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Procedure for Ball Cratering Test

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SUMMARY

This document describes a procedure for conducting ball cratering tests to determine the abrasion resistance of thin hard coatings. In the test, a ball is rotated and is pressed against the sample until a spherical depression is produced. By making a series of these craters and measuring the size of the scar dimensions, the wear rate of both the coating and the substrate can be calculated.

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CONTENTS

1 BACKGROUND

This procedure describes the method for performing tests with the ball cratering test system that has been developed for carrying out wear tests on thin hard coatings [1,2].

The procedure builds on work carried out both as part of the EC funded FASTE project on the Development and Validation of Test Methods for Thin Hard Coatings. The procedure will be validated through an EU funded project, through a DTI funded project, and also through the VAMAS Technical Work Area 1: Wear Test Methods.

2 TEST SYSTEM

The test system can either use a ball or a profiled wheel which is rotated and pressed against the coated sample. When a wheel is used the sample must also be rotated. Two different variants of the ball system are shown in Figure 1, where either the sample mounted on a dead-weight loaded lever is pressed against a directly driven ball, or the ball's own weight presses it against the sample.

In all cases, a slurry of SiC abrasive in water is drip fed onto the contact between the ball and the sample, and wear is measured by measuring the size of the wear scar on the sample using a microscope.

3 MATERIALS

The coated samples should have a flat area large enough to perform the necessary series of experiments. The coating thickness can be evaluated as part of the test procedure, but must be larger than 1 μm. The balls are 25 mm diameter hardened steel (AISI 52100).

Balls can be used in a polished condition, but it has been found [3] that the test behaviour is erratic and poor results are obtained if balls of this type are used without conditioning.

The conditioning treatment consists of running the test ball for 50 revolutions on a non-critical part of the sample under normal test conditions before starting the testing.

The abrasive is normally F1200 SiC abrasive, but F1200 silica or other fine abrasive can be used. The average size of the abrasive should not exceed 4 μm. An abrasive slurry should be made up from the abrasive powder and distilled water in the required proportions.

As the mode of wear that is observed depends critically on the abrasive concentration that is used, two concentrations are recommended.

These are:

1) Dilute (promotes grooving wear)
Concentration of 2 % by volume

For SiC this is achieved by mixing 6.4 g to 98 ml distilled water.

2) Concentrated (promotes rolling wear)

Concentration of 20% by volume

For SiC this is achieved by mixing 6.4 g to 8 ml distilled water

As an alternative to mixing slurries, ready mixed abrasive slurries can be used. If this is done all details of the supplier and makeup of the slurry should be reported.

4 TEST TYPES

Two different types of tests can be performed.

Type A: No perforation of coating.

In this type of test the duration of the test is controlled so that perforation of the coating does not occur. Some trials may be necessary before the required conditions are obtained. The wear is calculated from the measured size of the wear crater.

Type B: Perforation of coating.

In this type of test the coating is perforated. A series of craters with different durations is produced and the sizes of the craters are measured in each case. The wear rates for both the substrate and the coating can be calculated from an analysis of the measured crater sizes.

5 TEST CONDITIONS

Number of test repeats

Two repeat sets of tests should be carried out on the sample.

Load

If the load applied to the sample is too high the phenomenon of ridging occurs. To prevent this, it is suggested that the load applied should not be greater than 0.4 N. The recommended load is 0.25 N.

Speed

The speed of the ball should be controlled at a constant value throughout a set of tests. A recommended speed is 80 rpm.

When a wheel test system is used the sample rotation speed should be reported.

Number of revolutions: Test type A with no perforation

The number of revolutions required to give a crater which is easy to measure, but with no perforation needs to be determined by trials.

Number of revolutions: Test type B with perforation

The number of revolutions that is required will depend on the materials that are to be tested and the test conditions employed. However, a set of measurements for 100, 200, 300, 600 and 1000 revolutions has been found to be appropriate for tests using a concentrated SiC abrasive slurry under a load of 0.25 N and at a speed of 80 rpm.

6 TEST PROCEDURES

Type A: No perforation of coating.

1) The sample should be cleaned by the following procedure:
   Ultrasonically clean in acetone for 15 minutes
   Rinse in clean acetone
   Dry in oven at 110 °C for 10 minutes.

2) The sample should be clamped firmly into position on the test system.

3) The motor speed should be adjusted to give the correct speed.

4) The test system should be adjusted to give the correct normal loading between the ball and sample at a test point on the sample.

   Note: In free ball machines, the friction due to the ball rotation results in an error in the normal force acting on the sample. In these test systems a load cell should be employed to measure the true normal force.

5) The slurry drip feed should be started, with the slurry continuously stirred by a magnetic stirrer. The feed rate should be sufficient that the contact between the ball and sample is always well wetted by the slurry. The slurry should not be recirculated.

6) After the required test duration, the test should be stopped (motor and slurry feed stopped).

7) The sample should be removed and cleaned by the same procedure as in 3).

8) The size of the wear scar should be measured both parallel and perpendicular to the direction ball rotation. Both the full crater width, and the width of the substrate crater should be measured (Figure 2). The average of these measurements should be used as the sizes of wear scar b and a in the analysis described below.

9) The wear rate of the coating should be calculated using the method described below.

Type B: Perforation of coating.

Steps 1-6 are the same as in the type A test.

7) When the required number of revolutions has taken place for the first crater, the test should be stopped (motor and slurry feed stopped), the sample moved so that a new position on the sample is worn and the next test in the sequence performed.

8) When the sequence of tests has been completed, the sample should be removed and cleaned by the same procedure as in 3).

9) The size of the wear scars should be measured both parallel and perpendicular to the direction ball rotation. Both the full crater width, and the width of the substrate crater should be measured (Figure 2). The average of these measurements should be used as the sizes of wear scar b and a in the analysis described below.

10) The wear rate of the coating and substrate should be calculated using the method described below.

11) The thickness of the coating at the test position can also be calculated as described below

7 ANALYSIS OF RESULTS

Type A: No perforation of coating.

The volume of wear is given by:

$$V = \pi \frac{b^2}{64R} \qquad \text{for } h << R$$

where R is the radius of the ball and b is the crater diameter. The Archard wear equation relates the volume of wear to the normal load N and the sliding distance S as:

$$V = K_C SN$$

where K_C is the wear coefficient for the coating. Thus

$$K_C = \pi \frac{b^4}{64RSN}$$

Type B: Perforation of coating.

The basic equation which is assumed to govern wear is (1)

$$SN = \left(\frac{V_c}{K_c} + \frac{V_s}{K_s} \right) \qquad (1)$$

where S is the distance slid by the sphere, N is the normal load, V_c is the volume of coating removed, V_s is the volume of substrate removed, K_s is the wear coefficient for the substrate, and K_c is the wear coefficient for the coating.

Equation (1) can be expressed as

$$SN = \left(\frac{V_c K_s + (V - V_c) K_c}{K_c K_s} \right) \qquad (2)$$

where V is the total wear volume of the crater.

The total volume of the crater is given by

$$V = \pi \frac{b^4}{64R} \qquad \text{for } h \ll R \qquad (3)$$

where b is the external diameter of the crater, R is the radius of the ball and h is the depth of the scar, and the volume of the worn coating is given by

$$V_c = \pi t \left(\frac{b^2}{4} - Rt \right) \qquad \text{for } h \ll R \qquad (4)$$

where t is the thickness of the coating (calculated by the equation given in the Annex from the measurements of the scars).

Rearrangement gives

$$\frac{SN}{b^4} = \left(\frac{K_s - K_c}{K_s K_c} \right) \left(\frac{\pi t}{\ } - \frac{\pi R t^2}{\ } \right) + \left(\frac{1}{K_s} \right) \left(\frac{\pi}{64R} \right) \qquad (5)$$

Thus a plot of SN/b^4 against $(\pi t/b^2 - \pi Rt^2/b^4)$ should be linear with the intercept as $\pi/64RK_s$ and the slope of $(K_s - K_c)/K_s K_c$.

The values of b, a and t should be calculated for each individual scar, and a regression analysis performed of SN/b^4 against $(\pi t/4b^2 - \pi Rt^2/b^4)$.

If the intercept is C and the slope M, then

$$K_s = \frac{\pi}{64RC} \qquad (6)$$

and

$$K_c = \frac{K_s}{K_s M + 1} \quad (7)$$

8 REPORTING

The details of the materials should be clearly described.

The type of test that has been performed shall be given.

All test results should be reported giving full details of all values of scar diameter measurements, and the duration of test in revolutions when the measurements were obtained.

9 REFERENCES

1) A Kassman, S Jacobson, L Erickson, P Hedenqvist and M Olsson, A new test method for the intrinsic abrasion resistance of thin coatings, Surf. Coat. Technol., **50** (1991) 75-84.

2) K L Rutherford and I M Hutchings, A micro-abrasive test, with particular application to coated systems, Surf. Coat. Technol., **79** (1996) 231-239.

3) D N Allsop, R I Trezona and I M Hutchings, The effect of ball surface condition in the micro-abrasive wear test, Tribology Letters, 5 (1998) 259-264.

Figu

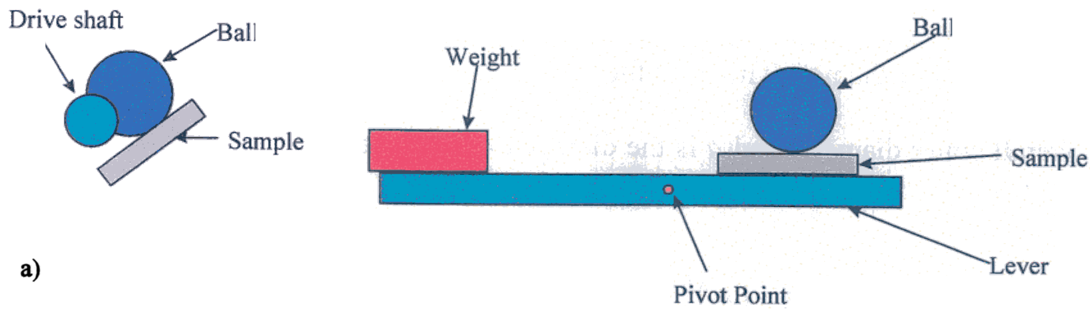

Figure T\ different types ›f ball cratering system, ı) free ball, fixed ball.

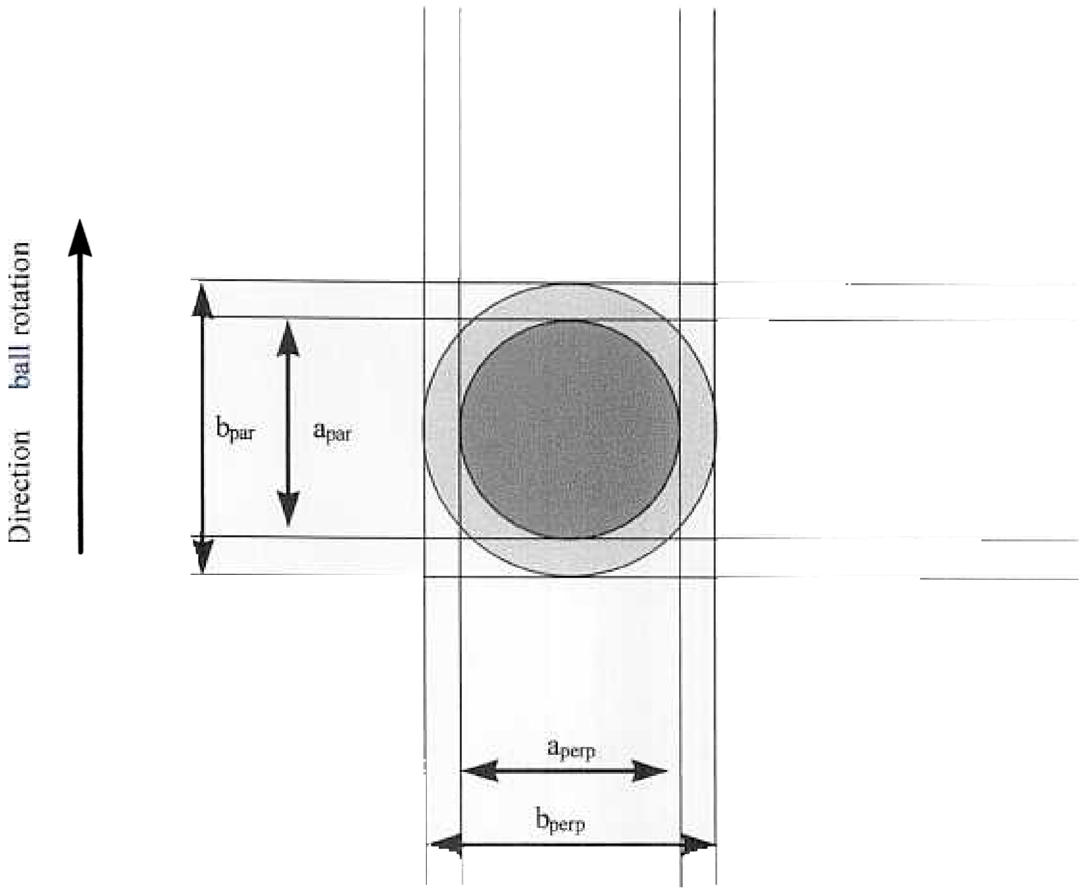

Figure Measurements on wear scar

ANNEX: MEASUREMENT OF COATING THICKNESS

The coating thickness *t* used in the analysis for the wear rates above should be calculated from the measurements of scar diameters made in the tests.

If *b* is the overall crater diameter and *a* is the diameter of the crater in the substrate, then t is given by:

$$t = | \quad \left(\frac{a}{2}\right)^{2})^{\frac{1}{2}} \quad R^{2} \quad \left(\frac{b}{2}\right)^{2})^{\frac{1}{2}}$$

The average of the values calculated with this equation should be used in the calculation of wear rates.