SECTION 2. TESTING OF METALS

4-16. HARDNESS TESTING. If the material type is known, a hardness test is a simple way to verify that the part has been properly heat-treated. Hardness testers such as Rockwell, Brinell, and Vickers can be useful to check metals for loss of strength due to exposure to fire or abusive heating. Also, under-strength bolts can be found and removed from the replacement part inventory by checking the hardness of the bolt across the hex flats. Although hardness tests are generally considered nondestructive, hardness testing does leave a small pit in the surface; therefore, hardness tests should not be used on sealing surfaces, fatigue critical parts, load bearing areas, etc., that will be returned to service. These hardness tests provide a convenient means for determining, within reasonable limits, the tensile strength of steel. It has several limitations in that it is not suitable for very soft or very hard steels. Hardness testing of aluminum alloys should be limited to distinguishing between annealed and heat-treated material of the same aluminum alloy. In hardness testing, the thickness and the edge distance of the specimen being tested are two factors that must be considered to avoid distortion of the metal. Several readings should be taken and the results averaged. In general, the higher the tensile strength, the greater its hardness. Common methods of hardness testing are outlined in the following paragraphs. These tests are suitable for determining the tensile properties resulting from the heat treatment of steel. Care should be taken to have case-hardened, corroded, pitted, decarburized, or otherwise nonuniform surfaces removed to a sufficient depth. Exercise caution not to cold-work, and consequently harden, the steel during removal of the surface.

4-17. ROCKWELL HARDNESS TEST. The Rockwell hardness test is the most common method for determining hardness of ferrous and many nonferrous metals. (See table 4-5.) It differs from Brinell hardness testing in that the hardness is determined by the depth of indentation made by a constant load impressing on an indenter. In this test, a standard minor load is applied to set a hardened steel ball or a diamond cone in the surface of the metal, followed by the application of a standard major load. The hardness is measured by depth of penetration. Rockwell superficial hardness tests are made using light minor and major loads and a more sensitive system for measuring depth of indentation. It is useful for thin sections, very small parts, etc. Calibration of Rockwell hardness testers is done in accordance with American Society of Testing Materials (ASTM E-18) specifications.

4-18. BRINELL HARDNESS TEST. In this test a standard constant load, usually 500 to 3,000 kg, is applied to a smooth flat metal surface by a hardened steel-ball type indenter, 10 mm in diameter. The 500-kg load is usually used for testing nonferrous metals such as copper and aluminum alloys, whereas the 3,000-kg load is most often used for testing harder metals such as steels and cast irons. The numerical value of Brinell Hardness (HB), is equal to the load, divided by the surface area of the resulting spherical impression.

$$HB = \frac{P}{(\pi \frac{D}{2}[D - \sqrt{(D^2 - d^2)}])}$$

Where P is the load, in kg; D is the diameter of the ball, in mm; and d is the diameter of the indentation, in mm.

a. General Precautions. To avoid misapplication of Brinell hardness testing, the fundamentals and limitations of the test procedure must be clearly understood. To avoid inaccuracies, the following rules should be followed.

(1) Do not make indentations on a curved surface having a radius of less than 1 inch.

(2) Do make the indentations with the correct spacing. Indentations should not be made too close to the edge of the work piece being tested.

(3) Apply the load steadily to avoid overloading caused by inertia of the weights.

(4) Apply the load so the direction of loading and the test surface are perpendicular to each other within 2 degrees.

(5) The thickness of the work piece being tested should be such that no bulge or mark showing the effect of the load appears on the side of the work piece opposite the indentation.

(6) The indentation diameter should be clearly outlined.

b. Limitations. The Brinell hardness test has three principal limitations.

(1) The work piece must be capable of accommodating the relatively large indentations.

(2) Due to the relatively large indentations, the work piece should not be used after testing.

(3) The limit of hardness, 15 HB with the 500-kg load to 627 HB with the 3,000-kg load, is generally considered the practical range.

c. Calibration. A Brinell Hardness Tester should be calibrated to meet ASTM standard E10 specifications.

4-19. VICKERS HARDNESS TEST. In this test, a small pyramidal diamond is pressed into the metal being tested. The Vickers Hardness number (HV) is the ratio of the load applied to the surface area of the indention. This is done with the following formula.

$$HV = P / 0.5393d^2$$

a. The indenter is made of diamond, and is in the form of a square-based pyramid having an angle of 136 degrees between faces. The facets are highly-polished, free from surface imperfections, and the point is sharp. The loads applied vary from 1 to 120 kg; the standard loads are 5, 10, 20, 30, 50, 100, and 120 kg. For most hardness testing, 50 kg is maximum.

b. A Vickers hardness tester should be calibrated to meet ASTM standard E10 specifications, acceptable for use over a loading range.

4-20. MICROHARDNESS TESTING. This is an indentation hardness test made with loads not exceeding 1 kg (1,000 g). Such hardness tests have been made with a load as light as 1 g, although the majority of microhardness tests are made with loads of 100 to 500 g. In general, the term is related to the size of the indentation rather than to the load applied.

a. Fields of Application. Microhardness testing is capable of providing information regarding the hardness characteristics of materials which cannot be obtained by hardness tests such as the Brinell or Rockwell, and are as follows.

(1) Measuring the hardness of precision work pieces that are too small to be measured by the more common hardness-testing methods.

(2) Measuring the hardness of product forms such as foil or wire that are too thin or too small in diameter to be measured by the more conventional methods.

(3) Monitoring of carburizing or nitriding operations, which is sometimes accomplished by hardness surveys taken on cross sections of test pieces that accompanied the work pieces through production operations.

(4) Measuring the hardness of individual microconstituents.

(5) Measuring the hardness close to edges, thus detecting undesirable surface conditions such as grinding burn and decarburization.

(6) Measuring the hardness of surface layers such as plating or bonded layers.

b. Indenters. Microhardness testing can be performed with either the Knoop or the Vickers indenter. The Knoop indenter is used mostly in the United States; the Vickers indenter is the more widely used in Europe.

(1) Knoop indentation testing is performed with a diamond, ground to pyramidal form, that produces a diamond-shaped indentation with an approximate ratio between long and short diagonals of 7 to 1. The indentation depth is about one-thirtieth of its length. Due to the shape of the indenter, indentations of accurately measurable length are obtained with light loads.

(2) The Knoop hardness number (HK) is the ratio of the load applied to the indenter to the unrecovered projected area of indentation. The formula for this follows.

$$HK = P / A = P / Cl^2$$

Where P is the applied load, in kg; A is the unrecovered projected area of indentation, in square mm; l is the measured length of the long diagonal, in mm; and C is 0.07028, a constant of the indenter relating projected area of the indentation to the square of the length of the long diagonal.

4-21. INDENTATIONS. The Vickers indenter penetrates about twice as far into the work piece as does the Knoop indenter. The diagonal of the Vickers indentation is about one-third of the total length of the Knoop indentation. The Vickers indenter is less sensitive to minute differences in surface conditions than is the Knoop indenter. However, the Vickers indentation, because of the shorter diagonal, is more sensitive to errors in measuring than is the Knoop indentation. (See figure 4-1.)

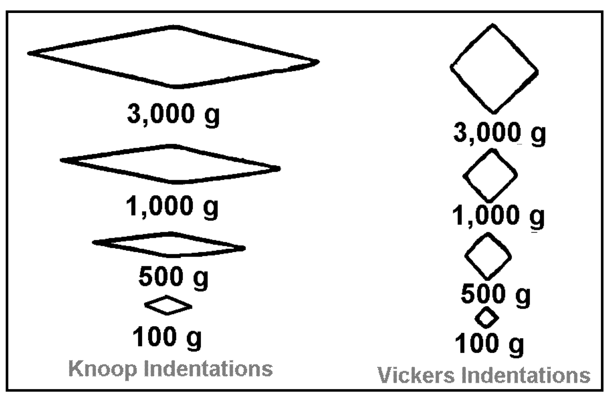

FIGURE 4-1. Comparison of indentation made by Knoop and Vickers indenters in the same work metal and at the same loads.

4-22. MAGNETIC TESTING. Magnetic testing consists of determining whether the specimen is attracted by a magnet. Usually, a metal attracted by a magnet is iron, steel, or an iron-base alloy containing nickel, cobalt, or chromium. However, there are exceptions to this rule since some nickel and cobalt alloys may be either magnetic or nonmagnetic. Never use this test as a final basis for identification. The strongly attracted metals could be pure iron, pure nickel, cobalt, or iron-nickel-cobalt alloys. The lightly attracted metals could be cold-worked stainless steel, or monel. The nonmagnetic metals could be aluminum, magnesium, silver, or copper-base alloy, or an annealed 300-type stainless steel.

4-23. ALUMINUM TESTING. Hardness tests are useful for testing aluminum alloy chiefly as a means of distinguishing between annealed, cold-worked, heat-treated, and heat-treated and aged material. It is of little value in indicating the strength or quality of heat treatment. Typical hardness values for aluminum alloys are shown in table 4-5.

a. Clad aluminum alloys have surface layers of pure aluminum or corrosion-resistant aluminum alloy bonded to the core material to inhibit corrosion. Presence of such a coating may be determined under a magnifying glass by examination of the edge surface which will show three distinct layers. In aluminum alloys, the properties of any specific alloy can be altered by work hardening (often called strain-hardening), heat treatment, or by a combination of these processes.

b. Test for distinguishing heat-treatable and nonheat-treatable aluminum alloys. If for any reason the identification mark of the alloy is not on the material, it is possible to distinguish between some heat-treatable alloys and some nonheat-treatable alloys by immersing a sample of the material in a 10 percent solution of caustic soda (sodium hydroxide). Those heat-treated alloys containing several percent of copper (2014, 2017, and 2024) will turn black due to the copper content. High-copper alloys when clad will not turn black on the surface, but the edges will turn black at the center of the sheet where the core is exposed. If the alloy does not turn black in the caustic soda solution it is not evidence that the alloy is nonheat-treatable, as various high-strength heat-treatable alloys are not based primarily on the use of copper as an alloying agent. These include among others 6053, 6061, and 7075 alloys. The composition and heat-treating ability of alloys which do not turn black in a caustic soda solution can be established only by chemical or spectro-analysis.

TABLE 4-5. Hardness values for aluminum alloys. (Reference MIL-H-6088G.)

Material Commercial Designation	Hardness Temper	Brinell number 500 kg. load 10 mm. ball
1100	0	23
	H18	44
3003	0	28
	H16	47
2014	0	45
	T6	135
2017	0	45
	T6	105
2024	0	47
	T4	120
2025	T6	110
6151	T6	100
5052	0	47
	H36	73
6061	0	30
	T4	65
	T6	95
7075	T6	135
7079	T6	135
195	T6	75
220	T4	75
C355	T6	80
A356	T6	70

4-24.—4-35. [RESERVED.]