

6.10 HARDNESS

hardness

Another mechanical property that may be important to consider is **hardness**, which is a measure of a material's resistance to localized plastic deformation (e.g., a small dent or a scratch). Early hardness tests were based on natural minerals with a scale constructed solely on the ability of one material to scratch another that was softer. A qualitative and somewhat arbitrary hardness indexing scheme was devised, termed the Mohs scale, which ranged from 1 on the soft end for talc to 10 for diamond. Quantitative hardness techniques have been developed over the years in which a small indenter is forced into the surface of a material to be tested, under controlled conditions of load and rate of application. The depth or size of the resulting indentation is measured, which in turn is related to a hardness number; the softer the material, the larger and deeper the indentation, and the lower the hardness index number. Measured hardnesses are only relative (rather than absolute), and care should be exercised when comparing values determined by different techniques.

Hardness tests are performed more frequently than any other mechanical test for several reasons:

1. They are simple and inexpensive—ordinarily no special specimen need be prepared, and the testing apparatus is relatively inexpensive.
2. The test is nondestructive—the specimen is neither fractured nor excessively deformed; a small indentation is the only deformation.
3. Other mechanical properties often may be estimated from hardness data, such as tensile strength (see Figure 6.19).

Rockwell Hardness Tests¹³

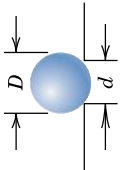
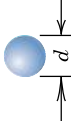
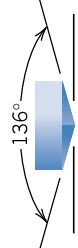


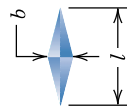
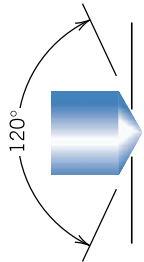

The Rockwell tests constitute the most common method used to measure hardness because they are so simple to perform and require no special skills. Several different scales may be utilized from possible combinations of various indenters and different loads, which permit the testing of virtually all metal alloys (as well as some polymers). Indenters include spherical and hardened steel balls having diameters of $\frac{1}{16}$, $\frac{1}{8}$, $\frac{1}{4}$, and $\frac{1}{2}$ in. (1.588, 3.175, 6.350, and 12.70 mm), and a conical diamond (Brale) indenter, which is used for the hardest materials.

With this system, a hardness number is determined by the difference in depth of penetration resulting from the application of an initial minor load followed by a larger major load; utilization of a minor load enhances test accuracy. On the basis of the magnitude of both major and minor loads, there are two types of tests: Rockwell and superficial Rockwell. For Rockwell, the minor load is 10 kg, whereas major loads are 60, 100, and 150 kg. Each scale is represented by a letter of the alphabet; several are listed with the corresponding indenter and load in Tables 6.5 and 6.6a. For superficial tests, 3 kg is the minor load; 15, 30, and 45 kg are the possible major load values. These scales are identified by a 15, 30, or 45 (according to load), followed by N, T, W, X, or Y, depending on indenter. Superficial tests are frequently performed on thin specimens. Table 6.6b presents several superficial scales.

When specifying Rockwell and superficial hardnesses, both hardness number and scale symbol must be indicated. The scale is designated by the symbol HR

¹³ ASTM Standard E 18, "Standard Test Methods for Rockwell Hardness of Metallic Materials."

Table 6.5 Hardness-Testing Techniques

Test	Indenter	Shape of Indentation		Load	Formula for Hardness Number ^a
		Side View	Top View		
Brinell	10-mm sphere of steel or tungsten carbide			P	$HB = \frac{2P}{\pi D [D - \sqrt{D^2 - d^2}]}$
Vickers microhardness	Diamond pyramid			P	$HV = 1.854P/d_1^2$
Knoop microhardness	Diamond pyramid			P	$HK = 14.2P/l^2$
Rockwell and superficial Rockwell	$\left\{ \begin{array}{l} \text{Diamond cone;} \\ \frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2} \text{ in.-} \\ \text{diameter} \\ \text{steel spheres} \end{array} \right\}$			$\left. \begin{array}{l} 60 \text{ kg} \\ 100 \text{ kg} \\ 150 \text{ kg} \end{array} \right\} \text{Rockwell}$ $\left. \begin{array}{l} 15 \text{ kg} \\ 30 \text{ kg} \\ 45 \text{ kg} \end{array} \right\} \text{Superficial Rockwell}$	

^aFor the hardness formulas given, P (the applied load) is in kg, whereas D , d , d_1 , and l are all in mm.

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Table 6.6a Rockwell Hardness Scales

<i>Scale Symbol</i>	<i>Indenter</i>	<i>Major Load (kg)</i>
A	Diamond	60
B	$\frac{1}{16}$ -in. ball	100
C	Diamond	150
D	Diamond	100
E	$\frac{1}{8}$ -in. ball	100
F	$\frac{1}{16}$ -in. ball	60
G	$\frac{1}{16}$ -in. ball	150
H	$\frac{1}{8}$ -in. ball	60
K	$\frac{1}{8}$ -in. ball	150

Table 6.6b Superficial Rockwell Hardness Scales

<i>Scale Symbol</i>	<i>Indenter</i>	<i>Major Load (kg)</i>
15N	Diamond	15
30N	Diamond	30
45N	Diamond	45
15T	$\frac{1}{16}$ -in. ball	15
30T	$\frac{1}{16}$ -in. ball	30
45T	$\frac{1}{16}$ -in. ball	45
15W	$\frac{1}{8}$ -in. ball	15
30W	$\frac{1}{8}$ -in. ball	30
45W	$\frac{1}{8}$ -in. ball	45

followed by the appropriate scale identification.¹⁴ For example, 80 HRB represents a Rockwell hardness of 80 on the B scale, and 60 HR30W indicates a superficial hardness of 60 on the 30W scale.

For each scale, hardnesses may range up to 130; however, as hardness values rise above 100 or drop below 20 on any scale, they become inaccurate; and because the scales have some overlap, in such a situation it is best to utilize the next harder or softer scale.

Inaccuracies also result if the test specimen is too thin, if an indentation is made too near a specimen edge, or if two indentations are made too close to one another. Specimen thickness should be at least ten times the indentation depth, whereas allowance should be made for at least three indentation diameters between the center of one indentation and the specimen edge, or to the center of a second indentation. Furthermore, testing of specimens stacked one on top of another is not recommended. Also, accuracy is dependent on the indentation being made into a smooth flat surface.

The modern apparatus for making Rockwell hardness measurements is automated and very simple to use; hardness is read directly, and each measurement requires only a few seconds. This apparatus also permits a variation in the time of load application. This variable must also be considered in interpreting hardness data.

¹⁴ Rockwell scales are also frequently designated by an R with the appropriate scale letter as a subscript, for example, R_C denotes the Rockwell C scale.

Brinell Hardness Tests¹⁵

In Brinell tests, as in Rockwell measurements, a hard, spherical indenter is forced into the surface of the metal to be tested. The diameter of the hardened steel (or tungsten carbide) indenter is 10.00 mm (0.394 in.). Standard loads range between 500 and 3000 kg in 500-kg increments; during a test, the load is maintained constant for a specified time (between 10 and 30 s). Harder materials require greater applied loads. The Brinell hardness number, HB, is a function of both the magnitude of the load and the diameter of the resulting indentation (see Table 6.5).¹⁶ This diameter is measured with a special low-power microscope, utilizing a scale that is etched on the eyepiece. The measured diameter is then converted to the appropriate HB number using a chart; only one scale is employed with this technique.

Semiautomatic techniques for measuring Brinell hardness are available. These employ optical scanning systems consisting of a digital camera mounted on a flexible probe, which allows positioning of the camera over the indentation. Data from the camera are transferred to a computer that analyzes the indentation, determines its size, and then calculates the Brinell hardness number. For this technique, surface finish requirements are normally more stringent than for manual measurements.

Maximum specimen thickness as well as indentation position (relative to specimen edges) and minimum indentation spacing requirements are the same as for Rockwell tests. In addition, a well-defined indentation is required; this necessitates a smooth flat surface in which the indentation is made.

Knoop and Vickers Microindentation Hardness Tests¹⁷

Two other hardness-testing techniques are Knoop (pronounced *nūp*) and Vickers (sometimes also called *diamond pyramid*). For each test a very small diamond indenter having pyramidal geometry is forced into the surface of the specimen. Applied loads are much smaller than for Rockwell and Brinell, ranging between 1 and 1000 g. The resulting impression is observed under a microscope and measured; this measurement is then converted into a hardness number (Table 6.5). Careful specimen surface preparation (grinding and polishing) may be necessary to ensure a well-defined indentation that may be accurately measured. The Knoop and Vickers hardness numbers are designated by HK and HV, respectively,¹⁸ and hardness scales for both techniques are approximately equivalent. Knoop and Vickers are referred to as microindentation-testing methods on the basis of indenter size. Both are well suited for measuring the hardness of small, selected specimen regions; furthermore, Knoop is used for testing brittle materials such as ceramics. (Section 12.11).

The modern microindentation hardness-testing equipment has been automated by coupling the indenter apparatus to an image analyzer that incorporates a computer and software package. The software controls important system functions to include indent location, indent spacing, computation of hardness values, and plotting of data.

¹⁵ ASTM Standard E 10, “Standard Test Method for Brinell Hardness of Metallic Materials.”

¹⁶ The Brinell hardness number is also represented by BHN.

¹⁷ ASTM Standard E 92, “Standard Test Method for Vickers Hardness of Metallic Materials,” and ASTM Standard E 384, “Standard Test Method for Microindentation Hardness of Materials.”

¹⁸ Sometimes KHN and VHN are used to denote Knoop and Vickers hardness numbers, respectively.

Other hardness-testing techniques are frequently employed but will not be discussed here; these include ultrasonic microhardness, and dynamic (Scleroscope), durometer (for plastic and elastomeric materials), and scratch hardness tests. These are described in references provided at the end of the chapter.

Hardness Conversion

The facility to convert the hardness measured on one scale to that of another is most desirable. However, because hardness is not a well-defined material property, and because of the experimental dissimilarities among the various techniques, a comprehensive conversion scheme has not been devised. Hardness conversion data have been determined experimentally and found to be dependent on material type and characteristics. The most reliable conversion data exist for steels, some of which are presented in Figure 6.18 for Knoop, Brinell, and two Rockwell scales; the Mohs scale is also included. Detailed conversion tables for various other metals and alloys

Figure 6.18
Comparison of
several hardness
scales. (Adapted
from G. F. Kinney,
*Engineering
Properties and
Applications of
Plastics*, p. 202.
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