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Low Load Multiple Scratch Tests of Ceramics and Hardmetals

Summary

Multiple pass low load scratch tests have been carried out on a range of hardmetals and ceramics to investigate the potential of the technique as a method for evaluating the likely response of these hardmaterials to abrasion.

The results show that the technique has great potential for evaluating how abrasion damage to materials builds up as the repeated individual abrasion events from different abrasive particles accumulate.

In particular, it was found that although the scratch width for the ceramics (as a measure of the damage to the sample) was often initially smaller than the initial scratch width for the hardmetals, the scratch width in the ceramic samples often increased rapidly as repeated scratch passes took place in contrast to the hardmetal samples where the scratch width increased more slowly.

This was due to the increased fracture that was observed in the repeated scratching of ceramics by contrast with the hardmetals.

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Introduction

Abrasion is a major cause of wear which leads to high costs for industry, for example through the breakdown in machinery and high maintenance costs because of the need for the replacement of components.

Although abrasion has been studied for many years, there is still a lack of understanding about the way that abrasion damage builds up as repeated abrasion takes place. A model test which has often been used in the study of abrasion is scratch testing in which an indenter is moved across the surface of a sample under carefully controlled conditions of applied load and test speed, and the degree of damage and the mechanisms of materials removal examined.

These experiments are normally carried out using a single scratch. However, in most applications where abrasion occurs removal of material is brought about by multiple abrasion events through many repeated scratching processes. Another potential pitfall is that these tests are normally performed under the same high load conditions that are used in the adhesion testing of thin hard coatings; although this is likely to be appropriate for many industrial applications where a high load will occur there are many other applications where the loading that occurs from single abrasive particles are much lower.

For both these reasons, an experimental system has been developed which can be used to perform scratch tests under low loads, and which can be used to examine the build up of damage to the sample as the number of repeat scratches along the same path is increased.

A range of hardmetals and ceramics were tested. All the samples were polished to a fine surface finish, and the hardmetals were also annealed at 800°C to remove residual stresses from the surface of the samples.

Test Description

The low load scratch test system was designed to enable tests to be carried out accurately at low applied loads. Key features of the test system, Figure 1, are:

- the frictionless bearings for the lever arm
- full computer control and data acquisition
- measurement of frictional load by a horizontal axis of a dynamometer
- measurement of the applied load by a static load cell in addition to the vertical axis of the dynamometer
- measurement of the horizontal position of the test-piece and the vertical position of the indenter.

Measurements were carried out using an applied load of 4 N and a horizontal test speed of 1 mm s^{-1}. Indenters with two different tip radii of 50 μm and 200 μm were used to simulate abrasion by small and large abrasive respectively. Arrays of seven scratches with 1, 2, 5, 10, 20, and 100 repeat scratches were performed.

The damage to the sample was determined by measuring the width of the scratch by optical microscopy, and the mechanisms of damage were evaluated by optical and scanning electron microscopy.

Results

One of the key results that was obtained in the low load scratch testing is the variation of average friction coefficient with number of repeat scratches. The behaviour that was observed varied considerably (Figure 2) for the hardmetals. In some cases the average friction rose steadily with number of repeats (2a; TC222 with 200 μm indenter,, 2; CWC15C with 200 μm indenter). In other cases there was an initial increase in average friction coefficient over the first few repeats followed by a plateau in the average friction coefficient (2b; MA10 with 200 μm indenter, 2e; SHMUF with 50 μm indenter). There was also some cases where the fiction coefficient initially reduced to a plateau value for the rest of the repeat scratches (2f; SHMUF with 200 μm indenter). In most cases the repeatability in the tests was quite good with the data points for the different scratches falling well within the error bands describing the variation in friction within a single repeat scratch. However, in a few cases the results for the different scratches did not agree so that there were significant differences in the data values from one scratch to another (Figure 2d).

Similar results are seen for the ceramic samples, but the most common behaviour is for an initial fairly rapid increase in friction to a maximum followed by a drop to a steady value (Figure 3).

One of the key purposes in performing repeated scratches with the low load test system is to examine the build up of damage as the number of passes of the diamond indenter over the same path on the sample 50 μm increases. Figure 4a shows that for the hardmetals with a indenter as the number of repeats increases the width of the scratch increases (with the rate of increase in width decreasing as the number of repeats increases). Figure 4b shows the same data with a logorithmic scale for the number of repeats. This shows an approximately linear relationship for many of the hardmetals.

The width of the scratches in the ceramics with the 50 μm radius indenter increases in a similar way to the hardmetals (Figure 5). However, the increase in scratch width is greater for most of the ceramics than for most of the hardmetals.

With the 200 μm radius indenter there is very little increase in scratch width with number of repeats for the hardmetals (Figure 6a). By contrast, the scratch width increases considerably with the number of repeats for most of the ceramics (Figure 6b).

Surface Examination

Optical micrographs of scratches on hardmetals are shown in Figures 7-10. There is a build up of gross damage to the microstructure of the samples as the number of repeats increases for all the hardmetals. However, the severity off this damage seems to be greater for the coarse grained materials (eg Figure 8c) than for the fine grained materials.

Gross damage builds up much more quickly for the ceramics (Figures 11-12). For the Vitox tested with the 50 μm indenter gross fracture of the material has taken place at the base of the scratch even for a single scratch (Figure 12a). By comparison, with the 200 μm indenter damage on this scale only occurs after a few repeat scratches have taken place (Figure 12b).

The build up of damage on the RBSC sample with the 200 μ indenter is particularly interesting (Figure 32). Even with a single pass, some fracture has occurred to the sample. Fracture damage rapidly increases with curved cracks aligned roughly perpendicular to the direction of scratching for the scratches with 2 and 10 repeats. Eventually the scratch surface suffers from gross failure (Figure 32d).

Discussion

The width of the scratch is a measure of the abrasion damage that is caused in a scratch. An increase in the scratch width was always observed as the number of repeat passes was increased, showing that the abrasion damage did increase as the number of contacts was increased.

It is particularly interesting that although the single pass scratch width for some of the ceramics with high hardness was lower than the width found with the hardmetals, the width of the scratches for the ceramics rapidly increased in most cases with the number of repeat passes so that the final scratch width was much larger for the ceramics than for the hardmetals. The exception to this was the sintered silicon nitride which showed only a small increase in scratch width with increasing number of repeat passes.

This was found to be due to the increased likelihood of fracture damage in the ceramics compared to the hardmetals. Thus fracture occurred much sooner with the ceramics than the hardmetals, and led to removal of much larger fragments of material and higher abrasion damage than for the hardmetals.

Fracture was nevertheless a major form of damage to the hardmetals. However, it generally occurred by fragmentation of single grains of material, and there was not much evidence for the removal of large fragments of material from the scratch.

Surface layers were formed as repeated scratching took place for both the hardmetals and ceramics. These were formed from the fine debris that accumulated in the scratches from the abrasion process, but there was also the possibility that some tribochemical reaction of the debris occurred with the surrounding environment.

One drawback with the current set of experiments is that as the damage to the sample increases with repeated passes of the indenter, because the scratch and the indenter are conformal, the applied pressure drops as the number of passes increases. This explains why the rate of increase in scratch width decreases with the number of repeat passes. It also suggests that if the number of passes were increased indefinitely, that a steady state position would be reached where the area of the scratch was sufficiently large to support the movement of the indenter without further damage to the sample.

This is clearly not a realistic simulation of abrasion in real applications where abrasion by a

Conclusions

Multiple low load scratch testing has been demonstrated to be an effective method to investigate the mechanisms of the build up of damage in abrasion. Clear differences in behaviour occur from one material to another, with a particularly large increase in damage observed for some ceramics.

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