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Corrosion reduces wet abrasive wear of structural steel

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ABSTRACT

Abrasive corrosive wear of materials is a phenomenon with great economical consequences. Here we present abrasive corrosive wear experiments performed on structural steel. We compare pin on disc experiments in artificial seawater, deionized water and ethanol. Counterintuitively the wear is observed to be smallest in seawater. We ascribe this result to the combined chemical modification of the steel surface due to local electrochemical interaction with the seawater and the mechanical interaction between the pin and the surface.

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Abrasive corrosive wear also known as tribocorrosion is the process resulting in wear due to the combined effect of abrasion and corrosion [1]. The knowledge of the tribological behaviour of materials couples in the absence of any aggressive media, and the knowledge of the electrochemical behaviour in the absence of any mechanical impact, are not sufficient to derive the tribocorrosion behaviour of that system in which the same material couple is used [2]. It has been noticed in many articulating systems that abrasive wear modifies the sensitivity of the constituting materials to corrosion, and on the other hand, corrosion affects wear resistance by changing the abrasion condition between moving contacting parts [3]. This usually expedites the tribo-chemical degradation of the material [4–9]. In the present study we investigate the influence of corrosion on abrasion performance of structural steel. Combinations of abrasive and corrosive conditions are typical for transport of a fluid mixture of a pulverized solid with a liquid (usually water), often used as a convenient way of handling solids in bulk through a pipeline: i.e. slurry transport. Various liquids were used to study the abrasive corrosive wear of a structural steel. Mechanical conditions, velocities and loads were varied as well to elucidate the interaction between corrosion and abrasion. Cathodic protection was employed to separate corrosion from abrasion in order to quantify the synergism.

Structural steel S235 was used in this study. According to European Standard EN 10025 [10], structural steel offers a good

combination of welding properties with guaranteed strength. S235, with a minimum yield strength of 235 MPa, is extensively used in engineering fields like dredging. The microstructure of S235 steel, shown in Fig. 1, consists of ferrite and pearlite. The grain size is around 20 μm . Cylindrical samples with a diameter of 30 mm and a thickness of around 8 mm were cut from a steel bar. Before experiments, the samples were sanded using silicon carbide sandpaper up to 2400-mesh and then polished using polishing liquid containing diamond particles up to 1 μm . Finally, the samples were cleaned ultrasonically in acetone followed by rinsing with distilled water and then dried with room temperature air. The counterpart used in this study was an aluminium oxide ball with a diameter of 6 mm. After each experiment the ball was either rotated or replaced to obtain fresh contact between the sample and the ball. A rotary pin on disc tribometer with an aluminium liquid container was used to conduct abrasive wear experiments. The sample was clamped to the bottom of the liquid container by an aluminium ring and three bolts. In case of cathodic protection a zinc plate was clamped underneath the sample. Three liquids were used, namely ethanol, deionized (DI) water and 3.5% NaCl solution to simulate seawater. Loads of 1, 2, 5 and 10 N were applied. These loads correspond to initial maximum Hertzian contact pressure of 432, 545, 739 and 931 MPa. Velocities of 1.25, 2.51, 5.02, 10.04 and 15.06 cm/s were used. These velocities were the results of rotational frequencies of 0.25, 0.5, 1, 2 and 3 Hz. All experiments were conducted at a radius of 8 mm. First the load was varied from 1 to 10 N with a fixed velocity of 10.04 cm/s, then the velocity was varied from 1.25 to 15.06 cm/s with a fixed load of 10 N. All experiments were carried out in three liquids. The

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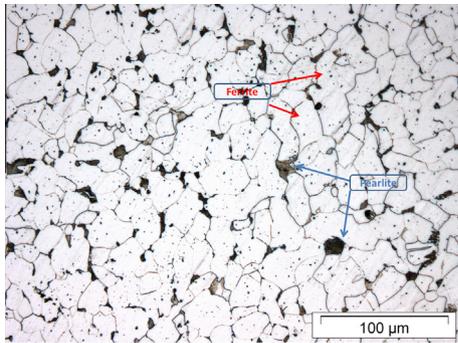


Fig. 1. Microstructure of sample obtained by optical microscope. 2% nital was used to etch the surface. Black regions are pearlite, and the white grains are ferrite.

coefficient of friction (COF) was recorded by the tribometer in real time. After experiments, a White Light Interferometer was used to measure wear track profile. Area of cross section was calculated and eventually converted to wear rate in the unit of mm^3/Nm [11]. Scanning electron microscopy (SEM) was used to observe the morphology of wear tracks. To see the isolated influence of corrosion environment on the surface of samples, identical samples were immersed in deionized water and seawater respectively for 24 h. After immersion, SEM was used to observe the surface morphology. After the experiments, the surface of the samples was observed to see whether corrosion products were formed during the tribocorrosion process.

Fig. 2 shows the wear rates of samples in three different liquids. As can be seen from Fig. 2(a), with increasing load, the wear rate increases for all three liquids. In seawater, the wear rate increases almost linearly with load. In ethanol, the wear rate increases linearly for loads up to 5 N. For DI water, from 1 to 5 N, the wear rate increases slightly, however, at 10 N the wear rate is much larger than that at smaller loads. Fig. 2(b) shows the relation between wear rate and velocity. The wear rate is independent of velocity for DI water and seawater. Only in ethanol, the wear rate slightly

increases with increasing velocity. Regardless of velocity, the wear rate in seawater is the smallest among the three liquids and the wear rate in DI water is the largest. Fig. 2(c) shows the relation between volume loss of wear and distance is linear for all three liquids. Clearly, in seawater the steel wears the least regardless of the load, velocity and distance. Fig. 2(d) shows a cross section of the wear tracks in seawater, ethanol and DI water respectively. The wear track of the DI water sample is rather rough compared to another two samples. Immersion experiments for 24 h showed a different surface morphology as illustrated in Fig. 3. For the sample immersed in seawater, white crystals appeared on the surface and the grain boundaries in the steel can be clearly seen. In contrast, on the surface of the sample immersed in DI water, similar crystals emerged on the surface but there was no sign of grain boundaries. Some local corrosion appearance was found. By applying cathodic protection in seawater, the sample was successfully protected from corrosion with the evidence that the surface was still shiny and no corrosion products were found. The wear rate under this circumstance was higher than that without applying cathodic protection as shown in Fig. 2(a). However, applying cathodic protection in DI water failed to protect the sample against corrosion. The surface of the sample was rusty and the wear rate did not change at all compared to not applying cathodic protection in DI water.

Archard in 1953 proposed a model for abrasive wear: volume loss due to wear is proportional to load, sliding distance and inversely proportional to hardness [12]. Wear in ethanol and DI water does not fit this model especially under larger loads, however wear in seawater is in compliance with the model. Moreover the wear in seawater is less than in ethanol or DI water. For this observation we offer the following explanation: a surface layer will be generated during the abrasive corrosive process and that layer diminishes the wear because it is harder than the original material. This explains the lower wear rate of samples in seawater at all velocities as shown in Fig. 2(b). Liquids with stronger corrosivity are extensively reported to result in higher wear rate [4–9]. The common explanation attributes this higher wear rate to the rise of chemical wear, the amount of wear caused by periodic removal

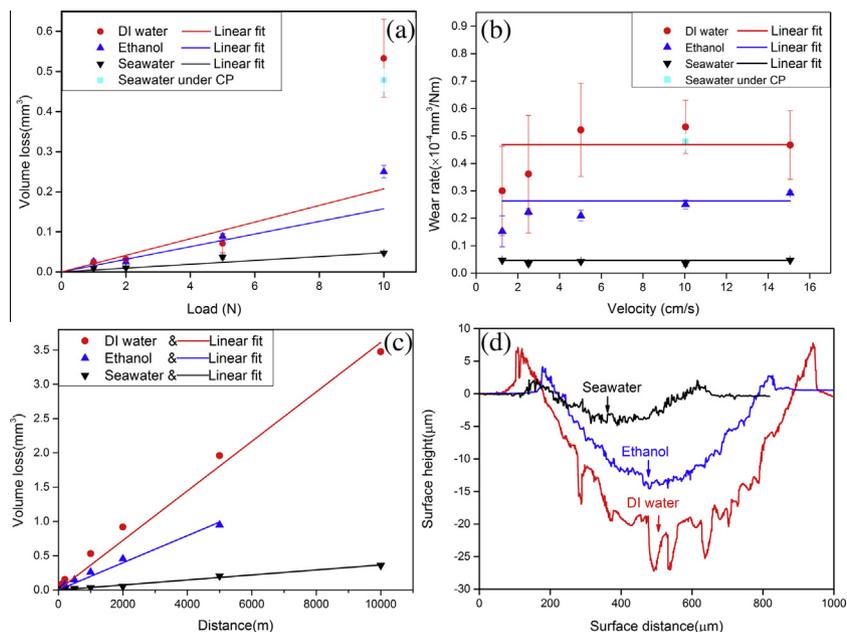


Fig. 2. Wear rates of samples in different liquids. (a) Volume loss as a function of load. CP stands for cathodic protection, linear fits were made based on Archard wear equation (from 1 to 5 N for ethanol and DI water, from 1 to 10 N for seawater); (b) wear rate as a function of velocity, load 10 N, CP stands for cathodic protection; (c) volume loss as a function of distance. Due to the volatile nature of ethanol, 10,000 m was not performed. For all three liquids, the load and velocity were 10 N and 10.04 cm/s respectively. A linear fit was made based on Archard wear equation; (d) wear tracks of samples in three liquids. Load, velocity and distance were 10 N, 10.04 cm/s and 1000 m respectively.

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