mo [%]	0.18		

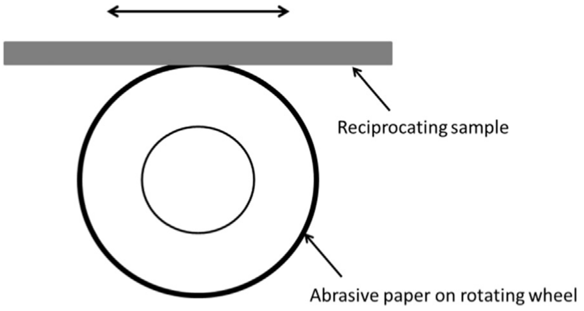

Fig. 1. Test configuration for abrasion wear tests.

2.1. Abrasion wear tests

Abrasion wear tests were performed at Lulea University of Technology using a modified ABR-8251 abrasive wear tester, presented in Fig. 1 [13]. The tester uses a flat reciprocating sample, sliding on top of abrasive paper (width 6 mm) wrapped around the surface of a wheel. The paper moves a certain distance after each reciprocating movement of the sample and new paper is mated for the next stroke. The initial surface roughness of the samples was approximately 15 μm. The abrasive paper used consisted of a mixture of 60% Al_2O_3 and 40% ZrO_2 particles with a grain size of approximately 270 μm and a measured hardness of 1750 $HV_{0.3}$. The sliding distance used was 180 m and the load was 16 N. The mass of the samples was measured before and after the test. Hardness and surface roughness of the samples were also measured before and after the tests.

2.2. Erosion wear tests

The erosion tests were conducted with a high speed slurry-pot type erosion tester [14] in Tampere Wear Center operated at Tampere University of Technology. Basic operation idea of pot type erosion wear testers includes a rotating main shaft where most often the samples are attached, as is the case here [14]. With the current tester the samples are attached in horizontal position directly to the shaft. During the wear tests the shaft with the samples are immersed in chosen erosive media, where the rotation motion of the shaft exposes the samples for erosive wear. For this study, new application oriented test method was developed, called high-speed slurry-pot with dry abrasive bed (dry-pot), in order to simulate erosive wear conditions in mining applications. In the dry-pot method the pot tester is used without a liquid carrier medium and the test samples are completely submerged under a bed of dry abrasive particles.

In this study, the tester was used with dry 8–10 mm granite gravel. Fig. 2 presents the test configuration, showing the round Ø 25 mm samples and the granite abrasives. During the tests the samples were located at the two lowest levels, as seen in the figure, on the rotating main shaft. For ensuring that the wear

Fig. 2. Dry-pot test configuration for the erosion wear tests. Before the start of the test samples are submerged in to the abrasive bed. The shaft rotates anticlockwise during the test.