

# On the construction of micro-abrasion maps for a steel/polymer couple in corrosive environments

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## Abstract

There has been significant recent interest in the interactions of micro-abrasion in aqueous conditions, particularly when the environment is corrosive. This is due to the fact that there are many micro-scale-abrasion processes where the presence of the corrosive media may modify the wear on the surface. Furthermore, if the surface dissolves, the mechanical properties of the surface may be modified as a result of the effects of corrosion.

In this work, the micro-abrasion of a steel/polymer couple was studied in carbonate/bicarbonate solution. The effects of two variables, applied load and potential, were investigated on the wear rate enabling quantification of the corrosion and wear contributions. Scanning Electron and Atomic Force Microscopy were used to characterize the surfaces following micro-abrasion-corrosion.

The results indicated possible micro-abrasion-corrosion mechanisms on the surface. These regimes were suggested on the basis of the ratio of the micro-abrasion to the corrosion rate. In addition, micro-abrasion-corrosion maps were constructed showing the transitions between the micro-abrasion-corrosion regimes as a function of load and applied potential.

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## 1. Introduction

In recent years, the study of micro-scale abrasion of materials has become of increasing interest due to its application to tribology of bio-medical materials. These include the wear mechanism observed in artificial hip and knee joints [1–3] (often polymeric materials) where wear may occur at relatively low loads and for particle sizes typically less than 10  $\mu\text{m}$ . In such cases, wear of the polymeric materials is caused by the presence of large volumes of small particles which are essentially debris which have arisen from the wear process.

Other bio-medical applications of micro-abrasion include oral environments, i.e. dentistry, where micro-abrasion and corrosion may accelerate each other [4,5]. Here, acid dissolution may significantly enhance the micro-abrasion process. On the other hand, if the particles are also

corrosive, they may have a role in modifying both the wear and corrosion on the surface.

One significant limitation of academic research in micro-abrasion is that there been little work carried out to study in a quantitative manner the effects of micro-abrasion on the corrosion rate. These effects are important to characterize because (as indicated above) micro-abrasion in bio-medical applications typically occurs in corrosion solutions in which the pH and electrochemical potential may vary significantly [2–6]. Understanding the combined effects of the tribological and corrosion variables is critically important for optimizing materials selection and tribo-corrosion parameters in such conditions.

Much recent work on micro-abrasion has concentrated on the construction of engineering maps to characterize the wear mechanisms [6–8]. These maps provide a means of identifying the wear regime and levels of wastage. However, to date, an important limitation of research to date in this area is that there has been no attempt to construct such diagrams for the micro-abrasion interaction in corrosive conditions although in all the tests conducted to date, in an aqueous slurry solution, corrosion undoubtedly plays an important role in the overall degradation rate.

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In this work, the micro abrasion-corrosion rate of a polypropylene ball against mild steel was assessed in an aqueous slurry solution of buffered pH (carbonate/bicarbonate, containing SiC particles), after exposure to a range of applied loads and potentials. The polypropylene ball was selected in preference to steel so that only one of the abrading surfaces could contribute to the corrosion process. Hence, the couple tested ensured accuracy of the measured corrosion contribution on the specimen, which was evaluated using electrochemical techniques. (For a steel on steel couple, measurement of the total area under corrosion during micro-abrasion is approached with some difficulty as it is not always possible, using conventional experimental techniques, to fully screen off the areas outside the wear scars particularly for exposure to high rotation speeds.)

The results in this study were used to separate the micro-abrasion and corrosion contributions and thus establish regimes of micro-abrasion-corrosion for the polymer/steel couple. Micro abrasion-corrosion maps, indicating mechanisms of degradation, were constructed based on the results. These were used to demonstrate the change in micro-abrasion-corrosion regime as a function of applied load and electrochemical potential.

## 2. Experimental details

Micro-abrasion tests were performed with a commercially available apparatus, the TE-66, micro-abrasion tester Fig. 1 (Plint and partners Phoenix, UK). The details of the experimental rig are as follows. A 25 mm ball was located between two-coaxial shafts, each carried in a support bearing. One shaft was driven by a variable speed DC geared motor. A batch counter was provided to measure and control the number of shaft revolutions. A peristaltic pump head was connected to the other end of the shaft and this was used for providing slurry feed to the contact. The test sample was clamped onto a platform, which was fitted to the pivoted L-shaped arm. This arm was rotated around its pivot

until the sample came into contact with the ball. The load was applied by adding dead weights to a cantilever arm. The corrosive slurry of 0.5 M  $\text{NaHCO}_3 + 0.5 \text{ M Na}_2\text{CO}_3$  and SiC 4  $\mu\text{m}$  particles, was stored in a container that could be agitated by means of a laboratory magnetic stirrer and was delivered to the specimen by a integral peristaltic pump. The slurry (concentration of  $0.25 \text{ g cm}^{-3}$ ) was fed to a position just above the contact point and collected in a waste tray underneath. The specification of the apparatus is shown in Table 1.

The arm, which holds the sample, could be moved horizontally in order that several tests on a single sample specimen could be carried out. (It is recognized that with this arrangement, the actual load may deviate, particularly if the specimen loses contact with the ball at higher rotation speeds, where some experimental stability may set in.) The sample was then removed from the apparatus and the diameter of the resulting abrasion scars was measured with profile projector and optical microscope.

The material of the ball used was polypropylene and was selected as stated above because it provided an inert surface against which corrosion of the counterface could be measured during the micro-abrasion test. The mild steel surfaces were ground and polished by conventional metallographic methods before testing. Following the test, the worn samples were examined by optical, scanning electron and atomic force microscopy in addition to profilometric methods. Repeat tests were carried out at various loads; the error in the experimental data was estimated to be  $\pm 20\%$ .

The wear volume was calculated using the standard technique [9] for measuring the wear scar of spherical geometry [3], i.e. the geometry of the wear scar is assumed to reproduce the spherical geometry of the ball, and the wear volume ( $V$ ) may then be calculated by measurement of either the crater diameter ( $b$ ) or its depth ( $h$ ).

$$V \approx \pi b^4/64R \quad \text{For } b < < R \quad (1)$$

$$V \approx \pi h^2R \quad \text{For } h < < R \quad (2)$$

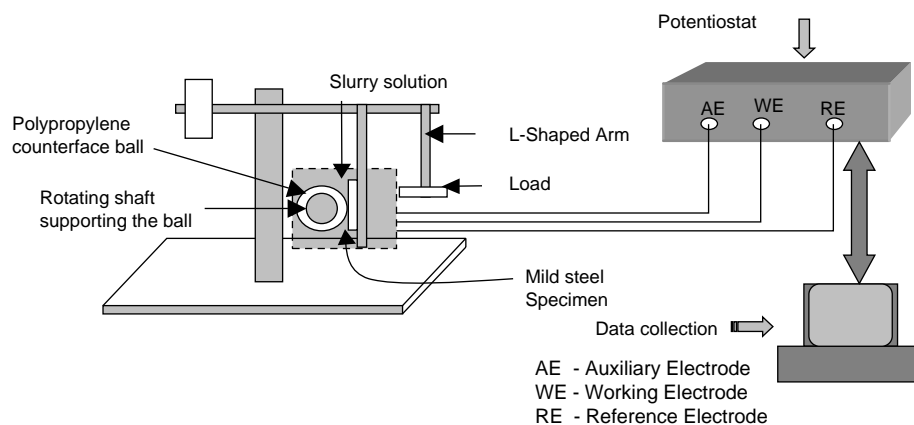


Fig. 1. Micro-abrasion corrosion apparatus.

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