



**International
Standard**

ISO 14577-1

**Metallic materials — Instrumented
indentation test for hardness and
materials parameters —**

**Part 1:
Test method**

*Matériaux métalliques — Essai de pénétration instrumenté pour
la détermination de la dureté et de paramètres des matériaux —*

Partie 1: Méthode d'essai

**Third edition
2026-06**

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 3, *Hardness testing*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 459/SC1, *Test methods for steel (other than chemical analysis)*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 14577-1:2015), which has been technically revised.

The main changes are as follows:

- Better specification of the approach speed of the tip.
- Addition of a loading method with constant strain rate.
- Change of order of hardness definitions: first H_{IT} then HM.
- Better proposals for cleaning the tip.
- Differentiation between contact area under load and in unloaded state.
- Complete reformulation of normative [Annex I](#) for radial displacement correction.

A list of all parts in the ISO 14577 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Hardness has typically been defined as the resistance of a material to permanent penetration by another harder material. The results obtained when performing Rockwell, Vickers, and Brinell tests are determined after the test force has been removed. Therefore, the effect of elastic deformation under the indenter has been ignored.

ISO 14577 (all parts) has been prepared to enable the user to evaluate the indentation of materials by considering both the force and displacement during plastic and elastic deformation. By monitoring the complete cycle of increasing and removal of the test force, hardness values equivalent to traditional hardness values can be determined. More significantly, additional properties of the material, such as its indentation modulus and elasto-plastic hardness, can also be determined. All these values can be calculated without the need to measure the indent optically. Furthermore, by a variety of techniques, the instrumented indentation test allows to record hardness and modulus depth profiles within a, probably complex, indentation cycle.

Although the indentation modulus (E_{IT}) value obtained in this test method is not directly equivalent to Young's modulus or the orientation specific elastic modulus of the material indented, E_{IT} is, however, equivalent to the isotropic Hill average of the elastic plane strain modulus of the material when there is no pile up and no residual stress.

ISO 14577 (all parts) has been written to allow a wide variety of post-test data analysis.

Part 1 of ISO 14577 specifies the method of indentation test for determination of instrumented indentation hardness and material properties.

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Metallic materials — Instrumented indentation test for hardness and materials parameters —

Part 1: Test method

1 Scope

This document specifies the method of instrumented indentation test for determination of hardness and other materials parameters for the following three ranges:

- macro range: $2\text{ N} \leq F \leq 30\text{ kN}$;
- micro range: $2\text{ N} > F$; $h > 0,2\text{ }\mu\text{m}$;
- nano range: $h \leq 0,2\text{ }\mu\text{m}$.

For the nano range, the mechanical deformation strongly depends on the real shape of indenter tip and the calculated material parameters are significantly influenced by the contact area function of the indenter used in the testing machine. Therefore, careful calibration of both instrument and indenter shape is required in order to achieve an acceptable reproducibility of the materials parameters determined with different machines.

The macro and micro ranges are distinguished by the test forces in relation to the indentation depth.

Attention is drawn to the fact that the micro range has an upper limit given by the test force (2 N) and a lower limit given by the indentation depth of 0,2 μm .

The determination of hardness and other material parameters is given in the normative [Annex A](#).

At high contact pressures, damage to the indenter is possible. For test pieces with very high hardness and modulus of elasticity, permanent indenter deformation can occur and can be detected using suitable reference materials. Indentations that result in damage or permanent deformation of the indenter are excluded from the scope of this test method.

This test method can also be applied to thin metallic and non-metallic coatings and non-metallic materials. In this case, it is recommended that the specifications in the relevant standards be taken into account (see also [7.3](#) and ISO 14577-4).

The analysis methods of this standard assume that materials behave like ideal materials. Any deviation (internal stress, pile-up, sink-in, densification, phase transitions, cracks) will result in additional uncertainties. This becomes especially important if comparisons shall be done to material parameters, obtained with other methods.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 14577-2:2026, *Metallic materials — Instrumented indentation test for hardness and materials parameters — Part 2: Verification and calibration of testing machines*

3 Terms and definitions

No terms and definitions are listed in this document.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <https://www.electropedia.org/>

4 Symbols and designations

For the purposes of this document, the symbols and designations in [Table 1](#) shall be applied (see also [Figure 1](#) and [Figure 2](#)).

Table 1 — Symbols and designations

Symbol	Designation	Unit
$A_p(h_c)$	Projected area of contact under load of the indenter at distance h_c from the tip	mm ²
$A_{p,UL}(h_c)$	Projected area of contact in unloaded state of the indenter at distance h_c from the tip	mm ²
$A_s(h)$	Surface area of the indenter at distance h from the tip in unloaded state	mm ²
C_{IT}	Indentation creep	%
C_T	Total measured compliance of the contact (dh/dF tangent to the force removal curve at maximum test force)	nm/mN
C_F	Machine compliance	nm/mN
C_S	Compliance of the contact after correction for machine compliance	nm/mN
E_{IT}	Indentation modulus of the test piece	GPa
E_r	Reduced plane strain modulus of the contact (combination of test piece and indenter plane strain moduli)	GPa
F	Test force	N
F_{max}	Maximum test force	N
h	Indentation depth under applied test force	mm
h_c	Contact depth of the indenter with the test piece at F_{max}	mm
h_{max}	Maximum indentation depth at F_{max}	mm
h_p	Permanent indentation depth after removal of the test force	mm
h_r	Point of intersection of the tangent c to curve b at F_{max} with the indentation depth-axis as identified on Figure 1	mm
H_{IT}	Indentation hardness	GPa
HM	Martens hardness	GPa
HM _s	Martens hardness, determined from the slope of the increasing force/indentation depth curve	GPa
HM _{diff}	Martens hardness, determined from the first derivative of h vs \sqrt{F}	GPa
ν_s	Poisson's ratio of the test piece	
r	Radius of spherical indenter	mm
R_{IT}	Indentation relaxation	%

NOTE 1 To avoid very long numbers, the use of multiples or sub-multiples of the units can be used.

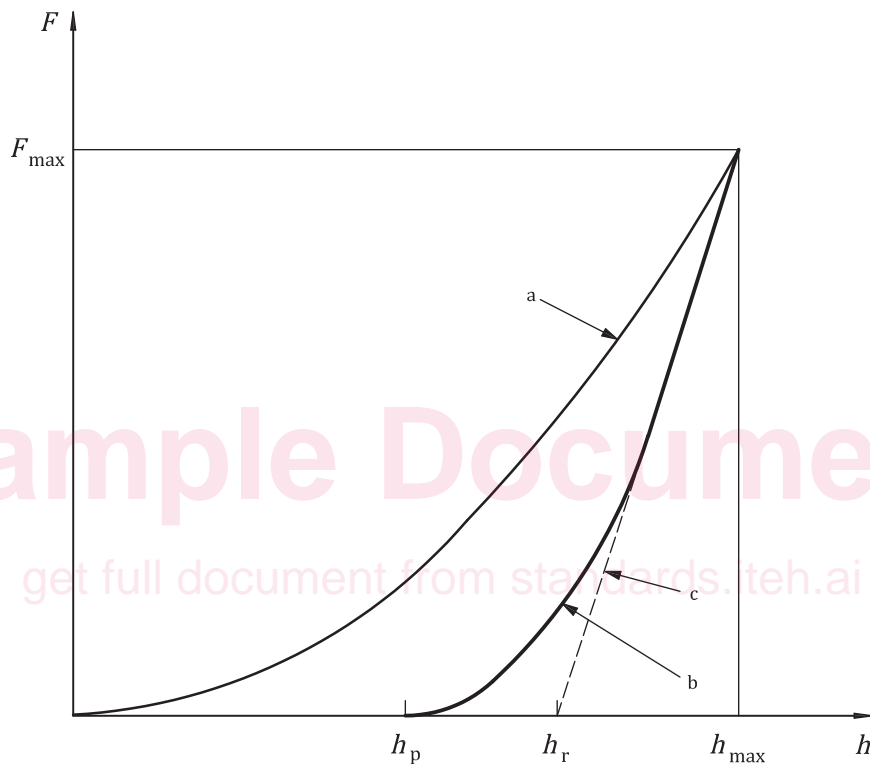
NOTE 2 The continued use of the unit N/mm² is allowed. 1 MPa = 1 N/mm².

Table 1 (continued)

Symbol	Designation	Unit
W_{elast}	Elastic reverse deformation work of indentation	N·m
W_{total}	Total mechanical work of indentation	N·m
α	Cone semi-angle or angle of facet to the indentation axis for pyramidal indenters	°
θ	Maximum angle between the contact surface and the indenter for calculation of radial displacement	°
η_{IT}	Ratio $W_{\text{elast}}/W_{\text{total}}$	%

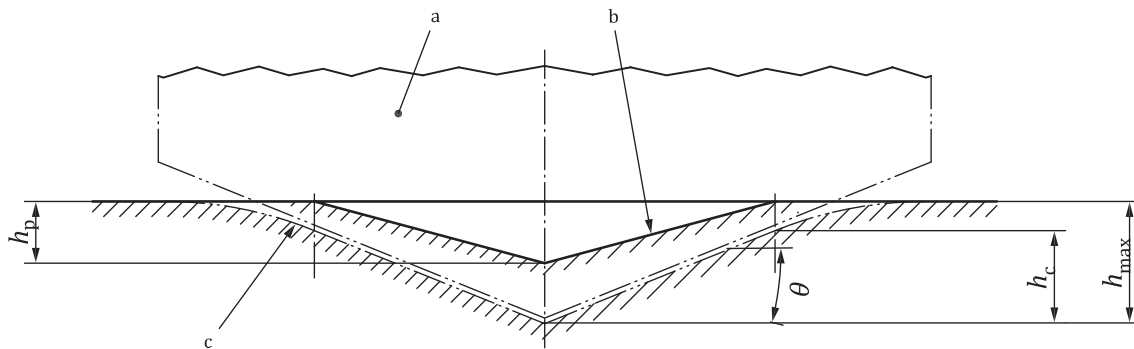
NOTE 1 To avoid very long numbers, the use of multiples or sub-multiples of the units can be used.

NOTE 2 The continued use of the unit N/mm² is allowed. 1 MPa = 1 N/mm².



- a Application of the test force.
- b Removal of the test force.
- c Tangent to curve b at F_{max} .

Figure 1 — Schematic representation of the test procedure

**Key**

- a Indenter.
- b Surface of residual plastic indentation in a test piece that has a “perfectly plastic” response.
- c Surface of test piece at maximum indentation depth and test force.
- θ maximum angle between the test piece surface and the indenter

Figure 2 — Schematic representation of the cross section of indentation in the case of material “sink-in”

5 Principle

Continuous recording of the force and the depth of indentation permits the determination of hardness and material properties (see [Figure 1](#) and [Figure 2](#)). The measured values of hardness and other material parameters shall be determined in accordance with [Annex A](#). An indenter consisting of a material harder than the material under test shall be used (i.e. the indenter shall not permanently deform and shall not be damaged as a result of indentation). For hardness testing the following shapes and materials can be used:

- a) indenter shaped as an orthogonal pyramid with a square base and with an angle $\alpha = 68^\circ$ between the axis of the diamond pyramid and one of the faces (Vickers pyramid; see [Figure A.1](#));
- b) pyramid with triangular base (e.g. modified Berkovich pyramid with an angle $\alpha = 65,27^\circ$ between the axis of the diamond pyramid and one of the faces; see [Figure A.1](#));
- c) ball indenter (especially for the determination of the elastic behaviour of materials);
- d) spherical tipped conical indenter.

This document does not preclude the use of other indenter geometries; however, care should be taken when interpreting the results obtained with such indenters. Diamond is the preferred material but other materials like sapphire may also be used for example to avoid chemical reaction between the indenter and the test piece, provided the above mechanical requirements of the indenter are met.

For indentation modulus testing, the indenter geometries for hardness testing are strongly recommended but, in principle, any geometry indenter may be used provided that the area function is known and the area function is monotonically increasing with indentation depth.

NOTE Due to the crystal structure of diamond, indenters that are intended to be spherical are often polyhedrons and do not have an ideal spherical shape.

The test procedure can either be force-controlled or displacement-controlled. The test force, F , the corresponding indentation depth, h , and time are recorded during the whole test procedure. The result of the test is the data set of the test force and the relevant indentation depths as a function of time (see [Figure 1](#) and [Annex B](#)).

For a reproducible determination of the force and corresponding indentation depth, the zero point for the force/indentation depth measurement shall be assigned individually for each test (see [7.3](#)).

Where time-dependent effects are being measured

- using the force-controlled method, the test force is kept constant over a specified period and the change of the indentation depth is measured as a function of the holding time of the test force (see [Figures A.3](#) and [B.1](#)), and
- using the indentation depth-controlled method, the indentation depth is kept constant over a specified period and the change of the test force is measured as a function of the holding time of the indentation depth (see [Figures A.4](#) and [B.2](#)).

The two kinds of control mentioned give essentially different results in the segment b of the curves in [Figure B.1 a\)](#) and [Figure B.2 b\)](#) or in [Figure B.1 b\)](#) and [Figure B.2 a\)](#).

6 Testing machine

6.1 The testing machine shall have the capability of applying predetermined test forces or displacements within the required scope and shall fulfil the requirements of ISO 14577-2.

6.2 The testing machine shall have the capability of measuring and reporting applied force, indentation displacement and time throughout the testing cycle.

6.3 The testing machine shall have the capability of compensating for the machine compliance and of utilizing the appropriate indenter area function according to [Annex C](#) and ISO 14577-2:2026, 5.5 and 5.6.

6.4 Indenters for use with testing machines can have various shapes, as specified in ISO 14577-2 (for further information on indenters, see [Annex D](#)).

6.5 The testing machine shall operate at a temperature within the permissible range specified in [7.1](#) and shall maintain its calibration within the limits specified in ISO 14577-2:2026, Clause 5.

7 Test piece

7.1 The test shall be carried out on a region of the test surface that allows the determination of the force/indentation depth curve for the respective indentation range within the required uncertainty. The contact area shall be free of fluids or lubricants except where this is essential for the performance of the test, in which case, this shall be described in detail in the test report. Care shall be taken that extraneous matter (e.g. dust particles) is not incorporated into the contact.

Generally, provided the surface is free from obvious surface contamination, cleaning procedures should be avoided. If cleaning is required, it shall be limited to the following methods to minimize damage:

- application of a dry, oil-free, filtered gas stream;
- application of a subliming particle stream of CO₂ (but keeping the surface temperature above the dew point);
- rinsing with a solvent (which is chemically inert to the test piece) and then setting it to dry.

If these methods fail and the surface is sufficiently robust, wipe the surface with a lint-free tissue soaked in solvent to remove trapped dust particles, after which, the surface shall be rinsed in a solvent as above.

Ultrasonic methods are known to create or increase damage to surfaces and coatings and should only be used with caution.

Surface finish has a significant influence on the test results that depends upon the relative size of the indentation depth, h , with respect to the arithmetic mean deviation roughness, R_a . The relative size of these parameters shall conform to the limits given in [Annex E](#).

The test piece surface shall be normal to the test force direction. The angle difference between test surface normal and indenter axis shall be less than 1°. The effect of surface tilt should be included in the uncertainty calculation.

The sample should be free from magnetism. Test pieces capable of becoming magnetised should be checked for magnetism and demagnetised before testing, if possible. Precautions should be taken to avoid the effect of magnetism on the measuring system.

7.2 If necessary, preparation of the test surface shall be carried out in such a way that any alteration of the surface hardness and/or surface residual stress (e.g. due to heat or cold-working) is minimized.

Due to the small indentation depths in the micro and nano range, special precautions shall be taken during the test piece preparation. When polishing is needed, a polishing process that is suitable for the particular materials shall be used.

Electropolishing is a recommended preparation method that can remove a work hardened surface layer. However, care should be taken that the surface roughness does not exceed the limits given in this standard.

7.3 The test piece thickness shall be large enough (or indentation depth small enough) such that the test result is not influenced by the test piece support. For hardness and modulus measurements, the test piece thickness shall be at least 10 times the indentation depth or 3 times the indentation diameter (see 8.7), whichever is greater. For modulus measurements a sample thickness larger than 30 times the indentation depth is recommended. For measurements of thinner samples, it is recommended to follow the analysis described in ISO 14577-4 for coatings.

When testing coatings, the coating thickness should be considered as the test piece thickness. For testing thin samples or coatings, see ISO 14577-4 for better testing procedures.

NOTE The above are empirically based limits based on hardness testing. The effect of test piece thickness on the elastic modulus result is not the same as the effect on the hardness result. The exact limits of influence of support on test piece depend on the geometry of the indenter used and the materials properties of the test piece and support.

8 Procedure

8.1 The temperature of the test shall be recorded. Tests shall be performed within ± 10 °C of the temperature of the instrument calibration.

The temperature stability during a test is more important than the actual test temperature. Any calibration correction applied shall be reported along with the additional calibration uncertainty. It is recommended that tests, particularly in the nano and micro ranges, be performed in controlled conditions, in the range (23 ± 5) °C and (45 ± 10) % relative humidity.

The individual tests, however, shall be carried out at stable temperature conditions because of the requirement of high depth measuring accuracy. This means that:

- the test pieces shall have reached the ambient temperature before testing,
- the testing machine shall have reached a stable working temperature (operating manual should be consulted),
- the ambient, instrument, and test temperature shall be within the range for which the machine calibration is valid, and
- other external influences causing temperature changes during individual test have been controlled.

To minimize thermally induced displacement drift, the temperature of the testing machine shall be adequately maintained over the time period of one testing cycle, or a displacement drift shall be measured and corrected. A decision tree to assist in estimating the drift during the experiment is shown in [Figure 3](#). If the drift rate is significant, the displacement data shall be corrected by measuring the drift rate during a hold at an applied force as close to zero force as is practicable or during a hold at a suitable place in the

force removal curve in accordance with [Annex G](#) and ISO 14577-2:2026, 5.3.3). In all cases where the drift rate would influence the maximum indentation depth by more than 1 % within the total indentation cycle time, the drift rate shall be corrected (see tolerances in ISO 14577-2:2026, Table 2 and 5.3.3). If a contact in the fully elastic regime can be obtained, a hold at initial contact is preferred. In this way, material influences (creep, visco-plasticity, cracking) can be minimized. When the measurement is significantly longer than the hold period for thermal drift measurement it is recommended to measure the thermal drift before and after the experiment and to correct the displacement using the average of the two drift rates. The difference between the two drift rates is an estimate of the drift rate uncertainty. The uncertainty due to the drift, or in the drift correction used, shall be reported.

To determine the drift of surface referenced instruments, contact between the reference indenter and the sample surface shall be elastic. This may be determined by calculation.

NOTE The significance of a particular drift rate upon the measurement depends upon the range of the indentation and the type of application.

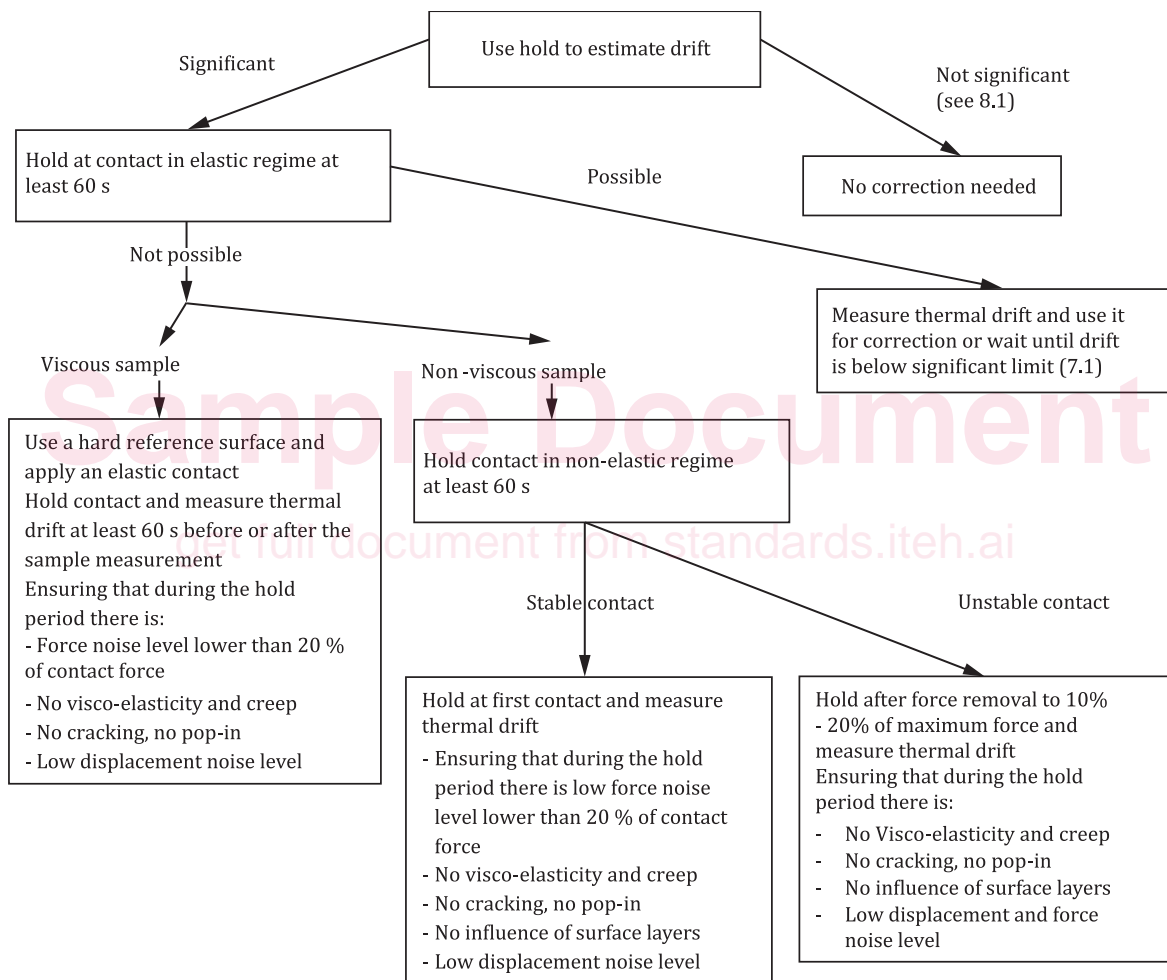


Figure 3 — Decision tree to assist in estimating thermal drift using a constant force hold period

8.2 The test piece shall be firmly supported such that there is no significant change in the testing machine compliance. The test piece shall either be placed on a support that is rigid in the direction of indentation or be fixed in a suitable test piece holder. The contact surfaces between test piece support and test piece holder shall be free from extraneous matter, which can increase the compliance (reduce the stiffness) of the test piece support.

If the sample is supported by materials or mounting methods other than those used when determining the machine compliance, then the different elastic response of these materials and mounting methods can cause additional compliance. A certified reference material, mounted in the same way as the sample, should be

used to check if the mounting method affects the frame compliance. A mounting problem is indicated if the measured modulus differs from the certified value and changes with the applied force.

8.3 The zero point for the measurement of the force/indentation depth curve shall be assigned individually to each test data set by one of the following methods. It represents the first touch of the indenter with the test piece surface. The uncertainty in the zero-point shall be reported. The uncertainty in the assigned zero point should not exceed 1 % of maximum indentation depth for the macro and micro ranges. The zero point uncertainty for the nano range can exceed 1 %, in which case the value shall be estimated.

a) Method 1: The zero-point is calculated by extrapolation of a fitted function to the force-application curve (see curve a in [Figure 1](#)); a power law fit with the exponent as a fitting parameter constrained to be $1 \leq m \leq 2$ is recommended. The fit shall be applied to values within the range from the first recorded data point to not more than 5 % of the maximum indentation depth. The fitted data shall not contain a change in indentation response such as the onset of plastic yielding. It is recommended that data are recorded during approach (before contact) so that they can be used for zero point determination. The uncertainty of the calculated zero point results from the fit parameters, the fitting function and the length of extrapolation. The uncertainty is calculated as the standard error of the intercept of the fit function at zero force with the depth axes.

NOTE 1 The first part of the indentation curve can be affected by vibration or other noise.

b) Method 2: The zero-point is the touch point determined from the first increase of either the test force or the contact stiffness. At this touch point, the step size in force or displacement shall be small enough such that the zero point uncertainty is less than the limit required.

NOTE 2 Typical small force steps values for the macro range are $10^{-4} F_{\max}$ and for the micro and nano range less than 5 μN .

8.4 The testing cycle can be either force-controlled or displacement-controlled. The controlled parameters can vary either continuously or step by step. A full description of all parts of the testing cycle shall be stated in the report, including the following:

- a) nature of the control (i.e. force or displacement control and whether a stepped or continuous change in the controlled parameters);
- b) maximum force (or displacement);
- c) force application (or displacement) function;
- d) length and position of each hold period;
- e) data logging frequency (or number of data points).

NOTE An example cycle for nano and micro ranges is the following: force application time, 30 s; hold at F_{\max} , 30 s; force removal 10 s. A 60 s hold period to measure thermal drift can also be required (see [Annex G](#)).

The time taken for a test can influence the results obtained. In order to obtain comparable test results the time taken for the test shall be recorded and reported.

8.5 The test force shall be applied, without shock or vibration that can significantly affect the test results, until either the applied test force or the indentation displacement attains the specified value. Force and displacement shall be recorded at the time intervals stated in the report.

During the determination of the touch point of the indenter with the test piece, the approach speed of the indenter shall be sufficiently low in order that the mechanical properties of the surface are not changed by the impact. For macro range indentations, it should not exceed 2 $\mu\text{m/s}$. The approach speed immediately before contact divided by the acquisition rate of the displacement signal should not be larger than 1 nm in the nano and 5 nm in the micro range. It is recommended that the approach speed and the acquisition rate is recorded and reported.

Force/indentation depth/time data sets are directly comparable only if the same indenter and test cycle (profile) is used. The test profile shall be specified in terms of either applied test force or indentation displacement as a function of time. The three most common single cycles are:

- a) constant applied test force rate
- b) constant indentation displacement rate.
- c) constant strain rate.

More complex multi cycle procedures like load-partial unload cycles may also be used to get information at different test forces in one measurement position.

Using more complex multi cycle procedures, like load-partial unload cycles in an indentation that increases incrementally in force to obtain many unloading curves referenced to the same zero point, it is possible to get information about contact compliance at different test forces at a single test site.

The rate of applied test force removal is subject to the requirements that: a sufficient number of data points for any subsequent analysis are recorded during applied test force removal, and that the total creep and any residual creep rate is within acceptable limits (see [Annex G](#)).

If the drift rate is significant (see [8.1](#) and [Annex G](#)), the depth data shall be corrected by use of the measured drift rate.

8.6 Throughout the test, the testing machine shall be protected from shock and vibration, air movements and variations in temperature, which can significantly influence the test result.

8.7 It is important that the test results are not affected by the presence of an interface, free surface or by any plastic deformation introduced by a previous indentation in a series. The effect of any of these depends on the indenter geometry and the materials properties of the test piece. Indentations shall be at least three times their indentation diameter away from interfaces or free surfaces and the minimum distance between indentations shall be at least five times the largest indentation diameter. For modulus measurements a distance from the sample edge of at least 20 times the indentation diameter is recommended.

The indentation diameter is the in-plane diameter at the surface of the test piece of the circular impression of an indent created by a spherical indenter. For non-circular impressions, the indentation diameter is the diameter of the smallest circle capable of enclosing the indentation. Occasional cracking can occur at the corners of the indentation. When this occurs, the indentation diameter should enclose the crack.

The minimum distances specified between indentations or between an indentation and the edge of the sample are best applicable to ceramic materials and metals such as iron and its alloys. For softer or very brittle materials, it is recommended that separations of at least 10 indentation diameters be used.

If in doubt, it is recommended that the values from the first indentation are compared with those from subsequent indentations in a series. If there is a significant difference in a nominally homogeneous sample, the indentations might be too close and the distance should be increased. A factor of two increases in separation is suggested.

It can be desirable to measure thin coatings in cross-section (e.g. to avoid problems due to surface roughness). In this case, there might not be enough coating thickness to meet the minimum spacing requirements as specified above. Smaller spacing can be used if there is experimental evidence that this does not significantly influence the force/indentation depth/time data sets with respect to correctly spaced indentations on similar test pieces with thicker coatings.

9 Uncertainty of the results

A complete evaluation of the uncertainty shall be carried out in accordance with ISO/IEC Guide 98-3. A detailed description of the method of evaluation of uncertainty is given in [Annex H](#).