CMMT(MN)30

An NPL Rotating Wheel Abrasion Test

Summary

This measurement note describes the development of a rotating wheel abrasion test system. The results of some exploratory experiments carried out with the test system are summarised.

The test is based on the well-established ASTM G65 dry sand/rubber wheel test where a sample is pressed against a rubber rimmed wheel with abrasive silica introduced between the wheel and the sample. There are other similar tests such as the ASTM B611steel wheel test and the ASTM G105 wet sand rubber wheel test. The system described here was developed to explore the potential of using a single test system to perform abrasive tests under the varied conditions experienced in the tests mentioned above.

A major problem with the traditional G65 test is the lack of control over the flow of abrasive. The test system investigated in this study uses a notched wheel feed mechanism which was found to work well, giving good control of the abrasive feed rate.

The test system can be used in a number of different operating modes. These include using dry or wet conditions, using a compliant rubber rimmed wheel or stiff steel wheel, and using tests with different abrasives and different abrasive sizes.

When the results of the exploratory tests on a die steel were examined, it was found that more wear was produced when a steel wheel was used instead of the compliant rubber wheel. There was higher wear with a smaller sized silica abrasive than with larger sized abrasive, and there was a reduction in wear for wet tests compared with dry tests.

M G Gee, A J Gant and W P Byrne

November 1998

Introduction

Abrasive wear is a major cause of loss in earnings to UK firms [1]. The need to reduce these losses is driving the requirement for more relevant data on the abrasive wear of materials.

Currently, there are a number of abrasive test methods that have been used to determine the abrasive wear performance of materials [2-4].

These include the ASTM G65 rubber wheel dry sand test [2]. In this test a sample is pressed against a rubber rimmed steel wheel, with a stream of sand (silica abrasive) introduced between the sample and the wheel (Figure 1). This test is widely used, but suffers from a number of problems associated with the control of the abrasive flow. In the ASTM G65 test the flow of sand is controlled by adjusting the size, shape and position of a nozzle placed above the wheel/sample interface. It is difficult to get the correct conditions with this arrangement, leading to likely errors in measurement such as inconsistencies of test performance and variation in results on a single material.

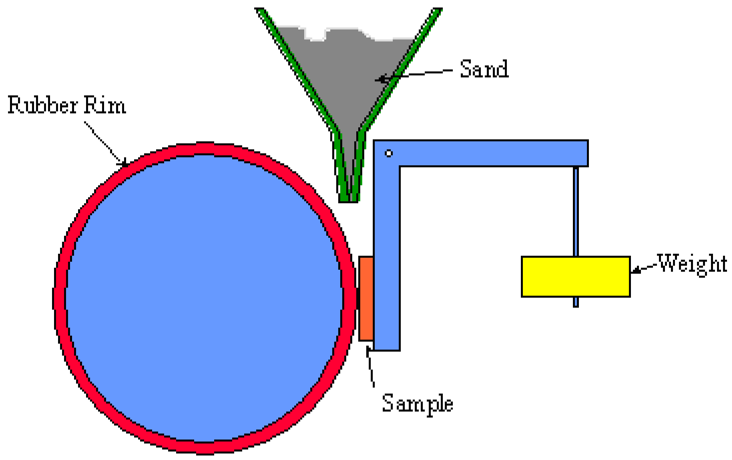


Figure 1, Schematic diagram of original ASTM G65 test system

A number of different groups have looked at better methods for supplying abrasive to the wear interface [5-7]. These are the use of a vibrating feed, a screw auger feed, and a notched cylinder feed mechanism.

Other similar abrasion tests are also in industrial use. These are the ASTM B611 test using a steel wheel and a wet slurry of abrasive [3], and the ASTM G105 test using a rubber rimmed steel wheel and a wet abrasive slurry [4].

This measurement note describes the development of a rotating wheel abrasion test system and describes the results of some exploratory experiments. The possibility of using the system as a flexible basis for evaluating other types of rotating wheel test has also been examined.

The test can be used by industry to simulate the wear of components which are subject to wear from a stream of abrasives. These include applications such as materials handling, raw materials processing, mining (for abrasive rock), and components for pipelines and machinery where abrasion is encountered (eg North Sea oil industry).

The particular advantage of the type of test system described in this measurement note is its adaptability. By changing the test parameters such as the resilience of the test wheel, type of abrasive, load and speed conditions, and whether tests are conducted wet or dry or, a wide range of different conditions can be generated which are relevant to many different industrial applications

Description Of Test System

The modified test system is shown in Figure 2. The major changes that have been made to the original ASTM G65 test system are:

- the use of a horizontal sample instead of a vertical sample
- the use of a fluid feed
- the use of a notched wheel abrasive feed mechanism
- the use of both steel and rubber wheels.

By positioning the sample horizontally, the abrasive can be deposited onto the test wheel in a well controlled way by the feed chute.

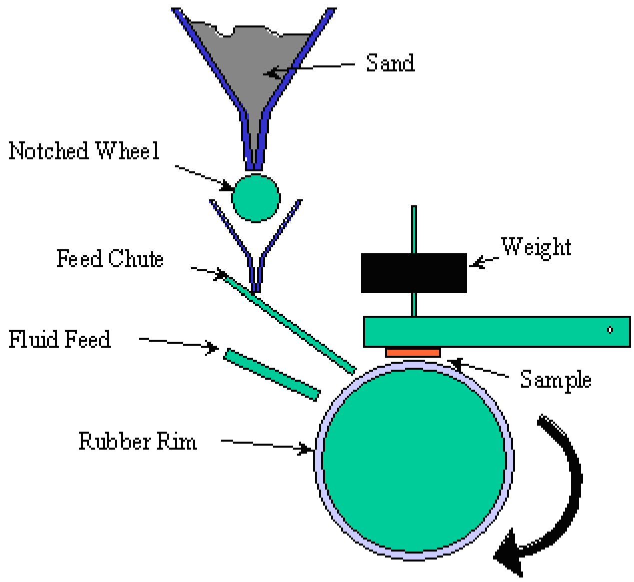
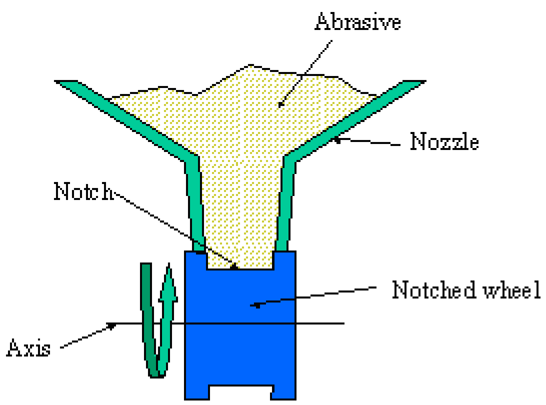
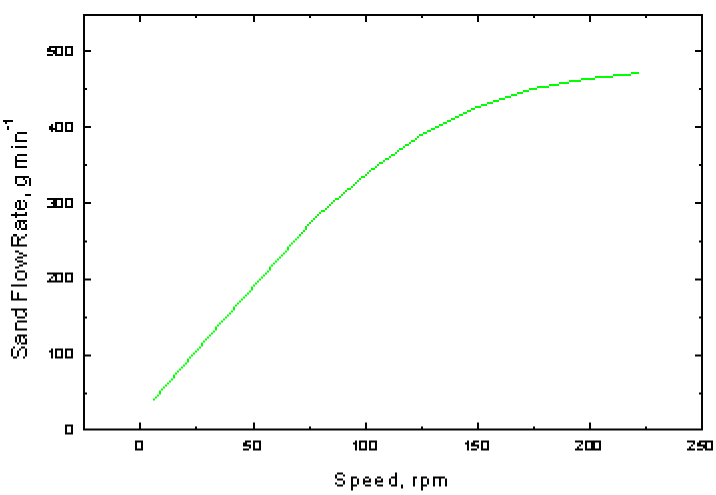


Figure 2, Schematic diagram of modified test system

The notched wheel gives a well controlled feed rate where the speed of the wheel controls the abrasive feed rate (Figure 3) [5]. At low notched wheel speeds, the feed rate increases sharply with wheel speed, with a lower increase in feed rate at higher wheel speeds.



a)



b)

Figure 3, a) Cross section through edge of notched wheel, b) variation in flow rate with notched wheel motor setting

The introduction of a fluid feed to the test system enables tests to be performed under wet conditions.

After some experimentation, the fluid feed nozzle was placed close to the test wheel behind the abrasive feed chute. This position was chosen to ensure that fluid from the nozzle was placed directly onto the wheel without the formation of any spray. It was found that when the nozzle was placed further away from the wheel, splashing occurred which wetted parts of the test system away from the wear interface such as the abrasive feed nozzle. A sludge of abrasive then built up on the nozzle under these conditions blocking the feed of abrasive. Positioning the nozzle so that the fluid comes into direct contact with the test wheel eliminated this problem. In practice it was found that excellent control of the fluid flow rate was obtained with the peristaltic pump that was used.

The use of a continuous fluid supply also eliminates the need for a fluid trough (used in tests ASTM B611 and ASTM G105).

The test system was designed for use with both rubber rimmed test wheels (prepared with a Rubber Hardness of Durometer A-60 as specified in the ASTM G65 test procedure), and mild steel test wheels.

A steel wheel gives a stiff support to the test abrasive which means that most of the test load is carried by a few of the largest abrasive grains and only a small degree of load sharing occurs. The rubber wheel is more compliant and abrasive sinks into the rubber. The applied load is then shared between most of the abrasive particles.

Exploratory Test Results

A series of tests were carried out on a D2 die steel with an average hardness of 745 HV30 (test conditions are given in the captions for figures which describe the results). The tests were all carried out with a wheel speed of 74 rpm (peripheral speed of 0.79 ms^{-1}). The abrasive flow rate was kept constant at 150 g min^{-1}.

The test matrix was designed to evaluate the effect of:

- performing tests wet or dry
- two different sizes of abrasive
- two different abrasives, alumina and silica
- test duration
- applied load.

A wear scar was formed on the sample after the test. The mass of the sample was measured before and after every test, with the volume of wear calculated from the mass loss of the sample and the density of the sample.

As the duration of the test increases the volume of wear increased (Figure 4). There was also an increase in wear volume with increased test load (Figure 5). When a wear rate was calculated from the values of wear volume, there was initially a higher wear rate which reduced to a relatively constant rate after the first few minutes (Figure 6).

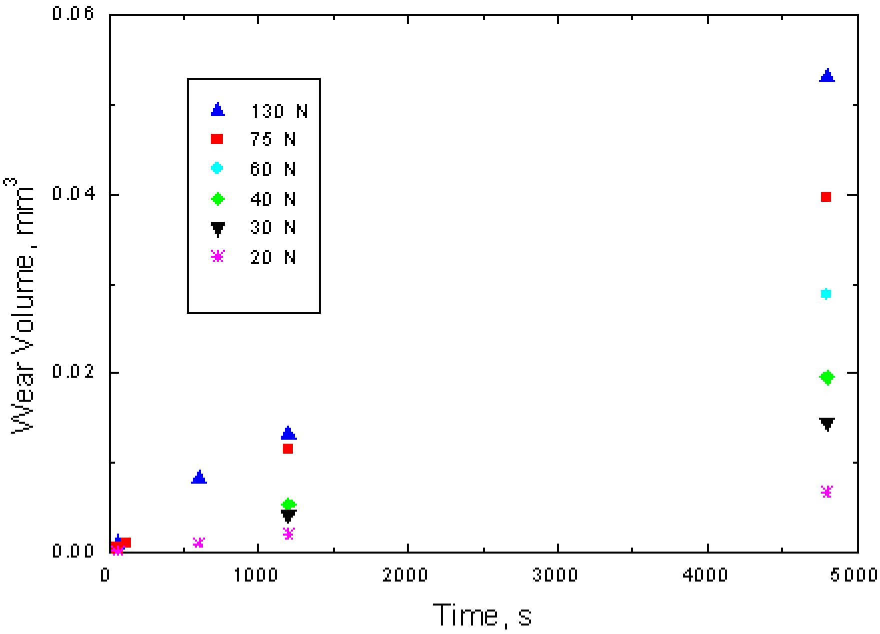


Figure 4, Variation in wear volume with test load and duration for tests carried out using rubber wheel and dry conditions

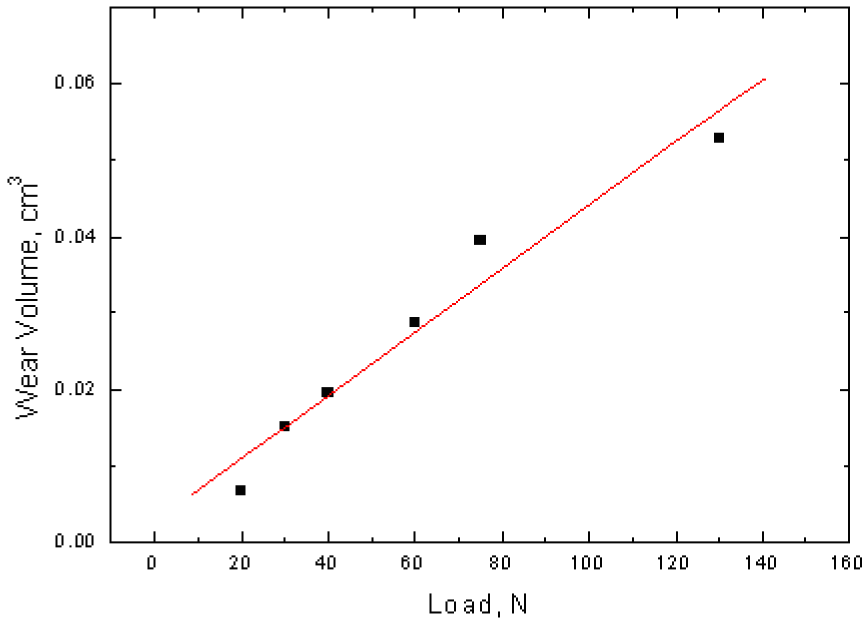


Figure 5, Variation in wear volume with test load for tests carried out using rubber wheel and dry conditions for a duration of 4800 s

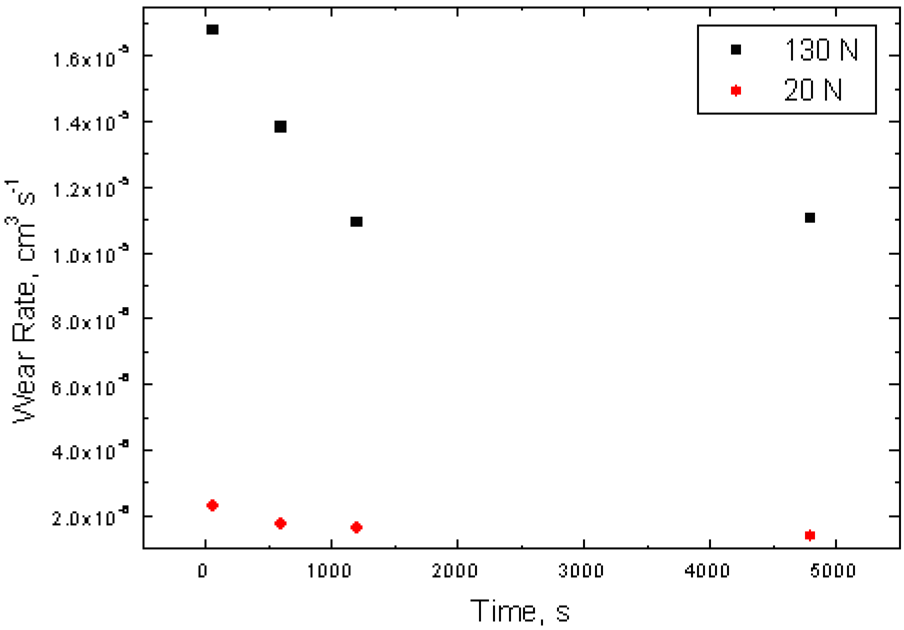


Figure 6, Variation in wear rate with time for two loads carried out using rubber wheel and dry conditions.

It can also be seen from Figure 6 that the wear rate at 130 N was higher than for 20 N. A normalised wear rate can be calculated as

$$k = \frac{V}{Nt}$$

where k is the normalised wear rate, V is the wear volume, t is the duration, and N is the applied load. The normalised wear rate for the tests carried out at 130 N (8.49×10^{-8} cm^3 N^{-1} s^{-1}; tested for 4800 s) is close to the value for the tests carried out at 20 N (6.96×10^{-8} cm^3 N^{-1} s^{-1}; tested for 4800 s).

The wear volume that was produced in tests with a rubber rimmed wheel was much lower than in tests where a steel wheel was used (Figure 7). There was also a smaller reduction in wear when tests were run wet.

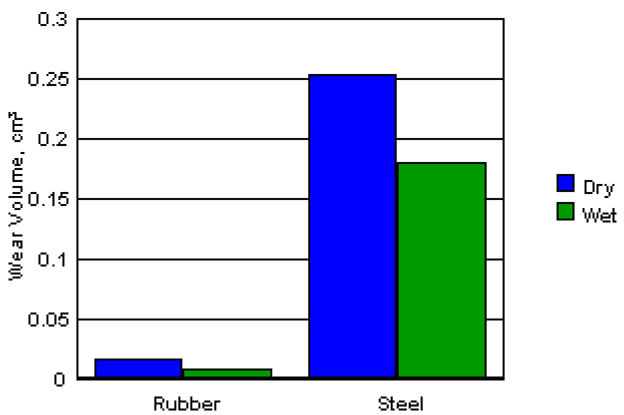


Figure 7, Variation in wear volume for wheel material in tests

There was a reduction of wear as the size of the abrasive was increased for silica abrasive (Figure 8). There was also an increase in wear volume when the abrasive was changed from silica to alumina. The reduction in wear when a rubber rimmed test wheel was used compared to the steel wheel is also shown in this figure, and is particularly marked for the tests carried out with 600 μm silica sand.

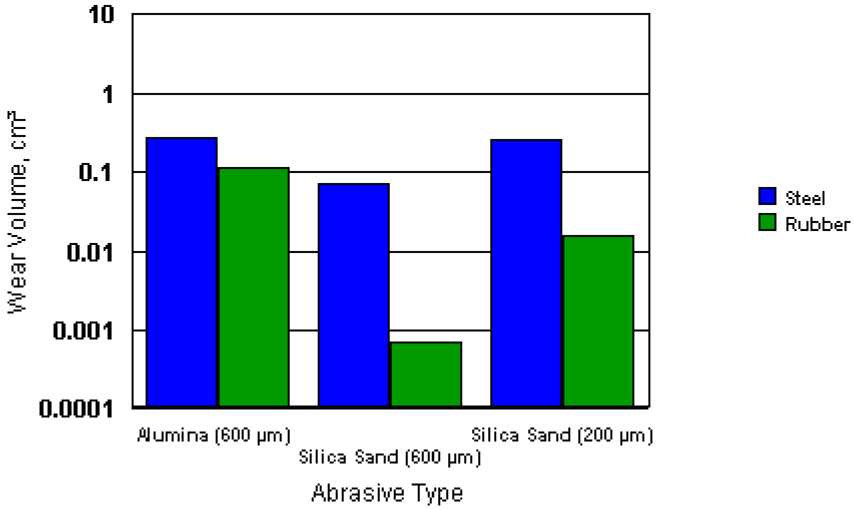


Figure 8, Variation in wear volume with type of abrasive

The variation in wear rate with test duration was also examined by carrying out an interrupted test where the test was stopped at preset times, weighed, and wear rate calculated. The initial wear rate calculated for the first minute of testing was high, but this reduced to a lower level which remained nearly constant for the remainder of the test (Figure 9). However, the wear rate measured during the interrupted tests was always higher than those recorded in continuous tests of equivalent total duration.

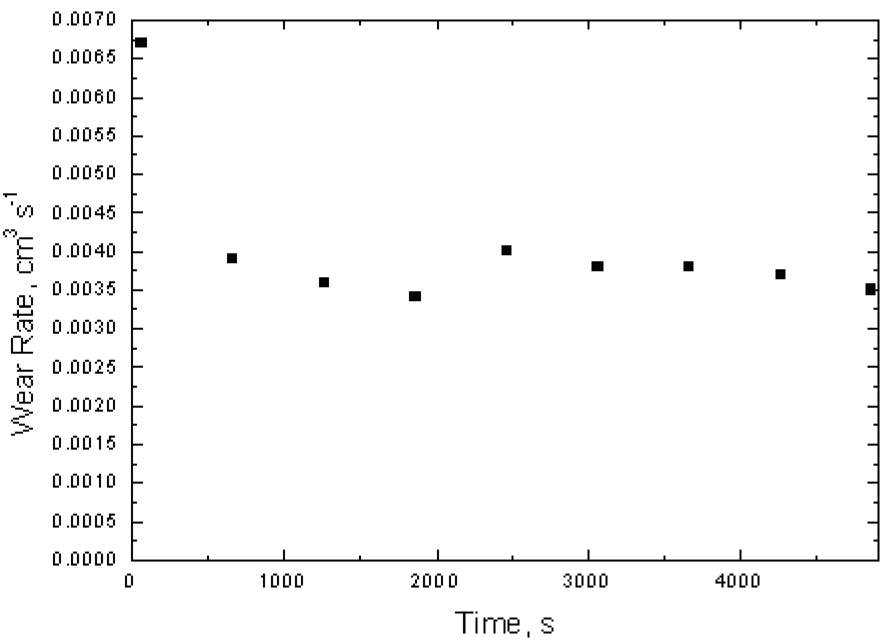
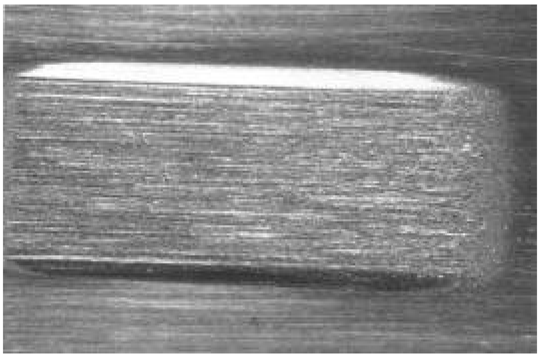


Figure 9, Variation in wear rate with time for interrupted test carried out using rubber wheel test under dry conditions and test load of 75 N.

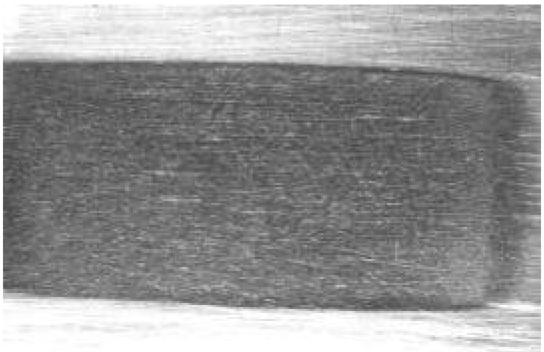
Microstructural Examination

The worn surfaces were examined by optical microscopy and at high magnification by high resolution scanning electron microscopy. Typical wear scars are shown in Figure 10. Wear scars were much shallower for the rubber wheel tests than the steel wheel tests because of the high compliance of the wheel which causes the wheel rim to deform when it comes into contact with the test sample. By contrast, the wear scars were deeper for the steel wheels because the steel wheel only deformed a small amount when brought into contact with the sample.

This difference is due to the fact that in steel wheel tests the wear scar is initially quite small but increases in size as the test proceeds (the depth of the scar increases in line with increase of the length because its shape conforms to that of the steel wheel).



a)



b)

Figure 10, Overall views of wear scars for a) steel wheel, b) rubber wheel

For the rubber wheeled tests, the scar length grows very quickly on initial contact as the rubber wheel deforms, but then increases more slowly as the test progresses; however, the depth of scar increases more or less linearly with test time.

Examination of the worn samples was carried out with a high resolution field emission scanning electron microscope. The worn surfaces are contrasted with the appearance of the original surface of the test sample which had a ground finish (Figures 11, 12 and 13).

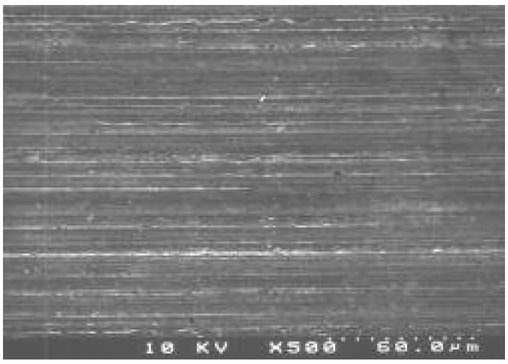


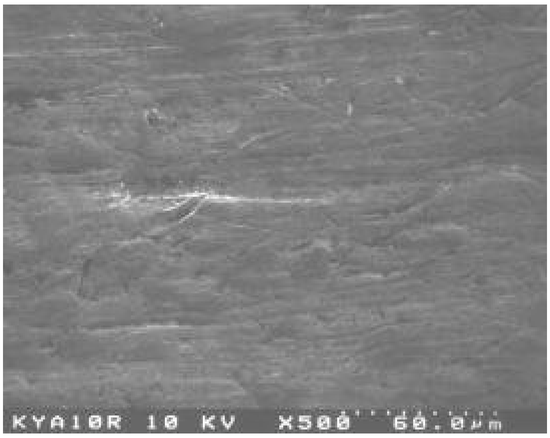
Figure 11, Original ground finish of sample

The samples tested with the rubber wheel showed a relatively smooth surface which was marked with a number of scratches (Figure 12). The majority of the scratches were aligned with the direction of wheel motion, but a significant number of scratches were at angles up to 20-30 degrees from this direction.

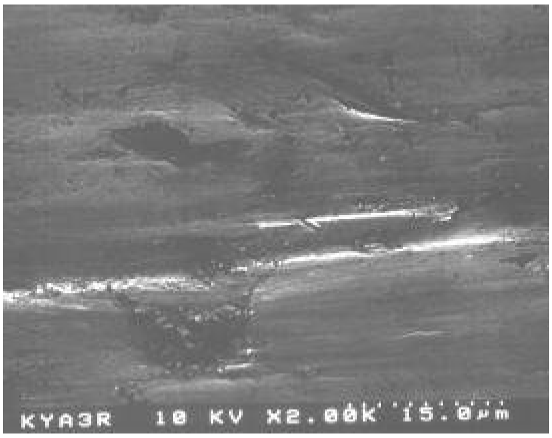
The surfaces worn by the steel wheel were more complex. The wear surfaces were often covered with wide grooves about 1 mm wide (Figure 13). Examination at higher magnification showed a highly deformed surface with some obvious scratching. There is also evidence for fracture of carbide particles at the wear surface of the steel sample.

There did not seem to be much difference in the appearance of surfaces worn by the alumina or the silica abrasive. The use of a rubber wheel or a steel wheel appears to be a more important factor.

No consistent difference was observed between the wear surfaces tested under dry or wet conditions.



a)



b)

Figure 12, Worn surface of sample tested with rubber wheel

Discussion

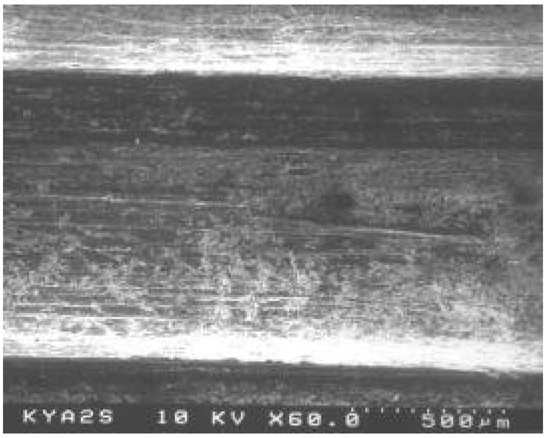
The steel wheel tests consistently gave higher wear than for rubber wheel tests carried out under otherwise equivalent conditions. Examination of the worn surfaces shows that the steel wheel produced more severe abrasion damage. This is likely to be due to the individual abrasive particles in contact with the test-piece more highly loaded than those on a compliant rubber surface.

The higher wear occuring with the alumina abrasive compared with the same size silica abrasive is expected to be due to the higher hardness of the alumina abrasive relative to the silica abrasive.

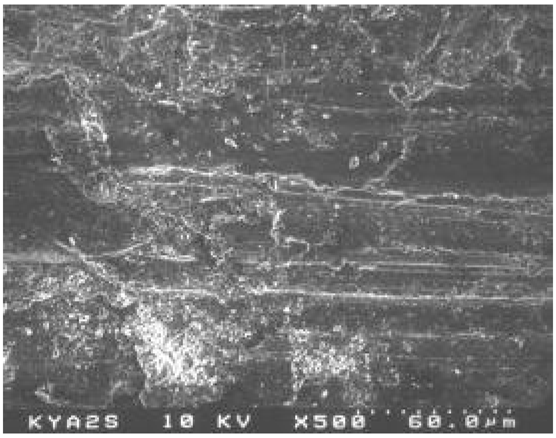
It is perhaps more surprising that more wear occurred with the smaller size silica abrasive than the larger abrasive.

However, this may be caused by the increased packing density of the smaller sized abrasive on the test wheel compared with the larger abrasive.

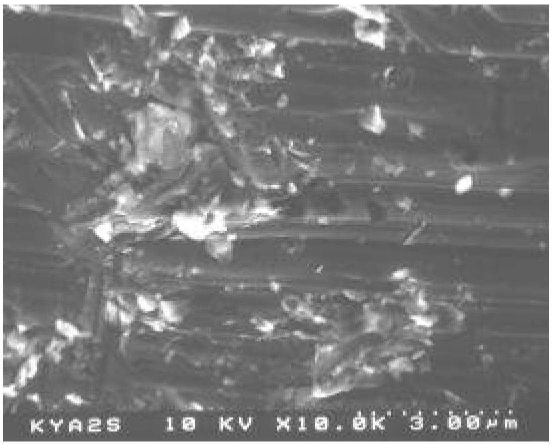
There is a reduction in wear for tests carried out wet compared to tests carried out dry. The reason for this is not completely clear, but factors which may contribute are the cooling of the abrasive contacts by the water and consequent reduction in temperature at the wear surface, the lubricating effect of the water, and possible changes in the dynamics of motion of the abrasive particles in the presence of water compared to air. However, although the cooling effect may contribute, it is not felt to be too important as the temperature of the wheel did not rise that sharply during tests. The possibility was also considered that the water washed away some of the abrasive, but measurements of the wheel abrasive loading showed that this was unlikely.



a)



b)



c)

Figure 13, Wear surface of sample tested with steel wheel

Conclusions

The rotating wheel abrasive test system described in this measurement note is a versatile test system which can be used in a number of different operating modes. Operating modes which have been explored in this measurement note are:

- tests under dry or wet conditions
- tests using compliant rubber rimmed wheel or stiff steel wheel
- tests with different abrasives and different abrasive sizes.

The notched wheel feed mechanism works well, giving good control of abrasive feed rate.

When the results of the exploratory tests on a die steel were examined, it was found that more wear was produced when a steel wheel was used instead of the compliant rubber wheel. There was higher wear with a smaller sized silica abrasive than with larger sized abrasive, and there was a reduction in wear for wet tests compared to dry tests.

Acknowledgements

The authors would like to acknowledge the support of DTI for this work through the Materials Measurement Programme on the Characterisation and Performance of Advanced Materials.

References:

1. M G Gee and S Owen-Jones, Wear Testing Methods and Their Relevance to Industrial Wear Problems, NPL Report CMMT (A)92, December 1997
2. ASTM G65-94, Standard test for measuring abrasion using the dry sand/rubber wheel apparatus, 1996 Annual Book of ASTM Standards, Volume 03.02, ASTM
3. J Ellis and B M Armstrong, Evaluation of Wear Resistant Materials for Use in Materials Handling Systems, Report Number SL/CS/P/13/90/O, British Steel Technical, Swinden Laboratories
4. D Stephenson, Modelling low stress abrasive wear, Wear, 213(1997)103-111
5. A N J Stephenson and I M Hutchings, Development of the dry sand / rubber wheel abrasion test, Wear, 195 (1996)232-240
6. ASTM B611-91, Test Method for Abrasive Wear Resistance of Cemented Carbides, 1996 Annual Book of ASTM Standards, Volume 02.05, ASTM
7. ASTM G105-89, Standard test method for conducting wet sand/rubber wheel abrasion tests, 1996 Annual Book of ASTM Standards, Volume 03.02, ASTM

For further information contact:

M Gee
Centre for Materials Measurement and Technology
Tel: 020 8943 6374 (MG)
Tel: 020 8943 6802 (AJG)
Fax: 020 8943 2989 (MG)
Email: Mark.Gee@npl.co.uk
Experts Link to Expert

National Physical Laboratory
Queens Road
Teddington
Middlesex
United Kingdom

TW11 0LW

Tel: 020 8977 3222
Fax: 020 8943 6458
Email: materials@npl.co.uk

CMMT(MN)30
An NPL Rotating Wheel Abrasion Test
November 1998