



**National Physical Laboratory**

**Guidelines for unlubricated  
sliding wear tests:  
Part 2, procedures for pin-on-disc testing**

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**ABSTRACT**

These guidelines describe procedures for the conduction of unlubricated pin-on-disc wear tests. They have been prepared for the UK Forum on Friction and Wear Testing and are based in part on results from interlaboratory exercises conducted by Technical Working Area 1, Wear Test Methods of VAMAS.

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## 1. INTRODUCTION

This document has been prepared by the author on behalf of the UK Forum on Friction And Wear Testing. The Forum has the overall objectives of improving the reproducibility and repeatability of friction and wear testing in the UK by open discussion and participation in national and international pre-standardisation activities. These guidelines build on the results of two international interlaboratory exercises [1,2] under the auspices of Technical Working Area 1 - Wear Test Methods of VAMAS (the Versailles Project on Advanced Materials And Standards), and two national interlaboratory exercises which were organised by NPL [3,4].

This document gives guidance on the procedures that should be followed in pin-on-disc friction and wear testing. It covers the same ground as the American Standard ASTM G-99 [5] and the draft German Standard DIN 50324 [6]. In order to avoid unnecessary divergence in practices, the recommendations in those Standards have been used as far as possible, but with specific modifications and extensions to accommodate UK needs and practice.

This document should be used in conjunction with the first part of this series of guidelines which serves as a general introduction to friction and wear testing (Part 1) [7].

## 2. SCOPE

These guidelines have the following applications and limitations.

- 2.1 They provide guidance for the measurement of friction and wear using the pin-on-disc wear test under conditions of constant load and speed.
- 2.2 They are limited to unlubricated tests.
- 2.3 They are limited to the testing of balls, pins with a spherical formed tip and flat ended pins against a rotating disc.
- 2.4 They are limited to testing at ambient temperatures.
- 2.5 They are applicable to the testing of samples of metal, ceramic, polymeric and composite materials.
- 2.6 They are not applicable to interrupted testing.

They are not intended to restrict the use of the pin-on-disc test method to a single set of test conditions, but to guide the user to the best practice use of pin-on-disc testing under a range of conditions that are defined by the user to fit his particular application.

The titles of publications referred to in this document are given at the end of the text.

## 3. DEFINITIONS

This section starts with definitions of friction and wear that are accepted widely in the international community. These are followed by definitions of terms which are used commonly in friction and wear testing, and are referred to in the rest of the Guidelines.

**NOTE** Reference to Figures 1 and 2 should be made.

### 3.1 Friction force

In the OECD Glossary of Terms and Definitions in the Field of Tribology [8] and ASTM standard G40 Standard Terminology Relating to Wear and Erosion [9], friction force is defined as:

**The resisting force tangential to the common boundary between two bodies when, under the action of an external force, one body moves or tends to move relative to the surface of the other.**

### 3.2 Wear

In ASTM G40 Standard Terminology Relating to Wear and Erosion [9], wear is defined as:

**Damage to a solid surface, generally involving progressive loss of material due to relative motion between that surface and a contacting substance or substances.**

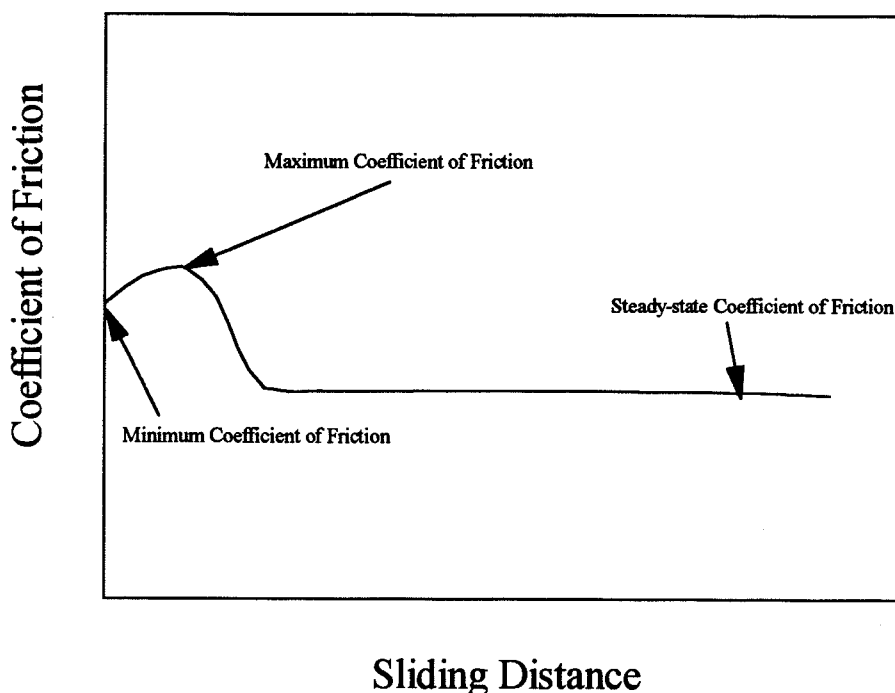


Figure 1, Schematic diagram of friction during test.

3.3 **Applied load** - load applied between two contacting surfaces normal to tangent of surfaces.

3.4 **Coefficient of friction** - the instantaneous value of friction divided by the instantaneous value of applied load. This is often approximated to the instantaneous value of friction divided by the mean applied load.

**NOTE:** These are not always even approximately the same over short time scales, and depend on the dynamic characteristics of the test system [10].

3.5 **Kinematic coefficient of friction** - the coefficient of friction under conditions of macroscopic motion between two bodies.

- 3.6 **Static coefficient of friction** - the coefficient of friction corresponding to the maximum friction force that must be overcome to initiate macroscopic motion between two surfaces.
- 3.7 **Initial coefficient of friction** - the coefficient of friction at the start of the test averaged over a period in which the disc makes a full revolution.
- 3.8 **Maximum coefficient of friction** - the maximum coefficient of friction measured during the test. In the absence of transitions in wear behaviour this often occurs shortly after the start of a test. This value is obtained as the mean value over a period in which the disc makes five full revolutions.
- 3.9 **Instantaneous coefficient of friction** - the value of the coefficient of friction defined at any point in the test. This value is obtained as the mean value over a period in which the disc makes five full revolutions.
- 3.10 **Steady state coefficient of friction** - the average value (or range of values) of the coefficient of friction over a large period of time in which the coefficient of friction is essentially constant. Such behaviour occurs after the initial transient changes in coefficient of friction have taken place.

**NOTE:** In some tests steady state behaviour does not occur, with coefficient of friction and wear rate continuing to vary over the duration of the test.

- 3.11 **Wear rate** - the rate of material removal or dimensional loss change due to wear per unit of exposure parameter, for example quantity of material removed (mass, thickness, volume) in unit distance of sliding or unit time.
- 3.12 **Dimensional wear coefficient,  $k$**  - defined by the equation

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

where  $V$  is the volume lost in a sliding distance  $d$ , and  $L$  is the applied load.

**NOTE:** In some cases the wear coefficient may be negative due to transfer of material from one specimen to another and the resultant increase in volume.

**NOTE:** Although this coefficient can be very helpful, it should not be assumed that the wear coefficient calculated above is independent of applied load. This should always be quoted when the dimensional wear coefficient is discussed.

- 3.13 **Dimensionless or Archard wear coefficient,  $K$**  - defined by the relationship

$$K = \frac{VH}{Ld}, \quad K = kH$$

where  $V$  is the volume lost in a sliding distance  $d$ , and  $L$  is the applied load, and  $H$  is the hardness of the material tested.

**NOTE:** This wear coefficient should be used with some care because of the ambiguity introduced by the measurement of hardness. Hardness is not an intrinsic property of a material, and the measured value depends on the class of material, and the type of hardness test and test conditions used. For this reason this wear parameter should only be used as a supplementary method of stating wear rates. If this coefficient is used, then the hardness value must be expressed in SI units.

- 3.14 **Initial wear rate** - the instantaneous wear rate at the start of a test. This can be found from the tangent to the curve of volume loss against sliding distance at the start of a test.

- 3.15 **Steady state wear rate** - the average value (or range of values) of the wear rate over a large period of time in which the wear rate is essentially constant. This is after the initial transient changes in the wear rate have occurred.

**NOTE:** In some tests, steady state behaviour does not occur, and coefficient of friction and wear rate continuing to vary over the duration of the test.

- 3.16 **Wear and friction transitions** - these are gross changes in the wear rate and / or coefficient of friction that occur when the test parameters are changed; or after some period of a test has occurred. They result from changes in the dominant mechanisms of friction and wear.

- 3.17 **Wear volume** - is the loss of volume to the specimen after a test. The wear volume should be quoted separately for the two specimens.

- 3.18 **Mass change (loss or gain)** - the change in specimen mass during the course of a test.

**NOTE** Mass gains can occur if chemical reaction of the sample with the environment occurs (e.g. oxidation), or if materials transfer takes place from one specimen to another.

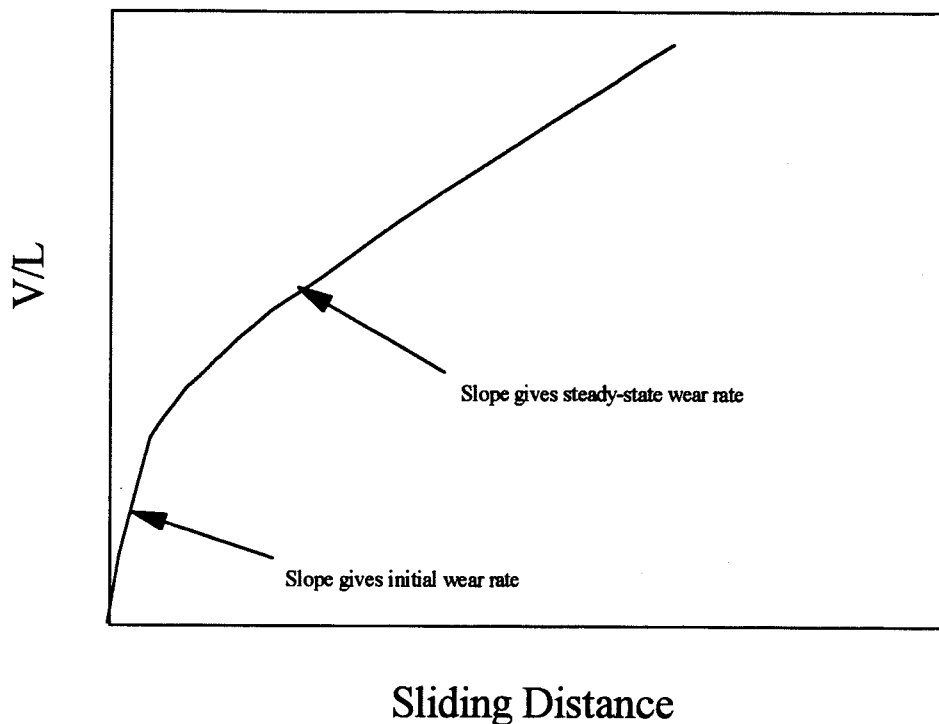


Figure 2, Schematic diagram of wear during test

- 3.19 **Wear displacement** - the displacement of one specimen towards (or more rarely away from) the other as a test proceeds.

## 4. APPARATUS

### 4.1 Testing machine

Testing should be carried out in a machine designed for pin-on disc wear testing, and which complies with the following detailed points

### 4.2 Loading system

The system which is used to load the pin against the disc can be dead-weight loading (with or without a lever arm), pneumatic or hydraulic.

4.2.1 With dead-weight loading, any frictional forces in bearings in the loading system must be negligible in comparison with the loads used in testing. This must be checked at regular intervals or when the loading system is altered. The weights which are used to apply the load must be calibrated and traceable to the National Standard of mass.

4.2.2 For pneumatic or hydraulic loading, the applied load must be calibrated and traceable to the National Standard of force. The loading system must be designed so that the applied load does not drift by more than 1% during the test, and so that variation in loading is not produced by movement of the specimens (e.g. by stiction for pneumatic cylinders).

### 4.3 Motor drive and control

The motor drive must give a constant speed of rotation, and must have sufficient power to continue at a constant speed (to  $\pm 1\%$ ) under the frictional loading that will be experienced in tests. The motor speed should be measured continuously.

### 4.4 Specimen orientation

The plane of the disc can be horizontal or vertical, and the pin or ball can be above or below the disc. However, the most usual arrangement is to have the disc horizontal and the pin pressed against the top surface of the disc.

### 4.5 Alignment of pin

4.5.1 If balls or spherical-ended pins are used, then alignment is not critical, but pins should nevertheless be held parallel to within  $2^\circ$  to the axis of rotation of the disc. The test machine should also be designed so that the centroid of the area of contact between the specimens does not move appreciably as wear of the specimens takes place (i.e. linear vertical (or horizontal) displacement).

4.5.2 For flat ended pins the two contacting surfaces should initially be parallel to within  $2^\circ$ . The test machine should be designed with location fixtures and alignment devices which simplify the process of pin alignment.

### 4.6 Alignment of disc

The contact surface of the disc should be aligned so that the variation in surface height along the projected wear track is no more than  $10\text{ }\mu\text{m}$ . This can be achieved for flat and parallel discs by ensuring that the motor drive and specimen clamping arrangement are designed so that no wobble is introduced to the specimen surface. For non-parallel specimens, a levelling system can be designed to enable adjustments to the level of the disc to be made.

#### 4.7 Specimen holding

The specimens should be mechanically clamped in position. The use of adhesives to secure the specimens in place is not recommended, as there is the possibility of deformation in the adhesive leading to inaccuracies in measurement, particularly when a large degree of frictional heating occurs.

#### 4.8 Thermal environment

The thermal environment of the specimens, and in particular the distance for each specimen from the contact surface to a significant sink of heat, has a large effect on friction and wear results. The specimen holders should be designed to give the shortest possible thermal path, such that the thermal environment will be constant from test to test.

#### 4.9 Machine dynamics

The dynamic mechanical response of the test machine can have a large effect on the results of friction and wear [11]. It is clear that the test machine should be designed so that the natural frequencies of the testing system are much higher than any vibrations generated from sources such as the motor drive or disc rotation.

#### 4.10 Environmental control

4.10.1 If air is used as the environment for the test, then the humidity should normally be controlled to  $\pm 5\%$  RH. If humidity control is not available, then a record should be kept of the humidity level during the testing.

4.10.2 If gases other than air are used as the test environment, then careful control needs to be maintained over the composition and levels of impurities in of the gas (e.g. oxygen and water vapour in argon).

#### 4.11 Measurement methods

##### 4.11.1 Mass change

The mass change of the specimen is measured as the difference in mass of the specimen recorded before and after the test. The specimens should be cleaned by the same procedure that was used to clean the specimen before the test. This will remove any foreign bodies or loose adherent layers from the specimens before weighing in a controlled way. Any debris collected should be retained for further analysis. The calibration of the balance must be checked at regular (e.g. annual) intervals. It is essential that specimens are handled as little as possible before weighing, and that clean lint-free gloves or clean tweezers are used to minimise contamination of the specimens.

##### 4.11.2 Dimension change

Useful information can often be obtained by measuring the change brought about by wear in a critical dimension. An example is the change in the length of a pin measured by the use of a calibrated micrometer. Calibrated transducers could also be used. Care in the interpretation of this measurement should be taken, as the shape of the specimen might have been altered by the wear process (i.e. rounding of a flat-ended pin).

#### 4.11.3 Wear scar measurements

For balls or spherical-ended pins the size of the wear scar can be measured by optical methods using projection systems, or microscopes. It is important that error in the measurement is not introduced by misalignment of the measurement system. The particular measurement technique that is used must be calibrated at regular intervals.

#### 4.11.4 Profilometric measurements

Surface texture instruments should be used to characterise the texture of the surfaces before and after testing; they can also be used to make measurements of wear volumes (or measurements that can be used to calculate wear volumes).

In the characterisation of surface texture, a major problem is that a large number of parameters can be derived from the measurements, and it is not clear which of these parameters is important from a wear testing point of view. However, a profile of the surface should be recorded, and the calculation of parameters such as the Ra value for specimens enables some indication of surface finish to be supplied fairly readily [12].

In the measurement of wear volume, for small areas of wear such as the wear scars on balls, modern 3D instruments can provide a highly accurate direct measurement. However, if only 2D instruments are available, the volume has to be estimated from the profile trace generated across the scar. Similarly, for wear tracks on the disc, the wear volume has to be estimated from the cross-sectional area of the wear scar at points around the track. It is recommended that for wear scars on balls at least two perpendicular profiles are used for this estimation (one perpendicular, and one parallel to the direction of sliding across diameters of scar) and on the disc four perpendicular traces are used (spaced equally around the disc and aligned parallel and perpendicular to any lay in the texture of the disc, along radii of the disc).

#### 4.11.5 Volume change

The volume change can be estimated from surface texture measurements (see section 3.11.5), from mass loss measurements, and from the dimensions of the wear scars. For mass loss measurements, the wear volume  $V$  is calculated from the relationship

$$V = \frac{M}{\rho}$$

where  $M$  is the mass loss and  $\rho$  is the density. If the wear scar on a ball (or spherically capped pin) is flat, then the wear volume  $V$  for the ball can be calculated from the formula

$$V = \frac{\pi}{3} h^2 (3r - h) \qquad h = r - \left( r^2 - \frac{d^2}{4} \right)^{0.5}$$

or from the approximate formula

$$V = \frac{\pi d^4}{64r}$$

where  $h$  is the depth of wear of the ball,  $r$  is the radius of the ball, and  $d$  is the diameter of the scar. This formula is correct to 1% for  $d < 0.3 r$ .

If no wear of the ball takes place, then the wear volume for the disc can be calculated exactly as

$$V = \pi D \left[ r^2 \sin^{-1} \left( \frac{d}{2r} \right) - \frac{d}{4} (4r^2 - d^2)^{0.5} \right]$$

or from the approximate formula

$$V = \frac{\pi D d^3}{12r}$$

where  $D$  is the wear track diameter,  $d$  is the track width and  $r$  is the pin radius. This formula is correct to 1% for  $d < 0.3r$ .

#### 4.11.6 Friction measurement

Friction measurements are made with a load cell, or instrumented deflection beam, these must be calibrated at regular intervals. The coefficient of friction is then calculated as the ratio of this measured frictional load to the applied normal load. If a normal load cell is also monitoring the instantaneous normal load, analogue or digital dividing may be used to derive a true instantaneous coefficient of friction. Otherwise the average normal applied load should be used in the calculation of coefficient of friction. Consideration should also be given to the mechanical attachment of the friction load cell to both the specimen holder and the machine frame. A common practice is to allow the specimen holder to rest against the measurement point on the friction load cell. Care should be taken to eliminate friction between the specimen holder and the friction load cell; this may alter the nominal load applied between the pin and disc. It should be recognised that this arrangement gives different dynamic characteristics from the situation where the specimen holder is clamped to the machine frame through the friction load cell.

#### 4.11.7 Wear displacement measurement

Wear displacement is normally measured by a transducer which is positioned to record the movement of the pin relative to the starting level of the disc. The output of the transducer is then taken to be equivalent to the wear displacement. This assumes that the unworn level of the rotating disc does not change with time. There is a dependence on the measurement point on the specimen holder.

It is important to minimise the distance of the measurement point on the specimen holder from the wear contact so that artefacts due to thermal drift are minimised. Dual displacement transducers have been developed recently. These eliminate thermal artefacts through differential measurement [13]. Some of the error from thermal sources can also be removed by measuring the displacement-temperature response of the test system and making a correction when the data is analysed [14].

#### 4.11.8 Supplementary measurements

Other measurements may be useful such as monitoring short term fluctuations in the applied and frictional loads, and vibration of the specimen holder.

#### 4.12 Recording of data

A minimum and necessary requirement is to record the variation in frictional load and wear displacement with time; digital data recording systems may be used to record the data, but calibrated analogue pen recorders are entirely satisfactory. It is important to use a high chart speed (or faster data recording rate for digital systems) at the start of a test and at any other point in the test where measured values are likely to change rapidly.

### 5. SPECIMENS

#### 5.1 Overall dimensions

It is not appropriate to prescribe specimen sizes in these guidelines as they are usually defined in relation to the requirements of the programme of study. However, it is important that the disc is sufficiently large so that wear tracks can be obtained which have a large enough diameter so that the difference in linear speed from the inside to the outside edges of the wear track will not result in significant error in results.

.Another important parameter is the overlap ratio which is defined as the ratio of the area on the disc which is in contact with the pin at some stage to the area on the pin which is in contact with the disc all the time [14]. Specimen sizes which have been used in recent interlaboratory exercises are discs 40 mm in diameter, and balls 10 mm in diameter. Pins 6 mm and 10 mm in diameter are also commonly used specimens.

#### 5.2 Specimen manufacture

The discs should be manufactured with flat and parallel faces. The pins or balls should be manufactured with the correct form. The finish on the specimen will be dictated by the programme of testing, but it is clear that the surface finish has a large effect on the friction and wear results that are obtained, with very rough surfaces leading to high wear, at least in the initial stages of a test. Conversely, for very high quality finishes which are very flat and smooth, wringing may occur, leading to abnormally high friction and possible wear. Care must be taken in the preparation of the surfaces of the specimens to avoid sub-surface damage.

#### 5.3 Specimen cleaning

It is essential that the contacting surfaces of the specimens are carefully cleaned to remove as much dirt, grease and other unwanted material from the surface as possible. However, it is not possible to give cleaning procedures which can be applied universally to all materials. Thus for many polymers, the use of some organic solvents can cause unacceptable swelling of the specimens. There are also problems with the use of solvents in the cleaning of porous samples where the solvents may remain trapped in the body of the sample unless considerable care is taken.

Several cleaning procedures are recommended:

- 1 The first was used in recent interlaboratory exercises [4] and consists of washing the specimens in trichlorofluoroethane, drying, washing again in trichlorofluoroethane, and drying in an oven at 120°C for 30 minutes. This procedure has the drawback that trichlorofluoroethane is a CFC, and is therefore environmentally unwelcome.
- 2 This consists of ultrasonic cleaning with acetone or alcohol for 2 minutes, warm air drying, rinsing with hexane, and drying for 30 minutes in an oven at 110°C.
- 3 Wash samples with a mild solution of laboratory glassware cleaner, warm air dry, ultrasonically clean with acetone for 2 minutes, warm air dry, ultrasonically clean with with methanol for 2 minutes, and drying for 30 minutes in an oven at 110°C.
- 4 Wash samples in mild solution of laboratory glassware cleaner, rinse in clean water, wash again in mild solution of laboratory glassware cleaner, rinse in clean water, blow dry in warm air.

The cleaning procedure must be described in detail in the report.

#### 5.4 Material description

The usefulness of the wear testing is increased if the materials under test are well characterised; conversely, if there is little materials information the wear test can never be compared with results of other tests. A minimum description of the material would include the chemical composition, the condition of the material (e.g. the heat-treatment for materials such as steel), the hardness of the material and a micrograph of the surface. Other information which would certainly be useful could be obtained from surface analysis, X-ray diffraction, examination of the microstructure of the material, and surface texture analysis.

If the materials conform to any national or international specifications or standards, this should be stated.

## 6. PROCEDURES

### 6.1 Pre-test specimen examination

Before the specimens are cleaned by one of the procedures listed in section 4.3, any micrographs of the surfaces should be taken, and surface texture measurements made. The specimens should then be cleaned, weighed to determine the initial specimen mass, and stored for the minimum period of time in a clean environment which will not alter the surface state before testing is carried out .

### 6.2 Specimen installation

The specimens should be clamped firmly into position in the test machine, ensuring that the contacting surfaces of the specimens are not touched. The position of the pin should be adjusted to give the correct wear track diameter, and the motor control adjusted to give the required speed at the chosen wear track diameter with the pin well clear of the disc surface. With the disc stationary, the zero of the friction measurement system should then be checked by adjusting the pin holder so that no loading of the friction load cell occurs. The pin should then be slowly lowered into contact with the disc so that the zero of the displacement measurement system can

be defined. The loading system should be adjusted to give the required applied load.

### 6.3 Environmental conditioning

The environmental conditioning system should be started, set at the required conditions, and allowed sufficient time to equilibrate before the test commences. It is recommended that the pin should be lifted clear of the disc and the motor of the test machine started so that the motion of the disc does not affect the environmental conditioning.

### 6.4 Start of test

The data recording equipment should be set appropriately and started, and the motor drive started. When the disc rotation is constant, the pin should be lowered carefully on to the disc to start the test. The rate of application of the load i.e. time from zero to full load should be controlled carefully and recorded so that it can be repeated in future tests. Periodic inspection of the test is recommended to ensure that the recording equipment is performing correctly and that the test is proceeding as expected.

### 6.5 Test termination

Test termination is often determined on the basis of a preset duration or sliding distance. However, another possibility is to continue testing until a preset wear displacement has occurred. This is particularly relevant for tests where low wear rates are expected such that measureable wear only takes place over a long period of time that cannot be predicted easily in advance.

### 6.6 Number of specimens tested

Because friction and wear are processes where some variation in results from test to test is a natural consequence of the statistical nature of the contact between the two surfaces, it is recommended that sufficient tests should be carried out under a single set of test conditions to reach the required confidence in the measurements. The number of test that are needed will depend on the scatter in results that is observed. This recommendation may be relaxed when examining the friction and wear in wear mapping, for example. The scatter from the observed trend of results gives information about the uncertainty in the measurements.

It is recommended that the appropriate standardised analysis methods laid down in the ISO standard on accuracy (trueness and precision) of measurement methods [16] and results should be used in the calculation of uncertainty in friction and wear measurements.

### 6.7 Post-test examination of specimens and debris

After testing, the specimens should be examined and the appearance of the worn surfaces and any debris adhering to the surface noted. Microscopical examination may be useful at this juncture. Any loose debris that was generated in the testing should be carefully collected and stored for later examination. The specimens should be cleaned, weighed to determine the post-test mass, and profilometry and measurement of wear scars carried out to determine the volume of wear that has occurred. The specimens and, if required, any debris, should then be stored in conditions which will not cause any change in the debris for further analytical examination at a later stage.

## 6.8 Analysis of data

The detail of the analysis that will be required will depend on the precise requirements of the testing programme. However, a minimum necessary requirement is the calculation of displacement and friction curves for the test, the calculation of initial, maximum and steady-state coefficient of friction, the calculation of wear volumes for the pin and disc from mass loss measurements and more direct measurement of the size of worn areas.

## 7. REPORTING

### 7.1 Minimum requirements

The minimum requirement for data reporting is as follows:-

A description of the materials for the pins and the disc including chemical composition and hardness (with hardness test load recorded).

A description of the specimen dimensions, surface finish of specimens, and contact geometry.

A description of the test system emphasising loading system, friction measurement system, and displacement measurement system.

A table of test conditions including wear track diameter, applied load, relative speed, humidity, temperature and test duration.

Graphs of the variation of wear displacement and friction with sliding distance.

A table of results including initial, maximum and steady state coefficient of friction, and wear volumes.

### 7.2 Other information

A wide range of other information can also be supplied from other examination techniques such as light and electron microscopy, surface analysis, and XRD [7].

## 8. EXAMPLES OF TESTING

Examples of well controlled pin-on-disc wear testing are summarised from the interlaboratory exercises performed for VAMAS [1], and in the UK [4]. These give some indication of the repeatability and reproducibility that can be achieved with current practice.

### 8.1 VAMAS

31 laboratories in seven countries participated in an interlaboratory exercise on the pin-on-disc wear testing of steel and alumina balls and discs [1]. The test configuration and orientation is shown in Figure 3. The balls were 10 mm in diameter, and the discs 40 mm in diameter and 6 mm thick. The roughness in Ra of the alumina ball was 0.12  $\mu\text{m}$ , the steel ball 0.01  $\mu\text{m}$ , the steel disc 0.113  $\mu\text{m}$  and the alumina disc 0.041  $\mu\text{m}$ . The steel for the balls and discs was AISI 52100 bearing steel with a composition in weight percent of 1.35-1.65 Cr, 0.95-1.1 C, 0.15-0.35 Si, and 0.25 to 0.45 Mn. The steel had a martensitic structure with minor constituents of iron carbides and austenite. The alumina was 95% alumina, with additives of  $\text{TiO}_2$ ,

MgO, and ZnO, and had an equiaxed grain structure. The hardness of the steel was  $840 \pm 20$  HV10 and the hardness of the alumina  $1605 \pm 120$  HV0.2. The test load was 10 N, speed was  $0.1 \text{ m s}^{-1}$  and sliding distance was 1000 m. The results are given in Table 1.

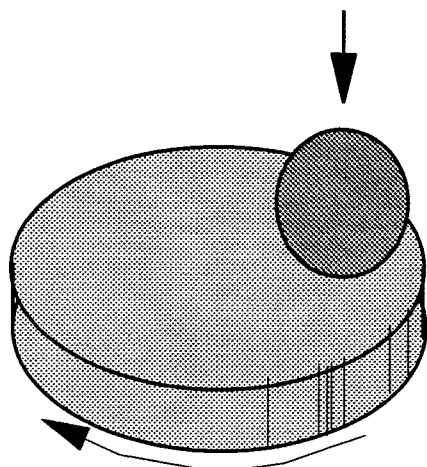


Figure 3, Geometry of VAMAS tests

Table 1, Results of VAMAS interlaboratory exercise [1]. Note figures after  $\pm$  are one standard deviation, and that calculated values are quoted as mean values only. NM is not measured.

| Results                                  | Specimen Pairs (Ball-Disc) |                 |                 |                 |
|------------------------------------------|----------------------------|-----------------|-----------------|-----------------|
|                                          | Steel-Steel                | Alumina-Steel   | Steel-Alumina   | Alumina-Alumina |
| Ball Wear Scar Diameter, mm              | $2.11 \pm 0.27$            | NM              | $2.03 \pm 0.41$ | $0.3 \pm 0.06$  |
| Ball Wear Volume, $10^{-3} \text{ mm}^3$ | 198                        | -               | 186             | 0.08            |
| Number of values                         | 102                        | -               | 60              | 56              |
| Disc Wear Track Width, mm                | NM                         | $0.64 \pm 0.12$ | NM              | NM              |
| Disc Wear Volume, $10^{-3} \text{ mm}^3$ | -                          | 480             | -               | -               |
| Number of Values                         | -                          | 60              | -               | -               |
| Friction Coefficient                     | $0.6 \pm 0.11$             | $0.76 \pm 0.14$ | $0.60 \pm 0.12$ | $0.41 \pm 0.08$ |
| Number of Values                         | 109                        | 75              | 64              | 76              |

## 8.2 UK

Eleven UK laboratories performed dry pin-on-disc wear tests on a 95 % alumina ceramic [4]. The test configuration and orientation is shown in Figure 4. The pins were 30 mm in length with the test surface given a spherical surface with a radius of 5 mm. The discs were 80 mm in diameter and 8 mm thick. Two surface finishes were used, with roughness values of 0.25 and 0.22  $\mu\text{m}$  Ra for the polished pin and polished disc, and roughness values of 0.53 and 0.35  $\mu\text{m}$  Ra for the ground pin and the ground disc. The test load was 40 N, the speed was 0.1  $\text{ms}^{-1}$  and the test duration was 21600 s. The reproducibility and repeatability in results that was found is given in Table 2.

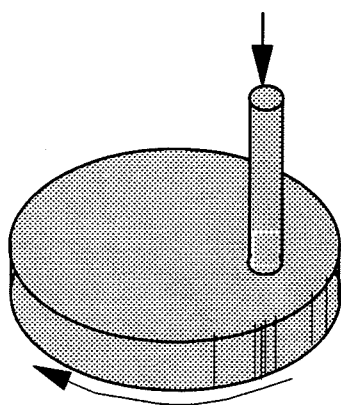


Figure 4, Geometry of UK tests.

Table 2, Reproducibility and Repeatability from UK Interlaboratory exercise on alumina [4]. Figures are quoted as percentages for the relevant standard deviations divided by mean. G and P refer to ground and polished specimens respectively.

| Parameters                  | Type of Specimen | Mean | Number of Values | Repeatability | Reproducibility |
|-----------------------------|------------------|------|------------------|---------------|-----------------|
| Pin Mass Loss, mg           | G                | 0.26 | 33               | 69            | 138             |
|                             | P                | 0.08 | 29               | 125           | 225             |
| Disc Mass Loss, mg          | G                | 0.94 | 28               | 89            | 114             |
|                             | P                | 3.37 | 25               | 3             | 39              |
| Scar Diameter, mm           | G                | 1.39 | 42               | 16            | 16              |
|                             | P                | 1.07 | 38               | 11            | 18              |
| Track Width, mm             | G                | 1.32 | 37               | 11            | 19              |
|                             | P                | 0.96 | 34               | 16            | 18              |
| Displacement, $\mu\text{m}$ | G                | 37.8 | 26               | 44            | 45              |
|                             | P                | 20.9 | 21               | 27            | 49              |
| Final Friction Coefficient  | G                | 0.65 | 41               | 9             | 18              |
|                             | P                | 0.75 | 36               | 45            | 44              |

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