https://en.wikipedia.org/wiki/Hardness **11/8/15**

Hardness is a measure of how resistant solid matter is to various kinds of permanent shape change when a compressive force is applied. Some materials, such as metal, are harder than others. Macroscopic hardness is generally characterized by strong intermolecular bonds, but the behavior of solid materials under force is complex; therefore, there are different measurements of hardness: ***scratch hardness*, *indentation hardness*, and *rebound hardness***.

Hardness is dependent on ductility, elastic stiffness, plasticity, strain, strength, toughness, viscoelasticity, and viscosity.

Common examples of **hard matter** are ceramics, concrete, certain metals, and superhard materials, which can be contrasted with soft matter.

Measuring hardness

There are three main types of hardness measurements: ***scratch*, *indentation*, and *rebound***. Within each of these classes of measurement there are individual measurement scales. For practical reasons conversion tables are used to convert between one scale and another.

Scratch hardness

Scratch hardness is the measure of how resistant a sample is to fracture or permanent plastic deformation due to friction from a sharp object.[1] The principle is that an object made of a harder material will scratch an object made of a softer material. When testing coatings, scratch hardness refers to the force necessary to cut through the film to the substrate. The most common test is Mohs scale, which is used in mineralogy. One tool to make this measurement is the sclerometer.

Another tool used to make these tests is the pocket hardness tester. This tool consists of a scale arm with graduated markings attached to a four-wheeled carriage. A scratch tool with a sharp rim is mounted at a predetermined angle to the testing surface. In order to use it a weight of known mass is added to the scale arm at one of the graduated markings, the tool is then drawn across the test surface. The use of the weight and markings allows a known pressure to be applied without the need for complicated machinery

Indentation hardness

Indentation hardness measures the resistance of a sample to material deformation due to a constant compression load from a sharp object; they are primarily used in engineering and metallurgy fields. The tests work on the basic premise of measuring the critical dimensions of an indentation left by a specifically dimensioned and loaded indenter.

Common indentation hardness scales are Rockwell, Vickers, Shore, and Brinell

Rebound hardness

Rebound hardness, also known as *dynamic hardness*, measures the height of the "bounce" of a diamond-tipped hammer dropped from a fixed height onto a material. This type of hardness is related to elasticity. The device used to take this measurement is known as a scleroscope.[3]

Two scales that measures rebound hardness are the Leeb rebound hardness test and Bennett hardness scale.

Hardening

There are five hardening processes: Hall-Petch strengthening, work hardening, solid solution strengthening, precipitation hardening, and martensitic transformation.

Brinell Hardness Testing 28/7/17

Hardness is a characteristic of a material, not a fundamental physical property. It is defined as the resistance to indentation, and it is determined by measuring the permanent depth of the indentation. More simply put, when using a fixed force (load) and a given indenter, the smaller the indentation, the harder the material. Indentation hardness value is obtained by measuring the depth or the area of the indentation using one of over 12 different test methods. Click here to learn more about hardness testing basics.

The **Brinell hardness test method** as used to determine Brinell hardness, is defined in ASTM E10. Most commonly it is used to test materials that have a structure that is too coarse or that have a surface that is too rough to be tested using another test method, e.g., castings and forgings. Brinell testing often use a very high test load (3000 kgf) and a 10mm wide indenter so that the resulting indentation averages out most surface and sub-surface inconsistencies.

The Brinell method applies a predetermined test load (F) to a carbide ball of fixed diameter (D) which is held for a predetermined time period and then removed. The resulting impression is measured across at least two diameters – usually at right angles to each other and these result averaged (d). A chart is then used to convert the averaged diameter measurement to a Brinell hardness number. Test forces range from 500 to 3000 kgf.

A Brinell hardness result measures the permanent width of indentation produced by a carbide indenter applied to a test specimen at a given load, for a given length of time. Typically, an indentation is made with a Brinell hardness testing machine and then measured for indentation diameter in a second step with a specially designed Brinell microscope or optical system. The resulting measurement is converted to a Brinell value using the Brinell formula or a conversion chart based on the formula. Most typically, a Brinell test will use 3000 kgf load with a 10mm ball. If the sample material is aluminum, the test is most frequently performed with a 500 kgf load and 10mm ball. Brinell test loads can range from 3000 kgf down to 1 kgf. Ball indenter diameters can range from 10mm to 1mm. Generally, the lower loads and ball diameters are used for convenience in "combination" testers, like Rockwell units, that have a small load capacity. The test standard specifies a time of 10 to 15 seconds, although shorter times can be used if it is known that the shorter time does not affect the result. There are other conditions that must be met for testing on a round specimen, spacing of indentations, minimum thickness of test specimens, etc.

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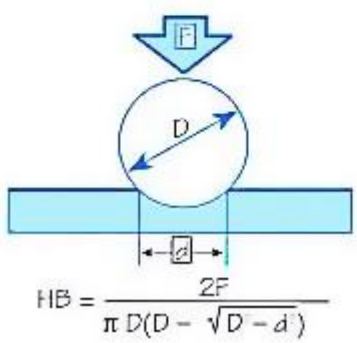
Test Method Illustration

D = Ball diameter
d = impression diameter
F = load
HB = Brinell result



Typically the greatest source of error in Brinell testing is the measurement of the indentation. Due to disparities in operators making the measurements, the results will vary even under perfect conditions. Less than perfect conditions can cause the variation to increase greatly. Frequently the test surface is prepared with a grinder to remove surface conditions. The jagged edge makes interpretation of the indentation difficult. Furthermore, when operators know the specifications limits for rejects, they may often be influenced to see the measurements in a way that increases the percentage of "good" tests and less re-testing.

Two types of technological remedies for countering Brinell measurement error problems have been developed over the years. Automatic optical Brinell scopes use computers and image analysis to read the indentations in a consistent manner. This standardization helps eliminate operator subjectivity so operators are less-prone to automatically view in-tolerance results when the sample's result may be out-of-tolerance.

Brinell units, according to ASTM E103, measure the samples using Brinell hardness parameters together with a Rockwell hardness method. This method provides the most repeatable results (and greater speed) since the vagaries of optical interpretations are removed through the use of an automatic mechanical depth measurement. Using this method, however, results may not be strictly consistent with Brinell results due to the different test methods – an offset to the results may be required for some materials. It is easy to establish the correct values in those cases where this may be a problem.

Rockwell Hardness Testing

The **Rockwell hardness test method**, as defined in ASTM E-18, is the most commonly used hardness test method. You should obtain a copy of this standard, read and understand the standard completely before attempting a Rockwell test. The Rockwell test is generally easier to perform, and more accurate than other types of hardness testing methods. The Rockwell test method is used on all metals, except in condition where the test metal structure or surface conditions would introduce too much variations; where the indentations would be too large for the application; or where the sample size or sample shape prohibits its use.

The Rockwell method measures the permanent depth of indentation produced by a force/load on an indenter. First, a preliminary test force (commonly referred to as preload or minor load) is applied to a sample using a diamond indenter. This load represents the zero or reference position that breaks through the surface to reduce the effects of surface finish. After the preload, an additional load, call the major load, is applied to reach the total required test load. This force is held for a predetermined amount of time (dwell time) to allow for elastic recovery. This major load is then released and the final position is measured against the position derived from the preload, the indentation depth variance between the preload value and major load value. This distance is converted to a hardness number.

Preliminary test loads (preloads) range from 3 kgf (used in the "Superficial" Rockwell scale) to 10 kgf (used in the "Regular" Rockwell scale) to 200 kgs (used as a macro scale and not part of ASTM E-18; see ASTM E-1842). Total test forces range from 15kgf to 150 kgf (superficial and regular) to 500 to 3000 kgf (macrohardness).

Test Method Illustration

A = Depth reached by indenter after application of preload (minor load)
B = Position of indenter during major load
C = Final position reached by indenter after elastic recovery of sample material
D = Distance measurement taken representing difference between preload and major load position

A variety of indenters may be used: conical diamond with a round tip for harder metals to ball indenters ranges with a diameter ranging from 1/16" to ½" for softer materials.

When selecting a Rockwell scale, a general guide is to select the scale that specifies the largest load and the smallest indenter possible without exceeding defined operation conditions and accounting for conditions that may influence the test result. These conditions include test specimens that are below the minimum thickness for the depth of indentation; a test impression that falls too close to the edge of the specimen or another impression; or testing on cylindrical specimens. Additionally, the test axis should be within 2-degress of perpendicular to ensure precise loading; there should be no deflection of the test sample or tester during the loading application from conditions such as dirt under the test specimen or on the elevating screw. It is important to keep the surface finish clean and decarburization from heat treatment should be removed.

Sheet metal can be too thin and too soft for testing on a particular Rockwell scale without exceeding minimum thickness requirements and potentially indenting the test anvil. In this case a diamond anvil can be used to provide a consistent influence of the result. Another special case in testing cold rolled sheet metal is that work hardening can create a gradient of hardness through the sample so any test is measuring the average of the hardness over the depth of indentation effect. In this case any Rockwell test result is going to be subject to doubt, there is often a history of testing using a particular scale on a particular material that operators are used to and able to functionally interpret.

Knoop Hardness Testing

The **Knoop hardness test method**, also referred to as a **microhardness test method**, is mostly used for small parts, thin sections, or case depth work. The Vickers method is based on an optical measurement system. The Microhardness test procedure, ASTM E-384, specifies a range of light loads using a diamond indenter to make an indentation which is measured and converted to a hardness value. It is very useful for testing on a wide type of materials as long as test samples are carefully prepared. A pyramid shaped diamond is used for testing in the Knoop scale. This indenter differs from the pyramid indenter used on a Vickers test. The Knoop indenter is more elongated or rectangular in shape. The Knoop method is commonly used when indentations are closely spaced or very near the edge of the sample. The width of the Knoop indentation can provide more resolution for measurement and the indentation is also less deep. Consequently, it can be used on very thin materials.

In a Knoop test, a predetermined test force is applied with a pyramid-shaped diamond indenter for a specified dwell time period. The indenter used on a Knoop test is pyramid-shaped but more elongated than the indenter used on a Vickers test. After this dwell period, the force is removed. Unlike the Vickers test where the indentation length on the vertical and horizontal axes are measured and averaged, the Knoop method only uses the long axis. This measurement is then converted to a Knoop hardness number using a chart.
Since the test indentation is very small in a Knoop test, it is useful for a variety of applications: testing very thin materials like foils or measuring the surface of a part, small parts or small areas, measuring individual microstructures, or measuring the depth of case hardening by sectioning a part and making a series of indentations to describe a profile of the change in hardness. The Vickers method is more commonly used microhardness test.

Sample preparation is usually necessary with a microhardness test in order to provide a small enough specimen that can fit into the tester. Additionally, the sample preparation will need to make the specimen’s surface smooth to permit a regular indentation shape and good measurement, and to ensure the sample can be held perpendicular to the indenter. Usually the prepared samples are mounted in a plastic medium to facilitate the preparation and testing. The indentations should be as large as possible to maximize the measurement resolution. (Error is magnified as indentation sizes decrease) The test procedure is subject to problems of operator influence on the test results.
Case depth is the thickness of the hardened layer on a specimen. Case hardening improves both the wear resistance and the fatigue strength of parts under dynamic and/or thermal stresses. Hardened steel parts are typically used in rotating applications where high wear resistance and strength is required. The characteristics of case hardening are primarily determined by surface hardness, the effective hardness depth and the depth profile of the residual stress. Gears and engine parts are examples where hardening is used. Effective case depth is the depth up to a further point for which a specified level of hardness is maintained. Total case depth is the depth to a point where there is no difference in the chemical or physical properties. Case depth testing often involves performing a series of hardness impressions from the edge of the specimen towards the center. The hardness progression is plotted on a graph and the distance from the surface to the hardness limit (HL) is calculated.

Mechanism of understanding for hardness

In solid mechanics, solids generally have three responses to force, depending on the amount of force and the type of material:

(1) They exhibit elasticity—the ability to temporarily change shape, but return to the original shape when the pressure is removed. "Hardness" in the elastic range—a small temporary change in shape for a given force—is known as stiffness in the case of a given object, or a high elastic modulus in the case of a material.

(2) They exhibit plasticity—the ability to permanently change shape in response to the force, but remain in one piece. The yield strength is the point at which elastic deformation gives way to plastic deformation. Deformation in the plastic range is non-linear, and is described by the stress-strain curve. This response produces the observed properties of scratch and indentation hardness, as described and measured in materials science. Some materials exhibit both elasticity and viscosity when undergoing plastic deformation; this is called viscoelasticity.

(3) They fracture—split into two or more pieces.

Strength is a measure of the extent of a material's elastic range, or elastic and plastic ranges together. This is quantified as compressive strength, shear strength, tensile strengthdepending on the direction of the forces involved. Ultimate strength is an engineering measure of the maximum load a part of a specific material and geometry can withstand.

Brittleness, in technical usage, is the tendency of a material to fracture with very little or no detectable plastic deformation beforehand. Thus in technical terms, a material can be both brittle and strong. In everyday usage "brittleness" usually refers to the tendency to fracture under a small amount of force, which exhibits both brittleness and a lack of strength (in the technical sense). For perfectly brittle materials, yield strength and ultimate strength are the same, because they do not experience detectable plastic deformation. The opposite of brittleness is ductility.

The toughness of a material is the maximum amount of energy it can absorb before fracturing, which is different from the amount of force that can be applied. Toughness tends to be small for brittle materials, because elastic and plastic deformations allow materials to absorb large amounts of energy.

Hardness increases with decreasing particle size. This is known as the Hall-Petch relationship. However, below a critical grain-size, hardness decreases with decreasing grain size. This is known as the inverse Hall-Petch effect.

Hardness of a material to deformation is dependent on its microdurability or small-scale shear modulus in any direction, not to any rigidity or stiffness properties such as its bulk modulus orYoung's modulus. Stiffness is often confused for hardness.[4][5] Some materials are stiffer than diamond (e.g. osmium) but are not harder, and are prone to spalling and flaking in squamose or acicular habits.

Mechanisms and theory

The key to understanding the mechanism behind hardness is understanding the metallic microstructure, or the structure and arrangement of the atoms at the atomic level. In fact, most important metallic properties critical to the manufacturing of today's goods are determined by the microstructure of a material.[6] At the atomic level, the atoms in a metal are arranged in an orderly three-dimensional array called a crystal lattice. In reality, however, a given specimen of a metal likely never contains a consistent single crystal lattice. A given sample of metal will contain many grains, with each grain having a fairly consistent array pattern. At an even smaller scale, each grain contains irregularities. There are two types of irregularities at the grain level of the microstructure that are responsible for the hardness of the material. These irregularities are point defects and line defects. A point defect is an irregularity located at a single lattice site inside of the overall three-dimensional lattice of the grain. There are three main point defects. If there is an atom missing from the array, a vacancy defect is formed. If there is a different type of atom at the lattice site that should normally be occupied by a metal atom, a substitutional defect is formed. If there exists an atom in a site where there should normally not be, an interstitial defect is formed. This is possible because space exists between atoms in a crystal lattice. While point defects are irregularities at a single site in the crystal lattice, line defects are irregularities on a plane of atoms. Dislocations are a type of line defect involving the misalignment of these planes. In the case of an edge dislocation, a half plane of atoms is wedged between two planes of atoms. In the case of a screw dislocation two planes of atoms are offset with a helical array running between them. In glasses, hardness seems to depend linearly on the number of topological constraints acting between the atoms of the network.[8] Hence, the rigidity theory has allowed predicting hardness values with respect to composition.

Planes of atoms split by an edge dislocation.

Dislocations provide a mechanism for planes of atoms to slip and thus a method for plastic or permanent deformation.[6] Planes of atoms can flip from one side of the dislocation to the other effectively allowing the dislocation to traverse through the material and the material to deform permanently. The movement allowed by these dislocations causes a decrease in the material's hardness.

The way to inhibit the movement of planes of atoms, and thus make them harder, involves the interaction of dislocations with each other and interstitial atoms. When a dislocation intersects with a second dislocation, it can no longer traverse through the crystal lattice. The intersection of dislocations creates an anchor point and does not allow the planes of atoms to continue to slip over one another[9] A dislocation can also be anchored by the interaction with interstitial atoms. If a dislocation comes in contact with two or more interstitial atoms, the slip of the planes will again be disrupted. The interstitial atoms create anchor points, or pinning points, in the same manner as intersecting dislocations.

By varying the presence of interstitial atoms and the density of dislocations, a particular metal's hardness can be controlled. Although seemingly counter-intuitive, as the density of dislocations increases, there are more intersections created and consequently more anchor points. Similarly, as more interstitial atoms are added, more pinning points that impede the movements of dislocations are formed. As a result, the more anchor points added, the harder the material will become.