

Best Practices for Rockwell Hardness Testing

Hardness Testing Basics

Hardness, as applied to most materials, and in particular metals, is a valuable, revealing, and commonly employed mechanical test that has been in use in various forms for more than 250 years. As a material property, its value and importance cannot be understated; the information from a hardness test can be used to provide critical material performance information and insight to the durability, strength, flexibility, and capabilities of a variety of component types from raw materials to prepared specimens, and finished goods. Hardness testing is widely used in a multitude of industries and plays particular significance in structural, aerospace, automotive, quality control, failure analysis, and many other forms of manufacturing.

What is indentation hardness testing? The most basic and commonly used definition is the resistance of a material to permanent, plastic deformation. It is measured by loading an indenter of specified geometry and properties onto the material for a specified length of time, and measuring either the depth of penetration or dimensions of the resulting indentation or impression. Rockwell testing is the most commonly used method by virtue of the quick results generated and is typically used on metals and alloys. It generates a value based on indentation depth or unrecovered indentation.

Importance of good practice

Paramount to accurate and reliable Rockwell hardness results is ensuring that the operators and the methods used are following proper test technique and practice. The precise nature and exactness of a Rockwell test require following strict hardness protocol and adherence to standards. With the unit of measurement for one regular Rockwell point equal to only 0.002 mm (approx. 0.00008 inch) it becomes obvious that such exact measurement requires a very precise measuring system and process. Failure to properly prepare and execute a Rockwell hardness test can result in compromised test data or false readings, potentially contributing to the production and delivery of substandard product. This could have detrimental and catastrophic effects on the performance and the integrity of the goods they are used in.

Rockwell Test Techniques

Following sound practice and complying with applicable standards is relatively straightforward and will greatly contribute to true and accurate results. Foremost to any Rockwell test process is identification of the proper hardness scale to be used on the component to be tested. There are 30 different Rockwell scales with the majority of applications covered by the Rockwell HRC and HRB scales for testing most steels, brass, and other metals. With the increasing use of materials other than common steel and brass, as well as requirements to test thin materials and sheet steel, a basic knowledge of the factors that must be considered in choosing the correct scale to ensure an accurate Rockwell test is necessary. The choice is not only between the regular hardness test and superficial hardness test, with three different major loads for each, but also between the diamond indenter and the 1/16, 1/8, 1/4 and 1/2 in. diameter steel ball indenters. Often an engineering specification is established at the material design phase and the operator can rely on documented scale requirements. If no specification exists or there is doubt about the suitability of a predetermined scale, an analysis should be made of the following factors that control scale

selection:

Test Scale

Type of material

Specimen thickness

Area / width

Test location

Material homogeneity

Scale limitations

Material Type

In the absence of a specified hardness scale the material type should be identified and compared with various tables that list the typical type of scale that is applicable to a given material. Usually this is based on historical data and empirical testing information. As a rule of thumb, using the heaviest load that the material can withstand is advisable as the larger indent will provide the greatest integrity and be minimally affected by material surface condition. Typically, diamond scale indenters are used on hardened steels and other very hard materials while the ball scales are more applicable to the brass, copper alloy, aluminum type of materials. While material composition knowledge is a necessary tool in scale selection, there are several other extremely significant material parameters that come into play in determining the proper test method and technique to be followed.

Material Thickness

Of primary importance in scale selection is the material thickness. Since the 30 Rockwell scales are distinguished by total test force, as well as the indenter type, a load or force that is excessive for the material thickness will be ultimately influence by the support anvil. Interruption in material flow such as this can will result in erroneous readings and significant misinterpretation of the actual material hardness. ASTM provides scale thickness requirements both in tabular as well as graphical form. It is recommended that these are used as a reference guide in deciding suitable scale based on material thickness. A general, albeit approximate only, rule is that the material should be a minimum of 10 times the depth of the indentation when using a diamond type indenter and at least 15 times the depth when using a ball type indenter. If necessary the actual depth of any indentation can be calculated to confirm this requirement is being met, but this is generally not necessary as the reference tables and graphs provide adequate information to make an educated decision. As a final rule, no deformation of the material should be evident on the supporting (underside) surface of the material.

Support

Specimen support is also extremely critical in Rockwell testing due to the fact that the method involves depth measurement. Any specimen movement is transferred to the indenter and the measurement system, resulting in an error being introduced into the test. With the precise nature of the test (keeping in mind that one Rockwell point on the regular scale equals 0.002 mm or 0.00008 of an inch) a movement of only 0.001 of an inch could cause an error of over 10 Rockwell points. The supporting anvil should be selected to match the specimen geometry and to provide full and uncompromised support and it is essential that the anvil is rigid enough to prevent any deformation during use. There are certain criteria that must be met on all anvils; a good reference is ASTM E18 where basic guidelines can be found including anvil hardness recommendations. The supporting

shoulder and the surface that the specimen sits on must be parallel to each other, and the anvil must present the test specimen perpendicular to the indenter. Both the supporting surface and the shoulder must be free of nicks, scratches and dirt, and be of sufficient design to properly support the material under test. Anvils should be checked on a regular basis, typically prior to each use, and if found too compromised they should be replaced. Damaged, nicked or dirty indenters can cause considerable drift and repeatability problems in hardness readings. A variety of standardized, as well as custom made fixtures, exist to accommodate the various specimen geometries that are tested. Some of the more common anvils include plane or flat anvils for supporting flat surfaces, the “V” style anvil for supporting cylindrical work, and the cylindron anvil for larger diameter parts. Another commonly used anvil is the pedestal spot anvil that has a small raised flat spot and is used when checking small, thin or irregularly shaped pieces as well as test materials not having a truly flat bottom. As it is essential that contact is made between the piece being tested and the part of the anvil immediately beneath the indenter, the small raised spot minimizes the effect that could be realized with non-flat test pieces by reducing the surface area of contact. Test pieces that are not flat should be placed on the spot anvil with the curved side down to ensure that solid contact is made with the anvil at the point of test. For support of thin sheet type product the diamond spot anvil is recommended, this anvil consists of a slightly raised, flat, polished diamond surface that supports the test piece and prevents damage and influence that might occur with a standard anvil. This anvil is only used with the 15 T or 30 T Rockwell scales. Using a diamond indenter with a diamond spot anvil is never recommended, as breakage of both the indenter and anvil is possible. The gooseneck anvil is recommended for testing outside diameter surfaces of thin walled tubing. It typically threads onto the tester lead screw or support holder and includes a mandrel at the top to support the part to be tested is placed over this mandrel to prevent material compliance during testing. Larger parts can be supported using large diameter test tables or a “T” slot style table that can be used to clamp the test piece to the table.

Due to the size and weight of the “T” slot table they can only be used with Rockwell® testers that actuate the indenter down to the stationary table that’s affixed to the base of the tester as opposed to introducing the part to the diamond via lead screw actuation. Another useful fixture is the Vari-Rest fixture that extends horizontally to support elongated pieces.

Perpendicularity

It is a fundamental requirement that the surface to be indented is perpendicular to the direction of travel of the indenter and that the test piece does not move or slip during the test cycle. A study showed that the effect on the HRC scale indicated a tilt angle of one degree between the specimen surface and the axis of the indenter could result in a 5% error in hardness. Tilt angle should never exceed 2 degrees to ensure accurate testing. The perpendicularity of the indenter to the specimen is influenced by many factors, including the opposing surfaces of the material, the supporting anvil, and the mechanical components in the tester. In addition, the indenter and indenter holder plays a crucial role in perpendicularity.

Indent Spacing

During specimen testing or coupon block verification, the spacing between indents, as well as from the material edge, must be properly maintained to prevent any adjacent indents or worked edge from influencing the next test.

The accepted criteria is that the distance from the center of any indentation shall be at least three times the diameter of the indentation. In regards to distance from material edge, the distance from the center of any indentation to the edge of the test piece shall be at least two and one-half times the diameter of the indentation. The purpose for these distances is to ensure that any indentation made is not influenced by work hardening and flow of material around the previous indentation. Also, the edge distance requirement ensures that the indentation's area of contact permits proper support.

Cylindrical Testing and Correction Factors

When testing on cylindrical surfaces the results will usually show a lower hardness value than if the material was flat. This condition is due to the curvature of the test piece and is dependent upon the applied force; the hardness of the material; the size and shape of the indentation; and the diameter of the test piece. If testing is to be used for control purposes only and all other factors are kept equal, (specimen diameter, scale and indenter), there will be sufficient information so that comparative data and subsequent testing is benchmarked. However, in most cases, it is better to compare the hardness of the rounded material with the hardness value of a flat piece, making correction factors necessary. In a cylindrical piece, the reduction in lateral support will result in the indenter penetrating further into the material which translates to lower hardness readings. If the diameter of the material is greater than 25 mm (1 inch) the surface will provide suitable surface structure for testing and corrections are not required. Lower diameter materials will need the correction factor added to the test result. Most digital Rockwell testers available provide the means to meet the cylindrical diameter and the correction factor will automatically be added to the result. In manual dial gage testers ASTM correction tables must be referenced to determine the correct factor to adjust by. Alternatively, and in contrast to convex surfaces, concave surfaces will provide higher material support due to the curvature towards the indenter and result in apparently harder material due to production of a shallower indent. In this case a correction factor must be subtracted. It should be noted that all corrections produce approximate results and should not be expected to meet exact specification. Also, it is critical to ensure the exact alignment of the indenter to the radius when cylindrical testing.

Surface Finish

As good practice, the material tested should be clean, smooth, and even. The degree of specimen surface roughness that can affect the hardness results is dependent on the Rockwell scale being used. Usually, the regular scales can tolerate a finished ground surface to obtain accurate results. However, as the applied forces get lighter, the surface's requirements become more influential and the need for a smoother surface becomes more important. For the lowest hardness test force, the 15 Kgf scales, a polished or lapped surface is recommended. Care should be taken when finishing any material prior to testing to avoid the possibility of causing a work hardened condition to the material.

Other Important Factors to Consider

Many basic but important factors should also be considered when conducting Rockwell tests.

Cleanliness of the material, the supporting anvils, indenters and any contacting surfaces, as well as the overall condition of the machine are crucial elements.

The instrument's environment should also be considered. Care to avoid areas where excessive vibration occurs will prevent any effects on the tester performance and hardness readings. Maintaining a consistent temperature range where the tester is placed should be ensured, ASTM recommends testing at ambient temperatures from 50–95° F (10-35° C). Operating the tester in temperature extremes may have adverse results on test data.

Daily indirect performance verification of the testing instrument is also important; the scales being used should be verified using standardized test blocks or coupons. If possible, it is recommended that the system is verified with each scale change and at each shift start-up. Blocks should be selected that are in the approximate range of the material being tested and used only on the calibrated side. Two “seating” indents should be made to set the anvils, block and indenter. These values should be discarded prior to actual recording of results. Five total readings should be made in the verification process; the measured values must fall within the tolerance stated on block and the block certificate. If verification fails, the machine should be removed from operation until the appropriate adjustments or repairs are made. Periodic visual inspection of the diamond and ball indenters for damage that could occur during testing should be carried out and compromised they should be replaced.

Finally, maintenance and authorized verification of the instrument is imperative to the continued smooth operation and assurance that the system meets the precision requirements of a Rockwell test. ASTM recommends annual maintenance and verification of a Rockwell tester and more frequent verification under heavy use or extreme conditions. Verification should be performed by an accredited verifying agency and the report should follow and reference ASTM E18 Rockwell test method.

Hardness testing is an important and useful tool in materials testing, quality control and acceptance, and performance of materials. We depend on the data produced to verify heat treatment, structural integrity, and quality of components to determine if a material has the properties necessary to ensuring that the materials utilized in the things we use everyday contribute to a well engineered, efficient, and safe world. Proper technique, procedure, strict adherence to standards, and following good practice will greatly contribute to the accuracy and usefulness of Rockwell testing.