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JANUARY 2001 / VOLUME 53 / NUMBER 1

Hardness At Work

An overview of the most common hardness testing methods.

Three elements of a metalcutting system are the workpiece material, cutting tool and machine tool. The properties of the work material need to be taken into account with the other two elements to make a metalcutting system as effective as possible.

The mechanical and physical properties of workpiece materials are what distinguish one from another. Of the mechanical properties, hardness and ultimate tensile strength are essential, since they affect the cutting forces and machining power.

Traditionally, guidelines for the selection of cutting tool geometry and grade have been based on tool application considerations. Only limited attention has been paid to workpiece hardness, which is a mistake.

Knowledge of the work material hardness and ultimate tensile strength enhances one's ability to select the best cutting tools for the application and leads to higher levels of accuracy when calculating cutting forces and machining power requirements.

In general, hardness is a measure of a material's resistance to deformation. From a machining standpoint, hardness is a measure of a material's resistance to being cut. In the case of cemented carbides and other cutting tool materials, hardness is a measure of rigidity.

Various dynamic and static-indentation methods are used to measure hardness, with the latter being the most common for measuring the hardness of metals. These methods include Rockwell, Brinell, Vickers and Knoop hardness testing. Different indenters and loads are utilized for each test.

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A hardness tester's indenter, when pressed into the sample material under a prescribed load, measures the material's resistance to deformation.

This article focuses on the different methods for measuring work material hardness. It is extracted from the author's formal and analytical study of hardness, titled "The Hardness-Ultimate Tensile Strength Relationship for a Wide Variety of Work Materials."

Rockwell Hardness

Rockwell hardness testing is applied to most metals and alloys, from annealed steels and copper alloys to cemented carbides. There are two types of tests: Rockwell standard and Rockwell superficial.

The letters "HR" stand for Hardness of Rockwell and are followed by a scale designation. There are 15 hardness scales: A, B, C, D, E, F, G, H, K, L, M, P, R, S and V. The most common are the A, B and C scales.

Rockwell superficial hardness scales include N, T, W, X and Y. The major loads for all five of these scales are 15 kgf, 30 kgf and 45 kgf (approximately 33 lbf, 66 lbf and 99 lbf, respectively). Thus, the total number of scales for Rockwell superficial hardness is also 15. The most commonly used scales for Rockwell superficial hardness tests are N and T. Examples of how to indicate superficial Rockwell hardness are 55 HR30N and 86 HR15T, while 89 HRA, 95 HRB and 65 HRC are examples of Rockwell standard hardnesses.

The correct way to indicate Rockwell hardness is with three letters. The "H" indicates hardness, the "R" is for Rockwell and the last letter indicates the scale in use—B, C and so forth. Indicating the scale with a subscript letter (R_A, R_B, R_C, etc.) is no longer considered best practice.

Scale A is used primarily to measure the hardness of cemented carbides, thin steel and shallow-casehardened steel. The major load is 60 kgf (132 lbf) applied to a 120°, spheroconical diamond indenter. Readings between 61 HRA and 85 HRA are normal range values when the hardness of heat-treated carbon, alloy and tool steels are measured. Typical hardness values for cemented carbides range from 83.0 HRA to 94.5 HRA.

Scale B is used to measure the hardness of nonferrous metals and alloys, including some grades of wrought aluminum alloys and wrought copper alloys, soft grades of cast irons and unhardened steels. The major load is 100 kgf (220 lbf), which is applied to a 1/16"-dia. (1.588mm) ball indenter. Readings between 20 and 100—the minimum and maximum values—are in the normal range. The Rockwell B hardness numbers for carbon and alloy steels in the annealed, normalized and quenched-and-tempered conditions are between 55 and 100.

Scale C is for heat-treated steels, cast irons, titanium alloys and other metals harder than 100 HRB. The major load is 150 kgf (330 lbf), which is applied to a 120°, spheroconical diamond indenter. Readings between approximately 20 and 68—the minimum and maximum values—are the most accurate and are accepted as the normal range. The hardness of cemented carbides and PVD and CVD coatings should never be tested with the Rockwell C scale.

N Scales are for materials similar to those tested with the A, C and D scales, except they are of a thinner gauge or case depth. Each of the three major loads mentioned above is applied to the same diamond indenter used for scale A. The Rockwell N superficial hardness numbers for carbon and alloy steels in the annealed, normalized and quenched-and-tempered conditions (measured at the 30-kgf load) are between 42 and 84—the minimum and maximum values.

T Scales are used for materials similar to those tested by the B, F and G scales, but they are of a thinner gauge. Each of the same three major loads are applied to the 1/16" (1.588mm) ball indenter. Readings between approximately 53 and 82—the minimum and maximum values—for the same steels and conditions are accepted as the normal range at a 30-kgf load.

Brinell Hardness

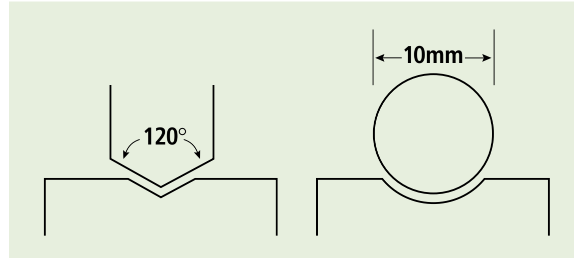
Brinell hardness testing is used for a wide variety of materials, including cast iron. Cast iron is a typical nonhomogeneous ferrous alloy, consisting of iron-iron carbide-graphite particles. These particles have significantly different hardnesses. So, the variable hardness of the very hard iron carbide particles and the softer graphite particles is *averaged* by using a comparatively large indenter—a 10mm-dia., hardened-steel ball whose indentation covers these harder and softer particles.

The Brinell hardness test is also suitable for nonferrous alloys such as aluminum, copper, titanium and heat-resistant alloys.

The Brinell hardness value is a combination of a number and letters. The proper way to indicate Brinell hardness is with the letters "HB," not BHN or Bhn. For example, 300 HB represents the Brinell hardness number of 300. The standard test loads are 500, 1,000, 1,500, 2,000, 2,500 and 3,000 kgf. The most common loads are 500 and 3,000 kgf (1,100 and 6,600 lbf), which are applied to the 10mm ball.

The 500-kgf load is used for testing aluminum and copper alloys, as well as soft steels. The most accurate readings are between 16 HB, for very soft aluminum, and 100 HB, for unhardened and soft-tempered steels, gray and malleable cast irons, and other nonferrous alloys.

The 3,000-kgf load and hardened steel ball are used for testing steels, cast irons, titanium alloys, nickel-based alloys and cobalt-based alloys. The most accurate readings are between 100 HB and 444 HB. A tungsten-carbide ball indenter is used for similar materials having a hardness number ranging between 444 HB and 627 HB.



To determine Rockwell hardness, a load is applied to a 120°, spheroconical indenter (left). The Brinell hardness test involves applying a load to a 10mm ball.

Vickers Hardness

The Vickers hardness value is a combination of a number and the symbol HV. For example, 400 HV represents the Vickers hardness number of 400. The numerical value equals the applied load in kilograms divided by the surface area of the indentation in square millimeters.

The Vickers indenter is a square-based, pyramidal diamond having an included angle of 136°. The load, which is applied for 30 seconds, may be 5, 10, 20, 30, 50 or 120 kg.

Vickers hardness numbers for carbon and alloy steels in the annealed, normalized and quenched-and-tempered conditions are between 85 and 940—the minimum and maximum values. Vickers hardness numbers for indexable inserts made of cemented carbides are between 1,000 HV and 1,950 HV.

Knoop Hardness

The Knoop hardness value is a combination of a number and the letters "HK." Knoop hardness numbers are similar to Vickers hardness numbers. The Knoop indenter is a rhombic-based, pyramidal diamond with an included longitudinal angle of 172° 30' and an included transverse angle of 130°. The load ranges from 1 to 10,000 grams (gf). The most commonly applied loads are 100, 500, 1,000 and 3,000 gf.

Knoop hardness numbers at the 500-gf load for carbon and alloy steels in the annealed, normalized and quenched-and-tempered conditions are between 97 and 920—the minimum and maximum values.

Vickers and Knoop hardness tests are often used for measuring hardness close to the edge of a workpiece—areas where Rockwell or Brinell hardness tests cannot be employed because their indenters require significantly higher loads. Vickers and Knoop hardness tests are applicable to thin metals, hard and brittle materials, and materials with surfaces that are shallowly carburized or nitrided.

For nonhomogeneous materials, such as cast irons and powdered-metal parts, which contain a mixture of both soft and very hard particles, Vickers and Knoop testing are the only suitable methods to determine microhardness accurately. The Vickers and Knoop methods also can be used to measure the microhardness of superhard materials such as CBN and diamond (5,700 to 10,400 HK).

About the Author

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