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Effect of abrasive particle size on slurry abrasion resistance of austenitic and martensitic steels

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ABSTRACT

The effects of the abrasive particle size and the pH-value of the aqueous solution on the abrasive wear resistance of H-13 steel and Hadfield steel were investigated. Abrasive wear tests, using a wet rubber wheel abrasion tester, were carried out applying abrasive sizes in the range of 0.15–2.40 mm. The pH-values of the aqueous solution ranged from 5.5 to 12.8. The microstructure of each material was characterized with optical microscopy. The wear surfaces and the wear particles (debris) were analyzed by scanning electron microscopy (SEM). The macro- and microhardness were measured before and after the wear tests using a Vickers hardness tester. The surface topography of the wear scars was examined by a non-contact 3D profiler in order to measure the depth of the abrasive penetrations.

The results demonstrated that Hadfield steel is more wear resistant than H-13 steel for all pH-values and all abrasive particle sizes used in the tests. Moreover, the micro-hardness of the wear scar surface of the Hadfield steel increased significantly with the size of the abrasive grain, while this increase was lower for the H-13 steel. The greater work-hardening of the austenitic Hadfield steels was considered to be responsible for this higher wear resistance in comparison with the martensitic H-13 steel. For both materials the loss of mass increased linearly up to a critical abrasive particle size (CPS); this CPS, the mass loss continued to increase but with a lower gradient. An explicit effect of the steel matrix on the mass loss behavior as a function of the abrasive grain size was not observed. The less acidic aqueous solution resulted in lower mass losses for both materials and for all abrasive grain sizes. This effect was greater for the two smaller abrasive grain sizes. For higher pH-values, lower depths of penetration of the abrasive particles were observed. The analysis of the wear particles in all test conditions displayed continuous and discontinuous chips for the H-13 steel but only discontinuous chips for the Hadfield steel,. For both materials two abrasive wear micromechanisms were determined: microcutting and microploughing. Finally, the results presented in this work suggest that the wear performance analysis of Hadfield steel, to be used in an abrasive environment, should consider the effects of the pH value of the aqueous solution and the abrasive particle size.

1. Introduction

Several researches about the effect of the size of abrasive particles on wear of materials for different wear configurations concluded in the existence of a critical particle size (CPS), marked by a change in the slope of the wear rate vs. the abrasive particle size. Beyond the CPS the wear rate behavior may vary and these variations were synthesized by Coronado and Sinatora [1] in Fig. 1. Beyond a particular CPS the wear rate as a function of the abrasive particle size can: further increase but with a lower gradient (curve 1), remain indifferent to further size increases (curve 2) or decrease (curve 3).

There are several explanations for the presence of a CPS; the most relevant are described in Table 1. Among the existing explanations for this CPS phenomenon, some are related to the characteristics of the abrasive particles (e.g. shape, hardness and toughness) and others consider the properties of the material (e.g. hardness and microstructure).

The combined effect of corrosion and abrasion on the degree of wear in aqueous environments is called “abrasion-corrosion synergism” [7,8] and assumed to result in a much higher wear rate than both effects would have individually. In literature it is further reported that the corrosive process on the specimen surface can aid the abrasion process, easing the removal of material by the mechanical forces resulting from the abrasion process, but, increasing the wear severity decreases the relative contribution of

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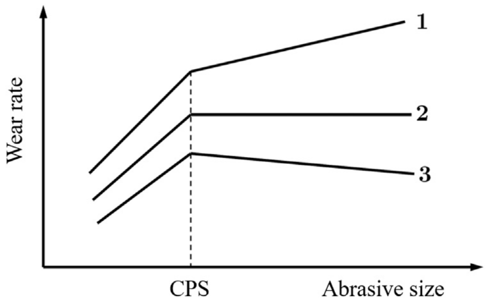

Fig. 1. Schematic representation showing the typical curves of wear vs. abrasive grain size [1].

corrosion on wear. However, any research relating to the effect of the pH level of the solution on the severity of wear by variation of the grain size was not found and this research aims to fill this gap.

Applications with high abrasive wear require the use of materials, which combine a strong abrasion resistance with high toughness. The austenitic manganese steel, known as Hadfield steel, combines excellent abrasion resistance to gouging abrasion with high toughness [9]. Microstructural changes and work hardening during field operation of Hadfield steel are important for controlling the wear resistance. Thus the knowledge of the initial hardness is not sufficient to predict the abrasion resistance of that material. Results obtained by Abbasi et al. [10], showed that the hardness of Hadfield steel was increased during wear, achieving a hardness value up to 502 HV, representing a microhardness increase of 2.5 times higher than the initial value.

The interaction of the size of the abrasive particles with the pH value of the aqueous solution and their effects on the wet abrasion resistance of two materials: a Hadfield steel (austenitic) and a H-13 steel (martensitic), is the subject of this work.

The intentional selected materials (austenitic and martensitic matrix) pretends to evaluate the phenomenon mentioned previously, for two typical microstructures. The authors understand that, in practice, materials are not used for the same specific application, and, are not possible substitutes for each other.

2. Methodology

The samples were analyzed in terms of microstructure and hardness, before and after wear tests. The initial microstructure of studied materials was characterized using optical microscopy and the wear surfaces and debris were examined by SEM. The hardness of materials was measured using the Vickers method with load of 30 kgf for macrohardness and 0.3 kgf for micro-hardness. Table 2 shows the chemical composition of the studied materials.

Table 2
Chemical composition of the studied materials.

	% Mass							
Material	**C**	**Mn**	**Cr**	**Mo**	**V**	**Si**	**Ni**	**S**
H-13	0.44	0.34	5.6	1.34	1.1	0.85	0.098	0.002
Hadfield	1.11	14.2	1.81	0.023	0.025	0.90	0.16	0.002

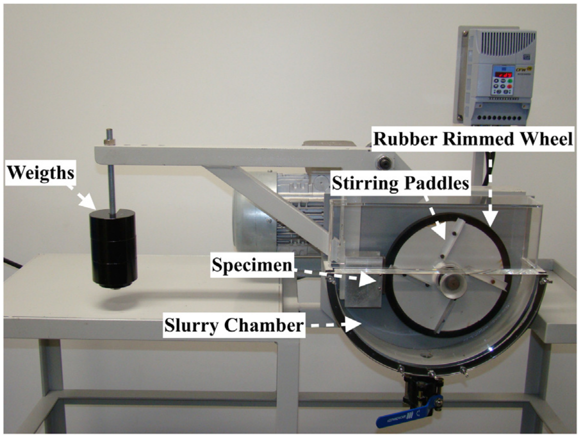

Fig. 2. Wear test apparatus.

Table 3
Size and shape of the abrasive particles.

	Particle size		Shape	
Sand abrasive	Average (mm)	Standard deviation (mm)	Sphericity (SPHT)	Aspect ratio (b/l)
N100 (0.15–0.30 mm)	0.204	0.071	0.798	0.702
N50 (0.30–0.60 mm)	0.455	0.111	0.790	0.701
N30 (0.60–1.20 mm)	0.968	0.205	0.803	0.707
N16 (1.20–2.40 mm)	1.827	0.419	0.826	0.710

2.1. *Abrasive wear test*

The wear tests with loose abrasive were performed using the wet rubber wheel configuration shown in Fig. 2. In this test, the specimen is pressed with a constant normal load of 130 N applied by a deadweight, against a wheel coated with rubber, rotating at 200 rpm in a mixture of 1500 g of abrasive and 940 ml of

Table 1
Justifications for the CPS.

Reference	Wear configuration	Explanations for the CPS
Avient et al. [2]	Fixed abrasive	Clogging, with wear particles and before of the CPS.
Sin et al. [3]	Fixed abrasive	Change of the wear micromechanism due to the variation of the abrasive shape. Smaller and rounded abrasive particles cause microploughing and larger angular abrasives particles cause microcutting.
Miller [4]; Chacon-Nava et al. [5]	Loose abrasive	Cracking of the abrasive particles beyond the CPS.
Misra and Finnie [6]	Fixed and loose abrasive	1- Smaller abrasive particles than the CPS cannot fully penetrate the hard layer near the surface. The influence of this layer decreases with increasing the abrasive particle size. 2- Smaller abrasives than the CPS cause a lower volume of deformation, resulting in a greater difficulty to movement of dislocations, due that yield strength in a small volume is higher than yield strength in larger volumes.
Coronado and Sinatora [1]	Fixed abrasive	A change of the wear micromechanisms caused by the variation of the shape of the abrasive: Smaller and angular abrasives cause microcutting whereas larger and rounded abrasives cause microploughing.