HARDNESS TEST

What is Hardness?

Hardness is the property of a material that enables it to resist plastic deformation, usually by penetration. However, the term hardness may also refer to resistance to bending, scratching, abrasion or cutting.

Measurement of Hardness:

Hardness is not an intrinsic material property dictated by precise definitions in terms of fundamental units of mass, length and time. A hardness property value is the result of a defined measurement procedure.

Hardness of materials has probably long been assessed by resistance to scratching or cutting. An example would be material B scratches material C, but not material A. Alternatively, material A scratches material B slightly and scratches material C heavily. Relative hardness of minerals can be assessed by reference to the Moh's Scale that ranks the ability of materials to resist scratching by another material. Similar methods of relative hardness assessment are still commonly used today. An example is the file test where a file tempered to a desired hardness is rubbed on the test material surface. If the file slides without biting or marking the surface, the test material would be considered harder than the file. If the file bites or marks the surface, the test material would be considered softer than the file.

The above relative hardness tests are limited in practical use and do not provide accurate numeric data or scales particularly for modern day metals and materials. The usual method to achieve a hardness value is to measure the depth or area of an indentation left by an indenter of a specific shape, with a specific force applied for a specific time. There are three principal standard test methods for expressing the relationship between hardness and the size of the impression, these being Brinell, Vickers, and Rockwell. For practical and calibration reasons, each of these methods is divided into a range of scales, defined by a combination of applied load and indenter geometry.

Hardness Test Methods:

Rockwell Hardness Test

Rockwell Superficial Hardness Test

Brinell Hardness Test

Vickers Hardness Test

Microhardness Test

Moh's Hardness Test

Scleroscope and other hardness test methods

Hardness Conversion or Equivalents:

Hardness conversion between different methods and scales cannot be made mathematically exact for a wide range of materials. Different loads, different shape of indeters, homogeneity of specimen, cold working properties and elastic properties all complicate the problem. All tables and charts should be considered as giving approximate equivalents, particularly when converting to a method or scale which is not physically possible for the particular test material and thus cannot be verified. An example would be converting HV/10 or HR-15N value on a thin coating to the HRC equivalent.

Hardness Conversion Tables and Charts:

Hardness Conversion Table (colour version - may take time to load)

Hardness Conversion Table (non-colour version)

Hardness Conversion Chart (1)

Hardness Conversion Chart (2)

Chart of Brinell, Vickers and Ultimate Tensile Strength Equivalents (1)

Chart of Brinell, Vickers and Ultimate Tensile Strength Equivalents (2)

Hardness Conversion Table related to Rockwell C Hardness Scale (hard materials)
(colour)

Hardness Conversion Table related to Rockwell C Hardness Scale (hard materials)
(non-colour)

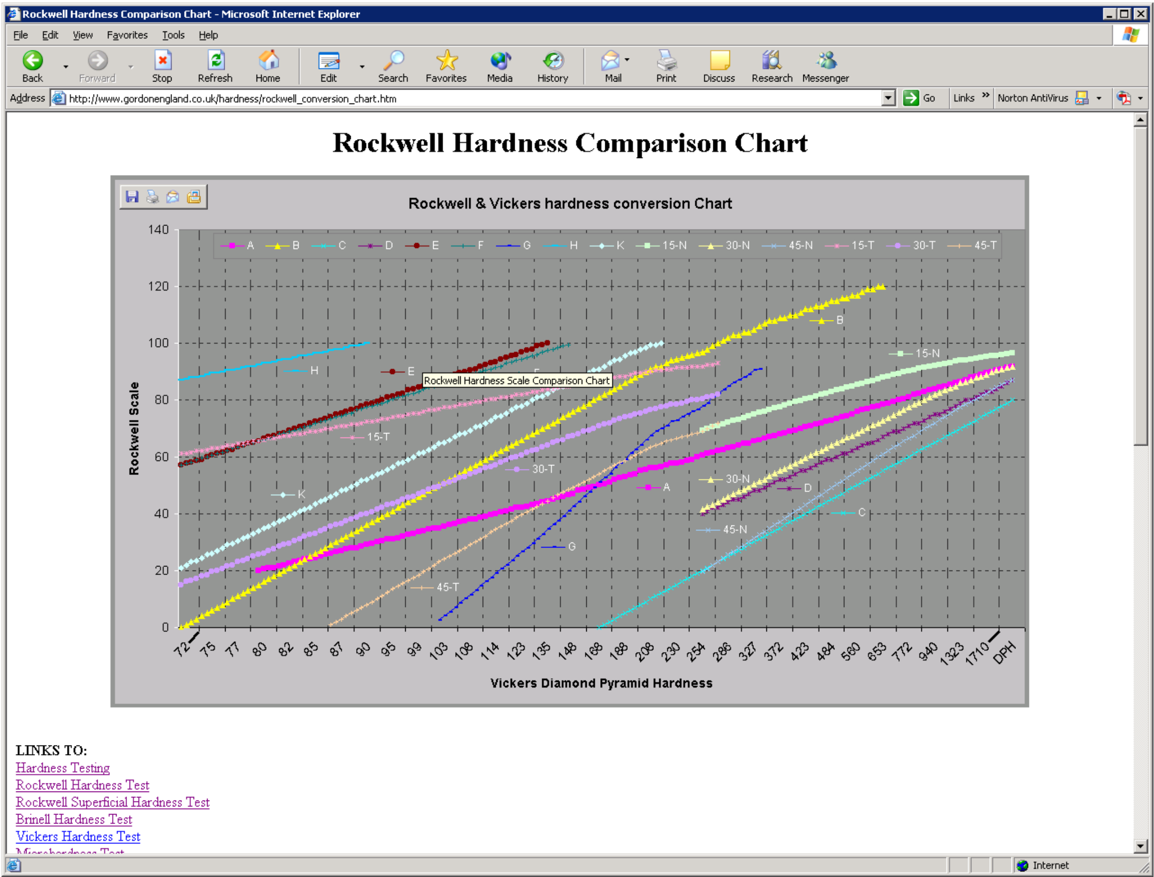
Hardness Conversion Chart related to Rockwell C Hardness Scales (hard materials)

Hardness Conversion Table related to Rockwell B Hardness Scale (soft metals)
(colour)

Hardness Conversion Table related to Rockwell B Hardness Scale (soft metals)
(non-colour)

Hardness Conversion Chart related to Rockwell B Hardness Scale (soft metals)

[HV, MPa and GPa Conversion Calculator]



Rockwell Hardness Test

The Rockwell hardness test method consists of indenting the test material with a diamond cone or hardened steel ball indenter. The indenter is forced into the test material under a preliminary minor load *F0* (Fig. 1A) usually 10 kgf. When equilibrium has been reached, an indicating device, which follows the movements of the indenter and so responds to changes in depth of penetration of the indenter is set to a datum position. While the preliminary minor load is still applied an additional major load is applied with resulting increase in penetration (Fig. 1B). When equilibrium has again been reach, the additional major load is removed but the preliminary minor load is still maintained. Removal of the additional major load allows a partial recovery, so reducing the depth of penetration (Fig. 1C). The permanent increase in depth of penetration, resulting from the application and removal of the additional major load is used to calculate the Rockwell hardness number.

$$\mathrm{HR} = E - e$$

F0 = preliminary minor load in kgf
F1 = additional major load in kgf
F = total load in kgf
e = permanent increase in depth of penetration due to major load F1 measured in units of 0.002 mm
E = a constant depending on form of indenter: 100 units for diamond indenter, 130 units for steel ball indenter
HR = Rockwell hardness number
D = diameter of steel ball

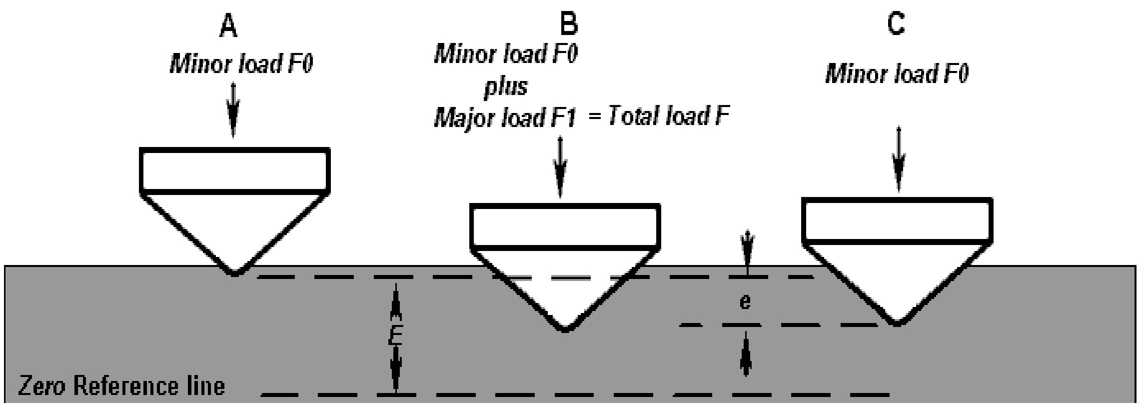


Fig. 1.Rockwell Principle

Rockwell Hardness Scales

Scale	Indenter	Minor Load *F0* kgf	Major Load *F1* kgf	Total Load *F* kgf	Value of *E*
A	Diamond cone	10	50	60	100
B	1/16" steel ball	10	90	100	130
C	Diamond cone	10	140	150	100
D	Diamond cone	10	90	100	100
E	1/8" steel ball	10	90	100	130
F	1/16" steel ball	10	50	60	130
G	1/16" steel ball	10	140	150	130
H	1/8" steel ball	10	50	60	130
K	1/8" steel ball	10	140	150	130
L	1/4" steel ball	10	50	60	130
M	1/4" steel ball	10	90	100	130
P	1/4" steel ball	10	140	150	130
R	1/2" steel ball	10	50	60	130
S	1/2" steel ball	10	90	100	130
V	1/2" steel ball	10	140	150	130

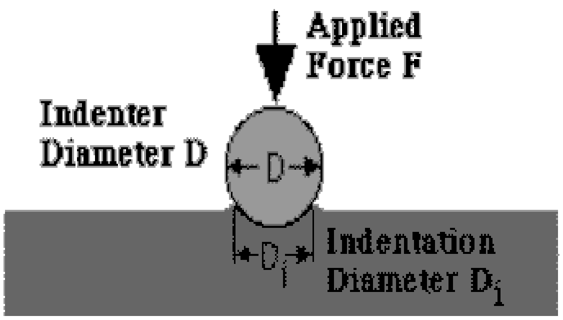
Typical Application of Rockwell Hardness Scales

HRA . . . . Cemented carbides, thin steel and shallow case hardened steel
HRB . . . . Copper alloys, soft steels, aluminium alloys, malleable irons, etc
HRC . . . . Steel, hard cast irons, case hardened steel and other materials harder than 100 HRB
HRD . . . . Thin steel and medium case hardened steel and pearlitic malleable iron
HRE . . . . Cast iron, aluminium and magnesium alloys, bearing metals
HRF . . . . Annealed copper alloys, thin soft sheet metals
HRG . . . . Phosphor bronze, beryllium copper, malleable irons HRH . . . . Aluminium, zinc, lead
HRK . . . . }
HRL . . . . }
HRM . . . .} . . . . Soft bearing metals, plastics and other very soft materials
HRP . . . . }
HRR . . . . }
HRS . . . . }
HRV . . . . }

Advantages of the Rockwell hardness method include the direct Rockwell hardness number readout and rapid testing time. Disadvantages include many arbitrary non-related scales and possible effects from the specimen support anvil (try putting a cigarette paper under a test block and take note of the effect on the hardness reading! Vickers and Brinell methods don't suffer from this effect).

The Brinell Hardness Test

The Brinell hardness test method consists of indenting the test material with a 10 mm diameter hardened steel or carbide ball subjected to a load of 3000 kg. For softer materials the load can be reduced to 1500 kg or 500 kg to avoid excessive indentation. The full load is normally applied for 10 to 15 seconds in the case of iron and steel and for at least 30 seconds in the case of other metals. The diameter of the indentation left in the test material is measured with a low powered microscope. The Brinell harness number is calculated by dividing the load applied by the surface area of the indentation.

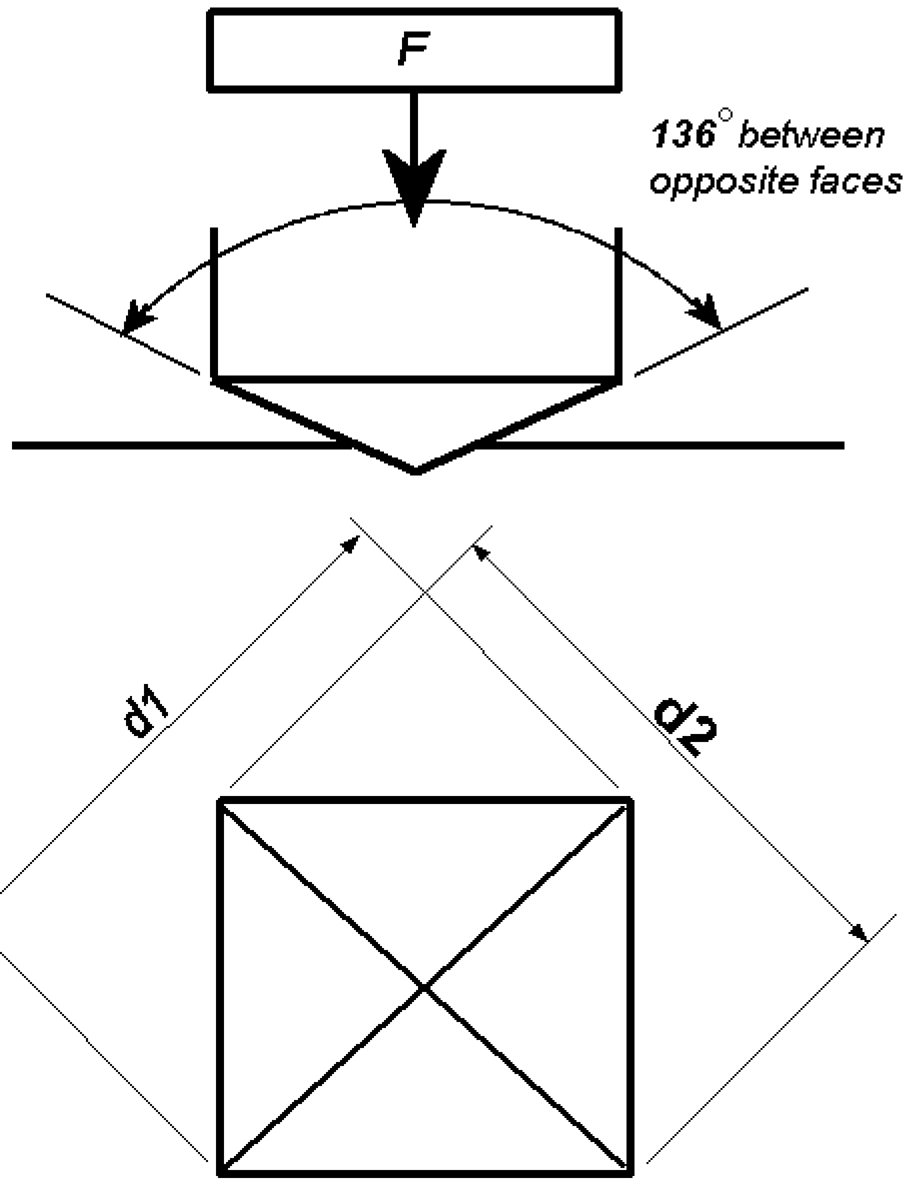


$$BHN = \frac{F}{\frac{\pi}{2} D \cdot \left(D - \sqrt{D^2 - D_i^2}\right)}$$

The diameter of the impression is the average of two readings at right angles and the use of a Brinell hardness number table can simplify the determination of the Brinell hardness. A well structured Brinell hardness number reveals the test conditions, and looks like this, "75 HB 10/500/30" which means that a Brinell Hardness of 75 was obtained using a 10mm diameter hardened steel with a 500 kilogram load applied for a period of 30 seconds. On tests of extremely hard metals a tungsten carbide ball is substituted for the steel ball. Compared to the other hardness test methods, the Brinell ball makes the deepest and widest indentation, so the test averages the hardness over a wider amount of material, which will more accurately account for multiple grain structures and any irregularities in the uniformity of the material. This method is the best for achieving the bulk or macro-hardness of a material, particularly those materials with heterogeneous structures.

Vickers Hardness Test

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left in the surface of the material after removal of the load are measured using a microscope and their average calculated. The area of the sloping surface of the indentation is calculated. The Vickers hardness is the quotient obtained by dividing the kgf load by the square mm area of indentation.



F= Load in kgf
d = Arithmetic mean of the two diagonals, *d1* and *d2* in mm

HV = Vickers hardness

$$HV = \frac{2F\sin\frac{136^{o}}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

When the mean diagonal of the indentation has been determined the Vickers hardness may be calculated from the formula, but is more convenient to use conversion tables. The Vickers hardness should be reported like 800 HV/10, which means a Vickers hardness of 800, was obtained using a 10 kgf force. Several different loading settings give practically identical hardness numbers on uniform material, which is much better than the arbitrary changing of scale with the other hardness testing methods. The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is more expensive than the Brinell or Rockwell machines.

There is now a trend towards reporting Vickers hardness in SI units (MPa or GPa) particularly in academic papers. Unfortunately, this can cause confusion. Vickers hardness (e.g. HV/30) value should normally be expressed as a number only (without the units kgf/mm^2). Rigorous application of SI is a problem. Most Vickers hardness testing machines use forces of 1, 2, 5, 10, 30, 50 and 100 kgf and tables for calculating HV. SI would involve reporting force in newtons (compare 700 HV/30 to HV/294 N = 6.87 GPa) which is practically meaningless and messy to engineers and technicians. To convert a Vickers hardness number the force applied needs converting from kgf to newtons and the area needs converting form mm^2 to m^2 to give results in pascals using the formula above.

To convert HV to MPa multiply by 9.807
To convert HV to GPa multiply by 0.009807

The Scleroscope Hardness Test

The Scleroscope test consists of dropping a diamond tipped hammer, which falls inside a glass tube under the force of its own weight from a fixed height, onto the test specimen. The height of the rebound travel of the hammer is measured on a graduated scale. The scale of the rebound is arbitrarily chosen and consists on Shore units, divided into 100 parts, which represent the average rebound from pure hardened high-carbon steel. The scale is continued higher than 100 to include metals having greater hardness. The Shore Scleroscope measures hardness in terms of the elasticity of the material and the hardness number depends on the height to which the hammer rebounds, the harder the material, the higher the rebound.

The Durometer

The Durometer is a popular instrument for measuring the indentation hardness of rubber and rubber-like materials. The most popular testers are the Model A used for measuring softer materials and the Model D for harder materials. The operation of the tester is quite simple. The material is subjected to a definite pressure applied by a calibrated spring to an indenter that is either a cone or sphere and an indicating device measures the depth of indentation.

Moh's Hardness Scale

The Moh's hardness scale for minerals has been used since 1822. It simply consists of 10 minerals arranged in order from 1 to 10. Diamond is rated as the hardest and is indexed as 10; talc as the softest with index number 1. Each mineral in the scale will scratch all those below it as follows:

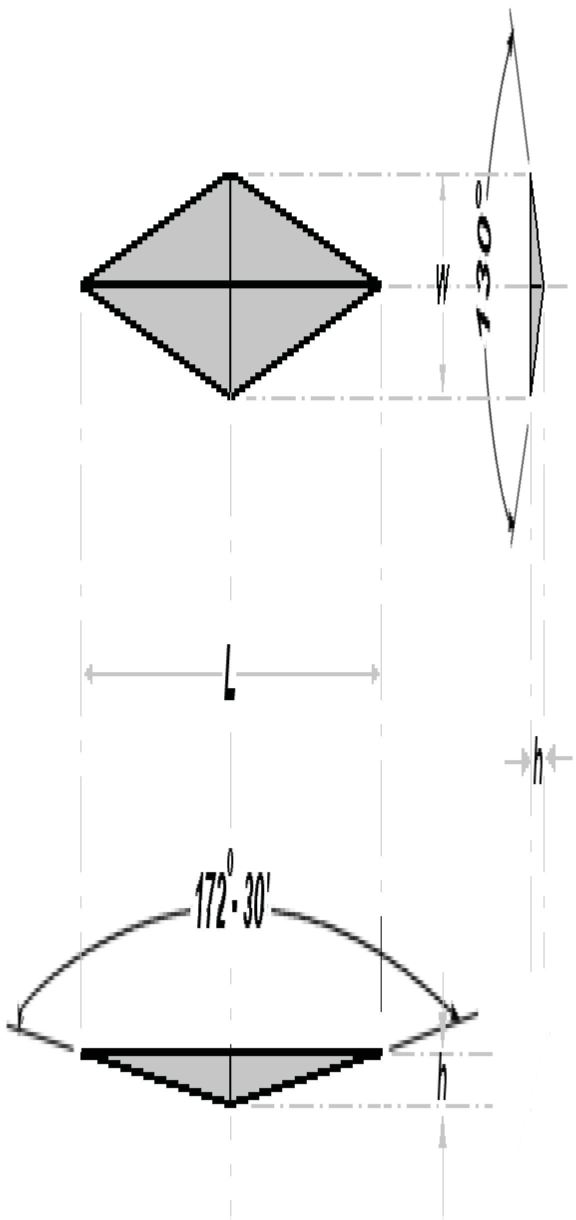
Diamond	10
Corundum	9
Topaz	8
Quartz	7
Orthoclase (Feldspar)	6
Aptite	5
Fluorite	4
Calcite	3
Gypsum	2
Talc	1

The steps are not of equal value and the difference in hardness between 9 and 10 is much greater than between 1 and 2. The hardness is determined by finding which of the standard minerals the test material will scratch or not scratch; the hardness will lie between two points on the scale - the first point being the mineral which is scratched and the next point being the mineral which is not scratched. Some examples of the hardness of common metals in the Moh's scale are copper between 2 and 3 and tool steel between 7 and 8. This is a simple test, but is not exactly quantitative and the standards are purely arbitrary numbers.

The materials engineer and metallurgist find little use for the Moh's scale, but it is possible to sub-divide the scale and some derived methods are still commonly used today. The file test is useful as a rapid and portable qualitative test for hardened steels, where convention hardness testers are not available or practical. Files can be tempered back to give a range of known hardness and then used in a similar fashion to the Moh's method to evaluate hardness.

Microhardness Test

The term microhardness test usually refers to static indentations made with loads not exceeding 1 kgf. The indenter is either the Vickers diamond pyramid or the Knoop elongated diamond pyramid. The procedure for testing is very similar to that of the standard Vickers hardness test, except that it is done on a microscopic scale with higher precision instruments. The surface being tested generally requires a metallographic finish; the smaller the load used, the higher the surface finish required. Precision microscopes are used to measure the indentations; these usually have a magnification of around X500 and measure to an accuracy of $\pm$0.5 micrometres. Also with the same observer differences of $\pm$0.2 micrometres can usually be resolved. It should, however, be added that considerable care and experience are necessary to obtain this accuracy.



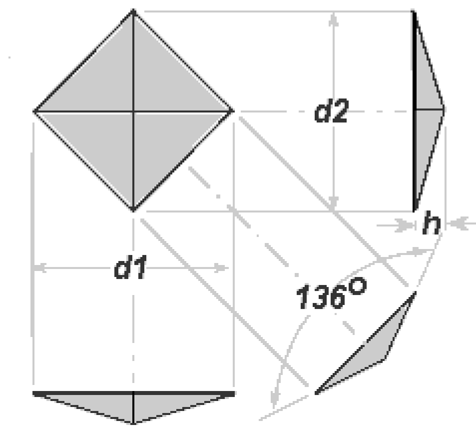
Knoop Hardness Indenter Indentation

The Knoop hardness number KHN is the ratio of the load applied to the indenter, P (kgf) to the unrecovered projected area A (mm^2)

$$KHN = F/A = P/CL^2$$

Where:
F = applied load in kgf
A = the unrecovered projected area of the indentation in mm^2
L = measured length of long diagonal of indentation in mm
C = 0.07028 = Constant of indenter relating projected area of the indentation to the square of the length of the long diagonal.

The Knoop indenter is a diamond ground to pyramidal form that produces a diamond shaped indentation having approximate ratio between long and short diagonals of 7:1. The depth of indentation is about 1/30 of its length. When measuring the Knoop hardness, only the longest diagonal of the indentation is measured and this is used in the above formula with the load used to calculate KHN. Tables of these values are usually a more convenient way to look-up KHN values from the measurements.



Vickers Pyramid Diamond Indenter Indentation

The Vickers Diamond Pyramid harness number is the applied load (kgf) divided by the surface area of the indentation (mm^2)

$$HV = \frac{2F\sin\frac{136^\circ}{2}}{d^2} \qquad HV = 1.854\frac{F}{d^2} \text{ approximately}$$

Where:
F= Load in kgf
d = Arithmetic mean of the two diagonals, *d1* and *d2* in mm
HV = Vickers hardness

The Vickers Diamond Pyramid indenter is ground in the form of a squared pyramid with an angle of 136°between faces. The depth of indentation is about 1/7 of the diagonal length. When calculating the Vickers Diamond Pyramid hardness number, both diagonals of the indentation are measured and the mean of these values is used in the above formula with the load used to determine the value of HV. Tables of these values are usually a more convenient way to look-up HV values from the measurements.