THE ROLE OF PARTICLE MOTION IN ABRASIVE AND EROSIIVE WEAR

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ABSTRACT

The traditional classification of abrasive wear into two- and three-body, high and low stress, open and closed etc. does not recognise the essential importance of particle motion, which is better described as either sliding or rolling. Abrasive wear tests with free abrasives can produce either type of motion, depending on the test conditions. The widely-used dry sand rubber wheel test often produces both motions over different areas of the sample. The more recent micro-scale abrasion test tends to favour one or the other over most of the wear scar area. Analytical models can be developed which allow the dominant particle motion to be predicted, and mapped using readily accessible parameters. In erosive wear, particle motion can also be important; recent work suggests that particle rotation is imparted in some types of erosive wear test, and that it may be responsible for the differences in wear rate found in tests under nominally identical conditions with different designs of apparatus. It is suggested that in the use of laboratory abrasion and erosion tests, and in the analysis of practical instances of wear by hard particles, close attention should be paid to the nature of particle motion, since this will influence both the dominant wear mechanisms and also the wear rates.

1. INTRODUCTION

Wear involving hard particles is usually classified as either abrasion or erosion. In both cases, an essential characteristic of the particle-surface interaction which determine the response of the surface is the motion of the particle. It has been suggested [1] that a description of the particle motion can provide a valuable means of classifying abrasive wear.

Whether the particles are fixed rigidly to a counterbody or are held momentarily by frictional traction or by interlocking in a bed of other particles, if they slide over the surface the resulting damage to a plastically deforming surface consists of characteristic linear grooves. Even if the surface experiences brittle fracture, the damage pattern is still highly anisotropic, with linear features in the direction of sliding. If the particles roll over the surface, however, the damage results from multiple indentations, and although a single particle may tend to roll in one direction and produce a row of indentations, the overall effect of the rolling of many particles is to produce a surface with an appearance of many random features, with no evident directionality. The differences between such surfaces are readily seen, and are associated with significant differences in wear mechanism and, usually, in wear rate.

Certain test methods for abrasive wear employ ‘fixed’ abrasive particles, which slide in a well-defined manner against the sample. These include tests in which the sliding motion is continuous, in a unique direction across the sample surface, as in pin-on-disc and pin-on cylinder tests, where the surface of the disc or cylinder is coated with abrasive paper, and the sample often travels in a spiral track so that it constantly comes into contact with fresh abrasive. In other tests with fixed abrasives, such as the Taber abraser, the sliding motion between particles and sample is not unidirectional. But in all these tests, the particles themselves are constrained to slide across the specimen surface, and cannot rotate to any significant extent. Similar constraints on particle motion apply in manufacturing processes such as grinding and honing with fixed abrasives.

If the abrasive particles are ‘free’, then whether they slide or roll against the specimen will be determined by mechanical and geometrical constraints which often depend on the
properties of the specimen, and may even vary over time, and between different areas of the specimen.

2. ABRASION BY ‘FREE’ ABRASIVE PARTICLES

‘Free’ abrasive particles are commonly encountered in practical cases of wear and are used in the dry sand rubber wheel (DSRW) test (ASTM standard G65). The pattern of wear produced on a metallic sample by the DSRW test is shown schematically in Figure 1. Often, there are regions at the inlet and exit zones where the particles have rolled, with a region of linear grooving in the middle. The dominant particle motion depends on the local pressure and on the hardness of the sample. Similar phenomena are seen in the recently-developed micro-scale abrasion test, in which a hard steel ball rotates against the specimen surface in the presence of a slurry of fine abrasive particles. The dominant particle motion (sliding or rolling) is found to depend on abrasive concentration (packing density in the contact), applied load and specimen hardness, and transitions in particle motion can be induced by changing any of these [1].

Figure 1. Schematic diagram of DSRW specimen, showing regions dominated by different types of particle motion

By balancing the forces acting on a single particle trapped between two surfaces (idealized in the simplest case as a two-dimensional problem), three possible types of motion can be identified for the case where one surface is harder than the other [2]: the particle rolls between the two surfaces; the particle slides relative to both surfaces, forming grooves in both; the particle embeds in the softer surface and forms a groove in the harder. The model predicts that the transition between rolling and sliding should depend only on the ratio between the particle size and the gap between the surfaces, but evidence from both the DSRW and micro-scale abrasion tests suggests that it also depends on surface hardness. In the latter case the transition can be described in terms of a simple relationship between the ratio of the hardnesses of the two surfaces and a measure of the severity of the contact conditions [3]. The severity $S$ is defined by $S = W/AvH$ where $W/A$ is the nominal contact pressure, $v$ is the volume fraction of abrasive, and $1/H = (1/H_{\text{sample}} + 1/H_{\text{counterface}})$.

3. EROSI VE WEAR

The importance of particle motion at the point of impact has long been recognized in erosive wear: if an angular particle rolls forwards as it strikes, it causes significantly different damage from the case where it rolls backwards [4]. However, the possibility that the angular velocity of the particles before impact can also influence erosion mechanisms and rates has only recently been studied. Significant differences in wear rates are seen for erosion tests performed with the same materials under nominally identical conditions of impact angle and velocity, when different methods are used to accelerate the particles; a centrifugal particle accelerator can be used to demonstrate clearly that particle spin has an important effect on erosion rate [5].


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