Operation of Rockwell Hardness Testers

1 Introduction

The Rockwell hardness of a material is a measure of its ability to resist permanent deformation when in contact with an indenter under load. Hardness measurements can aid in determining material production characteristics (alloy class and heat treatment), degradation (during service or post-service exposure) and the uniformity of the material throughout a component. Components can also be tested to determine conformance with specified hardness requirements.

Due to fairly accurate quantitative relationships between hardness and other mechanical properties of materials, hardness tests can be used to estimate the tensile strength of some metals without the need to perform more destructive mechanical testing.

2 Scope

This document applies to personnel using the associated instrument(s)/equipment in the following disciplines/categories of testing: general physical and chemical analysis in support of metallurgy examinations. Hardness can be tested on components of any shape, as long as the part can be mounted in a fixture that provides sufficient support to isolate the test load application from any other load and that prevents contact between the component and any part of the indenter other than its tip.

3 Principle

The Rockwell hardness test is based on the difference of indenter depth from two load applications. An indenter is pressed into the material under an initial minor load to establish a zero point. A major load is then added, causing additional penetration into the specimen. After the specified dwell time for the major load, it is removed while still keeping the minor load applied. The resulting Rockwell number represents the difference between the zero level established by the minor load prior to the major load being deployed and the depth associated with the minor load after the major load is withdrawn.

There are two general classes of Rockwell test: Rockwell and superficial Rockwell. In Rockwell testing, the minor load is 10 kgf and the major load is 60, 100 or 150 kgf. In superficial Rockwell testing, the minor load is 3 kgf and major load is 15, 30 or 45 kgf. In both types of test the indenter may be either a diamond cone or a tungsten carbide ball. Each Rockwell scale is defined by the use of a specific indenter and major load. The appropriate scale will depend upon the size of the component to be tested and on its actual hardness.

4 Specimens

At a minimum, a specimen subjected to Rockwell hardness testing must be large enough to receive three hardness indentations. The centers of all indentations must be at least three indentation diameters apart and not less than two and one half diameters from all edges. The specimen thickness must be a minimum of 10 times the indentation depth for a homogeneous material and may be more for unfavorably oriented material. Tables correlating the minimum required specimen thicknesses with the measured hardness are available (see section 16 References). Adjustment of the test loads or indenter type may be necessary during testing to accommodate these requirements.

For accurate and precise measurement, the test surface presented to the indenter must be flat and perpendicular to the loading axis. The specimen may be ground using methods that do not impart elevated temperature or cold work that could alter the material hardness. Finish grinding is usually sufficient to provide reproducible measurements, but superficial testing may require a lapped or polished finish. Correction tables exist for measurements made on smooth, curved surfaces such as pipes and can be used when surface grinding is undesirable (see section 16 References). Prior to hardness testing of case samples, the user will verify the instrument performance using one or more CRM test blocks. The performance check procedure can be found in section 9 Procedure.

5 Equipment/Materials/Reagents

a. Rockwell Hardness tester, such as Wilson Model 524T Rockwell Hardness Tester, or equivalent, with diamond brale 120° cone or 1/16 inch diameter carbide ball indenter

b. Certified reference material (CRM) test block(s) appropriate for the hardness scale(s) in use

c. Various geometries of platens and specimen holders

d. Lint-free wipes

6 Standards and Controls

Adequate instrument performance is verified using CRM test blocks. CRMs will be tested and the results recorded every time the instrument is powered up for use or the load or indenter is changed. CRM blocks must be certified for the indenter and load (scale) of test performed in order to assure the indenter is seated properly, it contains no defects, and the load application is reliable. At least one CRM in the expected hardness range (within 15 Rockwell points if possible) of the sample must be tested prior to analysis. Additional blocks may be tested at the examiner's discretion, typically one above and one below the expected hardness range of the sample to be measured.

7 Calibration and Verification

The instrument is calibrated annually by a certified and licensed service provider that meets the LOM requirements. Prior to hardness testing of case samples, the user will verify the instrument performance using one or more CRM test blocks. The performance check procedure can be found in 9 Procedure.

8 Sampling

Whole components, or sections thereof, are typically presented to the indenter for hardness testing. Hardness readings should be interpreted to apply only to that material in the immediate vicinity of the indentation. Since cold work and thermal gradients during heat treatment can alter hardness, regions of a component with differing thickness, geometry and/or surface treatment should be examined separately.

Sampling of items examined under this protocol is determined by the nature of the evidence received and can consist of multiple items or one or multiple regions of interest on one item. Sometimes the physical nature of the sample will best lend itself to hypergeometric sampling or other standard random sampling methods. If large numbers of physically indistinguishable samples are received for Rockwell hardness testing, a sampling plan may be employed for testing. If the sampling plan will be used to make an inference about the population, then the plan will be based on a statistically valid approach. All of the samples may be tested at the examiner's discretion. Any sampling plan and corresponding procedure used will be recorded in case notes.

9 Procedure

9.1 Instrument Performance Check

a. Select an appropriate combination of indenter type and load (scale) for the samples to be tested. Some of the available tests include the following:

Rockwell Scale	Indenter	Load (kgf)
A	C diamond	60
B	1/16" carbide ball	100
C	C diamond	150
N-15	N diamond	15
N-30	N diamond	30
N-45	N diamond	45
T-15	1/16" carbide ball	15
T-30	1/16" carbide ball	30
T-45	1/16" carbide ball	45

For homogeneous bulk materials, either the Rockwell B or C scale is typically appropriate depending on the material properties. Superficial tests (N and T scale) may be run when the sample is too thin to use a B or C scale or when the indents produced would be too destructive. The A scale is used primarily for testing tungsten carbide and other very hard materials. The list above is not inclusive, and other Rockwell tests are available.

b. To ensure that the indenter is seated properly, make at least one hardness measurement on a suitable test piece using the maximum load for the indenter to be used; do not record these results. Repeat this step any time the indenter is changed during use.

c. Select a CRM test block for the hardness range and test scale being run. It is recommended that the hardness of a standardized test block and the sample fall within +/- 15 Rockwell points for carbide ball or diamond brale indenter tests. Alternatively, two standardized test blocks; one with a higher hardness and one with a lower hardness than the sample of interest, within the same scale, may be used for verification. Additional CRM test blocks may also be tested at the examiner's discretion.

d. Place the appropriate CRM block onto the specimen stage (platen). Measure only the certified side of the test block. Indentations made on the opposite side are not only invalid but may also deleteriously affect readings subsequently taken on the correct certified side of the block.

e. Raise the stage until the test block contacts the indenter and the minor load is applied. Adjust the zero offset of the scale if necessary.

f. Apply the major load. The instrument will indicate the end of the appropriate dwell time. For manual machines, release the major load. Read the Rockwell Hardness Number (HR) from the correct scale on the analog dial face. For an automatic tester, the major load is removed without intervention. The HR will appear in the electronic readout.

g. Repeat the test to obtain at least two readings from the CRM, adjusting the sample position away from the center of any previous indentations by at least three indentation diameters to avoid any plastically deformed or damaged material.

h. Ensure that the hardness readings are consistent with the hardness range reported on the CRM certification sheet. Alternatively, see 16 References (ASTM E18) to calculate the error E and repeatability R for comparison to the maximum tolerances given. If consistent hardness readings are not obtained, wipe the platen surface and the back of sample with a clean cloth to remove any debris from the standard and retest to verify. If this is not successful, replace the indenter and re-verify. If all efforts to alleviate inconsistent readings are unsuccessful, the instrument will be serviced and recalibrated by a certified and licensed service provider that meets the LOM requirements.

i. Record the date, operator, measured values, verification result and other appropriate information on the instrument log.

9.2 Sample Testing

a. Clean any loose debris or scale from both the specimen test surface and the support surface. Align the specimen so the test region is flat relative to the indenter geometry and the test region and support surface are perpendicular to the load axis. Curved surfaces may be tested subject to the limitations described below. Small components may be mounted in polymer molds to accommodate polishing. Mounted samples that rely on the mounting material to provide the support surface must be tested using a superficial hardness scale.

b. For steels, consult section 16 References (ASTM E18) for minimum thickness guidelines for the selection of the appropriate Rockwell scale. For other materials, the sample thickness should be a minimum of ten times the indentation depth. In general, materials with a surface hardness gradient (e.g. due to carburizing or alloy depletion) should be tested using the microhardness method.

c. For convex cylindrical surfaces, consult section 16 References (ASTM E18) for minimum diameter guidelines.

d. Mount the sample beneath the indenter on an appropriate platen or gripping fixture. Assure that the manner of mounting will support the applied test load, and the specimen will not move when load is applied.

e. Apply the minor load and inspect to assure that only the indenter tip will contact any part of the specimen.

f. Apply the major load. The instrument will indicate the end of the appropriate dwell time. For manual machines, release the major load. Read the measurement from the correct scale on the analog dial face. For an automatic tester, the major load is removed without intervention. The measurement will appear in the electronic readout.

g. If the measured hardness is outside of the range initially verified, repeat the performance check procedure in 9.1 with appropriate test block(s).

h. Repeat to acquire a minimum of three test readings. If comparative statistics are required, acquire additional readings in the areas of interest. Typically, 5 to 10 measurements per area will provide sufficient data for meaningful statistical comparisons.

10 Instrumental Conditions

The instrument must not be subject to vibration when the test is underway. The indenter must be seated securely and must be free of foreign material. Indenters must be free of nicks, broken edges or flat areas. Compromised indenters must be replaced, a new indenter securely seated, and the instrument must be performance checked..

The test load and indenter type used are dependent upon the hardness and shape of the material in the test region.

11 Decision Criteria

Verification is acceptable when the hardness values determined by the instrument on a given CRM fall within the range of values indicated on its certificate or if calculated E and R are within the maximum tolerances allowed (see step 9.1.h Instrument Performance Check). If the verification remains unsuccessful after assuring that the test block and indenter are sound, then the instrument must be serviced and re-calibrated by a certified and licensed service provider that meets the LOM requirements.

Variability in hardness measurements may be significant. If this occurs the results should not be averaged but should be reported individually or as a range for the area tested.

When evaluating whether sets of test readings from different locations on a single specimen or from different specimens are statistically distinguishable, a Student t-test of the local means will be employed.

12 Calculations

12.1 Quantitative Analysis

a. Hardness values are automatically calculated by the instrument software. These readings, and their associated measurement uncertainty, may be used to report a range or series of measurements.

b. To report averaged hardness measurements collected over a broader area, collect at least five values. Calculate and report the mean and expanded measurement uncertainty.

Mean is calculated as: $\bar{x} = \frac{\sum_{i=1}^{n} x_i}{n}$, where $\sum_{i=1}^{n} x_i$ is the sum of the measurements, n is the number of measurements and $\bar{x}$ is the mean hardness value.

c. In order to determine whether a part is of sufficient thickness, the depth of a Rockwell indentation can be calculated as follows (HR = Rockwell Hardness Number):

For a diamond indenter:

Depth (mm) = (100 – HR) x 0.002 mm

For a ball indenter:

Depth (mm) = (130 – HR) x 0.002 mm

For Rockwell superficial tests, regardless of indenter used:

Depth (mm) = (100 – Superficial Hardness Number) x 0.001 mm

Such values can also be interpreted from a table that relates maximum allowed hardness for a given thickness on a specific scale (see section 16 References, ASM Handbook vol. 8).

d. General correlation between hardness scales, e.g. Rockwell to Brinell, can be read from appropriate conversion charts (see step 14.e Limitations).

12.2 Comparative Analysis

Where quantitative data from two specimens are being compared, a pooled, two-tailed, Student-t test statistic of the sample means is typically used for the comparison. Two samples are deemed to be "indistinguishable" in the property under consideration if the two samples differ by less than the preselected critical t value ($t_{critical}$). The critical t value is typically chosen so that a value of $\alpha = 0.05$ can be achieved for the analysis and is determined by the degrees of freedom associated with the measurement. An $\alpha = 0.05$ means there is a 5.0% chance of incorrectly rejecting a match between two samples when one actually exists.

To perform this test, the means and variances of each sample are determined as follows:

The mean value: $\bar{x}_a = \frac{\sum_{i=1}^{n_a} x_i}{n_a}$ where $\bar{x}_a$ is the average value of the measurements on sample "a",

$\sum x_i$ is the sum of the individual measurements and n_a is the number of measurements made on that sample. The variance of the individual measurement values from sample "a" is given by:

$$s_a^2 = \frac{\sum_{i=1}^{n_a} (x_i - \bar{x})^2}{n_a - 1}$$

The mean and variance of the data from sample "b" are calculated in the analogous manner.

The pooled sample variance is then calculated as: $s_p^2 = \frac{(n_a - 1)s_a^2 + (n_b - 1)s_b^2}{(n_a + n_b - 2)}$

A standard two-tailed statistical test of the two sample means is performed.

If $\left| \frac{(\bar{x}_a - \bar{x}_b)}{\left(\sqrt{s_p^2 (\frac{1}{n_a} + \frac{1}{n_b})}\right)} \right| > t_{critical}$, the samples are concluded to have a statistically significant difference in hardness. If not, the samples are concluded to be indistinguishable in hardness.

Typically five or more measurements per sample are used for performing comparisons.

13 Measurement Uncertainty

In the event that it is necessary to calculate the expanded uncertainty of a measurement, it will be done in accordance with the Chemistry Unit *Procedures for Estimating Measurement Uncertainty*. Each time measurement uncertainty is calculated and reported, the repeatability component(s) will be updated. Often the variation present in a part production run, or allowed in a part specification, is substantially larger than the uncertainty contribution from the measuring instrument. In these cases, instrument measurement uncertainties will not be reported because they are considered negligible.

Quantitative data are sometimes used for comparative purposes. Expanded uncertainty should not be used for these inter-comparisons because it increases the probability that two samples will appear to be analytically indistinguishable and therefore increases the likelihood of type II errors (false inclusion).

14 Limitations

a. There is no upper hardness limit when using the diamond indenter for Rockwell testing. Because Rockwell diamond indenters are not calibrated below 20 HRC (Rockwell hardness C) points, they should not be used when the readings fall below this level. Rockwell scales using ball indenters range from 0 to 130 points; however, readings above 100 points should be avoided since the ball can be easily damaged. When testing with a ball indenter above 100 points, it is necessary to change the ball frequently to avoid measurement errors.

b. The material immediately surrounding the indentations is cold worked due to the plastic flow of material caused by the indentation process. Specimen geometry in this test region must not interrupt this normal flow. For example, measurements made on concave or convex surfaces will be altered by additional constraint, or lack thereof. Such measurements should be considered approximate. Estimated correction factors for some geometries are provided in section 16 References (ASTM E18).

c. Inhomogeneities in the plastic flow region of an indentation will adversely affect the hardness measurement. Materials with large inclusions or a surface hardness gradient may be better characterized using a microhardness method.

d. Cold work typically extends below an indentation to approximately ten times the indentation depth. It is recommended that the thickness of the specimen be a minimum of 10 times the indentation depth. For specimens of insufficient thickness to meet this requirement for an appropriate Rockwell scale, superficial Rockwell or microhardness testing may be considered. For steels, see section 16 References (ASTM E18) for minimum thickness guidelines for the selection of the appropriate Rockwell scale. These guidelines for appropriate specimen dimension are not to be substituted for the sound engineering judgment of the trained operator.

e. Conversion tables relating hardness values measured on different scales are only approximate and never mathematically exact due to the difference in cold working response of a material to the indenter shape and load applied. All conversion tables of hardness scales, including those in section 16 References, are based on the assumption that the metal tested is homogeneous to a depth several times as great as the indentation. If not, different loads and different indenter shapes would penetrate, or encounter the resistance of, metal of varying hardness depending upon the indentation depth.

Nevertheless, conversion is of considerable value when comparing different hardness scales in a general way.

f. Estimates of the tensile strength of carbon steels based on hardness measurements are generally considered to be accurate to ±10% of the estimated strength.

15 Safety

Standard safety precautions, such as wearing protective gloves, should be observed when handling evidentiary materials of hazardous nature. Electrical or mechanical hazards may require special precautions.

This instrument SOP has the following specific safety requirements:

- Wear safety glasses when making hardness indentations
- Wear personal protective gear and use engineering controls that are appropriate for the task being performed when preparing specimens.

If additional guidance is required, contact the Laboratory Health and Safety Group.

16 References

ASM Handbook, Volume 8, Mechanical Testing and Evaluation, ASM International, Materials Park, OH 2000, or latest revision

ASTM Method E18: *Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials*, ASTM International, West Conshohocken, PA, latest revision

ASTM Method E140: *Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Knoop Hardness, Scleroscope Hardness, and Leeb Hardness*, ASTM International, West Conshohocken, PA, latest revision

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FBI Laboratory Quality Assurance Manual, Federal Bureau of Investigation, Laboratory Division, latest revision

Rev. #	Issue Date	History
3	02/05/2014	Section 4 updated to align required indentation spacings with those of ASTM E18-12. Updated section 5 to reflect requirement to use a carbide ball in testing. Section 9.1 updated to include requirement to test specified test blocks when performing verification of the tester. Text amended to require verification measurements to be recorded in the instrument verification log. Minor formatting change made. Section 9.2 includes minor change in terminology. Minor grammatical change made in section 10. Section 11 updated to include requirement to include expanded estimate of uncertainty when reporting hardness values. Section 12 includes minor language updates. Formula for sample variance simplified. Typographical error in formula for variance of mean corrected. Section 13 has been rewritten to better reflect requirements on measurement uncertainty. Section 14 updated and reference source for correction factors added. Section 16. References have been updated.
4	12/21/2018	Renumbered Metallurgy SOP Manual documents; this document was formerly Metal 14 and is now designated Metal 701. Added personnel to section 2. Made minor editorial corrections throughout document. Added item to section 5. Revised sampling statement in section 8. Created a table in section 9.1 to clarify procedure. Separated quantitative and comparative calculations in 12. Added α and $t_{critical}$ selection process to 12. Added additional detail to section 14. Updated measurement uncertainty policy in section 13. Revised PPE requirements in section 15. Updated references section 16.

Approval

Redacted - Signatures on File

Metallurgy Technical Leader - Date: 12/20/2018

Chemistry Unit Chief - Date: 12/20/2018

QA Approval

Quality Manager - Date: 12/20/2018