Hardness Testing

Introduction

Hardness is the resistance of a material to plastic deformation. It is measured with the depth or area of indentation. The smaller the indentation the higher is the hardness. Hardness is a mechanical property, which can be dramatically changed by processing and heat treatment. It can correlate with tensile strength, in the case of many metals, and can be an indicator of wear resistance and ductility.

Numerous hardness tests exist, some of which are for special purposes only. In specifying a hardness value, it is necessary not only to give the numerical value but also to indicate the scale or type of test used. Hardness testing abbreviations start with H (“hardness”) followed by additional letters and numbers indicating the specific type of test.

How hardness is measured

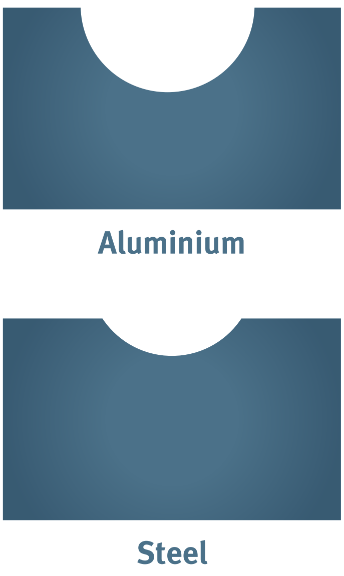


Figure 1: Comparison of hardness testing indentations on aluminium (above) and on steel (below)

Testing is made by pressing or indenting one material into another with a known amount of mechanical force. Since the ability of the material to resist deformation is related to the yield point and the material’s capacity for work-hardening, the result is actually a measurement of relative hardness.

Indenters are produced from the hardest materials available, such as diamond, and the deformation is limited to the testing material. The shape of indenters is defined by the respective standard of hardness testing and can be very different, depending on whether the indenter is a cone, pyramid or sphere. At the point of contact between the indenter and tested material, the stress easily exceeds the yield strength of the tested material, which is plastically deformed as the indenter moves into the material. All hardness tests are based on the same principle.

Applying the same test load to stainless steel and aluminium, the indentation in stainless steel is smaller. This means that stainless steel’s hardness reading will be higher.

There are a number of tests available for hardness testing, all standardised by different standardisation organisations (ISO, EN, ASTM). The applicable standards are listed below.

Vickers hardness test

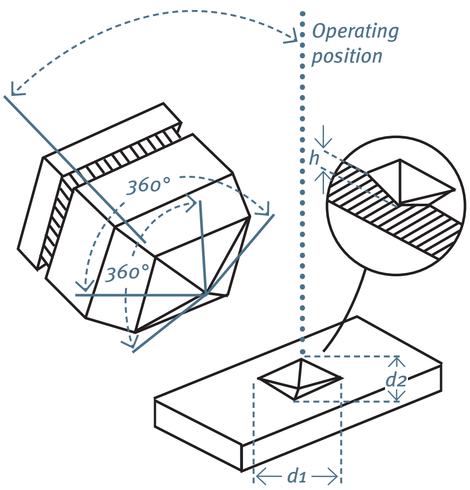
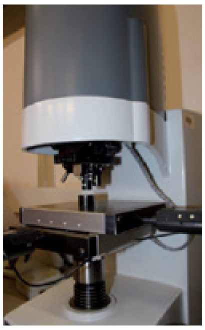


Figure 2: Vickers hardness test. Schematic view of the square-based diamond pyramidal indenter used for the Vickers test (Source: ASM Handbook, Mechanical Testing and Evaluation, Volume 8, 2000)



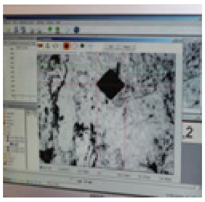


Figure 3: Vickers hardness test. Measuring Vickers indents

The Vickers hardness test indenter is a diamond pyramid with an inclination of 136°. Three different ranges of test force are used:

Ranges of test force, *F* N	Hardness symbol	Designation
F ≥ 49.03	≥ HV5	Vickers hardness test
1.961 ≤ F < 49.03	HV0.2 to < HV5	Low-force Vickers hardness test
0.09807 ≤ F < 1.961	HV0.01 to < HV0.2	Vickers micro-hardness test

The load is normally applied for 10–15 seconds and then removed. The diagonals are measured with a microscope or measuring device capable of determining the length of the indentation diagonals. For homogenous materials, these are equal in size. The tester then looks up the measured diagonal length in tables that give the corresponding Vickers hardness number. The Vickers hardness test is specified in ISO 6507 for length of indentation diagonals between 0.020 mm and 1.400 mm. The Vickers hardness number is given as a number related to the applied force and the surface area of the measured indentation made by a pyramid-shaped indenter. It can be calculated from the indentation load and mean diagonal of indentation.

In laboratory practice, simple tables are usually used. The latest computer-based programmes provide direct readings of results.

The results are expressed in the format shown in the example below:
640 HV 30/20
which has to be interpreted as follows:
640 ..... *Vickers hardness value*
HV .... *hardness symbol*
30 .... *approximate kgf equivalent value of applied force where (30 kgf = 294.2 N)*
20 .... *duration time of test force (20 s) if not within the specified range (10 s to 15 s)*

Vickers hardness testing is universal. It is often used for very hard steels, for small or thin samples and for hardness measurements of hard layers such as nitrided parts. There are two distinct types of test: macroindentation and microindentation. The principle used is similar, the difference being largely in the test forces, which are much smaller in the latter than in the former. A microindentation hardness test can be used for testing materials which are too thin or small for macroindentation testing. It also allows specific phases or constituents of microstructure to be evaluated.

Standards

EN ISO 6507-1	Metallic materials – Vickers hardness test – Part 1: Test method
EN ISO 6507-2	Metallic materials – Vickers hardness test – Part 2: Verification of testing machines
EN ISO 6507-3	Metallic materials – Vickers hardness test – Part 3: Calibration of reference blocks
EN ISO 6507-4	Metallic materials – Vickers hardness test – Part 4: Tables and hardness values
ASTM E 384	Standard Test Method for Knoop and Vickers Hardness of Materials

Brinell hardness test

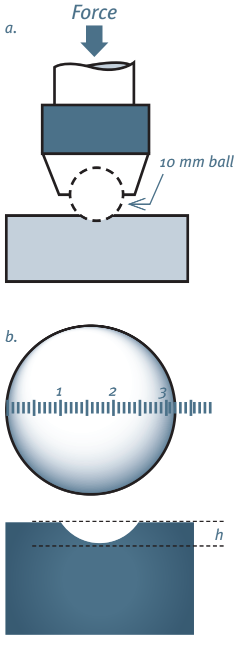


Figure 4: Brinell indentation process. a) Schematic of the principle of the Brinell indentation process, b) Brinell indentation with measuring scale in millimetres (Source: ASM Handbook, Mechanical Testing and Evaluation, Volume 8, 2000)

The Brinell test is a simple indentation test involving a spherical indenter. It can serve to determine the hardness of a wide range of materials. Hardness is determined as a Brinell hardness number (BH, BHN or HB). Different test forces are used for different testing conditions (30 N/mm², 15 N/mm², 10 N/mm², 5 N/mm², 2.5 N/mm², 1 N/mm²). The standard force-diameter ratio for steel is 30 N/mm² and the time the load applied is limited to 10–15 seconds. This is length of time necessary to ensure that the plastic deformation of the material is finished. With the latest testing equipment, the time is set automatically. The recovered indentation is measured in millimetres. The size of the tungsten carbide indenter can be 1 mm, 2.5 mm, 5 mm or 10 mm. Indenter size and test load are based on sample thickness and material hardness. Testing is done on the flat surface of a workpiece, which should be large enough to accommodate a relatively large indentation. After removal of the load, the diameter of the round indentation is measured in millimetres under the microscope.

The Brinell hardness number is load divided by the curved surface area of the indentation. The units are kilograms per square millimetre, but results are usually given without units and only the numerical value is provided. Brinell hardness numbers are available in tabular form for various combinations of loads and indenter sizes.

The results are expressed in the following format:
600 HBW 1/30/20
which contains the following information:

600 .... Brinell hardness value
HB .... Hardness symbol
W .... indication of indenter type; tungsten carbide[1]
1 .... ball diameter in mm
30 .... approximate kgf equivalent value of applied test force where 30 kgf = 294.2 N
20 .... duration of test force (20 s) if not within the specified range (10 s to 15 s)

The Brinell hardness number is approximately proportional to tensile strength. It has been found that the tensile strength for steels is:

R_m (MPa) = 3.55 · HB (HB ≤ 175)
R_m (MPa) = 3.38 · HB (HB > 175)

Standards

EN ISO 6506-1	Metallic materials – Brinell hardness test – Part 1: Test method
EN ISO 6506-2	Metallic materials – Brinell hardness test – Part 2: Verification and calibration of Brinell hardness testing machines
EN ISO 6506-3	Metallic materials – Brinell hardness test – Part 3: Calibration of reference blocks
EN ISO 6506-4	Metallic materials – Brinell hardness test – Part 4: Table of hardness values
ASTM E 10	Standard test method for Brinell hardness of metallic materials

Rockwell hardness test

Rockwell hardness numbers are based on the difference of indenter depths from two load applications. Initially, a minor load is applied, which serves as a starting position. Then a major load is applied

[1] from German "Wolfram"

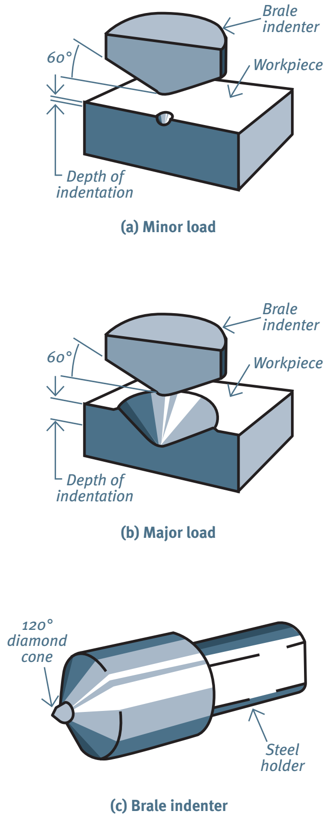


Figure 5: Indentations in a workpiece made by application of minor load (a) and major load (b) from a diamond Brale indenter in Rockwell hardness testing. (c) (Source: Chandler, H., Metallurgy for the Non-Metallurgist, ASM Handbook, 1998)

for a certain period of time, which increases the penetration depth. After a specified dwell time for the major load, the major load is removed, but the minor load is still maintained. The difference in depth is the Rockwell hardness number. The initial application of the minor load increases the accuracy of the testing, since it eliminates the effect of surface layers, which may not be representative of the bulk material.

Rockwell hardness values are expressed as a combination of hardness number and a scale symbol representing the indenter and the minor and major test force. The Rockwell hardness is expressed by the symbol HR and the scale designation. With the combination of three different indenters and three different loads there are nine scales available for testing (HRA, HRB, HRC, HRD, HRE, HRF, HRG, HRH and HRK). In addition to these testing methods there are also superficial hardness testing methods used for thin or fragile samples.

The majority of applications for testing steel are covered by the Rockwell C and B scales. For example, a diamond cone indenter is used for Rockwell scale C (HRC scale values 20–90) and a ball indenter for scale B (HRB, scale values 20–100). Indenter, indenter size and test force are selected according to the type of material, sample thickness, test location and scale limitations.

Rockwell hardness testing has several advantages over other testing methods:

- Very different materials can be tested with the same testing method, for comparison.
- The HRB scale is used for softened steel.
- HRC measurements are preferred methods for hard steels.
- The procedure is fast, the entire testing taking only 5–10 seconds.
- Hardness results are directly read on the measuring device.

An example of a test result is shown as:
70 HR 30T W
which means:
70 .... Rockwell hardness value
HR .... Rockwell hardness symbol
30T .... Rockwell scale symbol
W .... indication of type of ball used, S = steel, W = tungsten carbide

Standards

EN ISO 6508-1	Metallic materials – Rockwell hardness test – Part 1: Test method (scales A, B, C, D, E, F, G, H, K, N, T)
EN ISO 6508-2	Metallic materials – Rockwell hardness test – Part 2: Verification and calibration of testing machines (scales A, B, C, D, E, F, G, H, K, N, T)
EN ISO 6508-3	Metallic materials – Rockwell hardness test – Part 3: Calibration of reference blocks (scales A, B, C, D, E, F, G, H, K, N, T)
ASTM E 18	Standard test methods for Rockwell hardness of metallic materials

General

ISO/TR 10108	Steel – Conversion of hardness values to tensile strength values
ISO 18265	Metallic materials – Conversion of hardness values
ISO 14577-1	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 1: Test method
ISO 14577-2	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 2: Verification and calibration of testing machines
ISO 14577-3	Metallic materials – Instrumented indentation test for hardness and materials parameters – Part 3: Calibration of reference blocks
ASTM E 140	Standard hardness conversion tables for metals relationship among Brinell hardness, Vickers hardness, Rockwell hardness, superficial hardness, Knoop hardness, Scleroscope hardness and Leeb hardness

Conversion tables

An approximate comparison between different hardness testing methods is available from the British Stainless Steel Association article "Hardness test methods and hardness conversion tables" (http://www.bssa.org.uk/topics.php?article=97)