Rockwell Hardness Testing

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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 case working personnel using the associated instrument in support of metallurgy examinations.

This document contains test procedures for quantitative and comparative analysis of Rockwell hardness on metal evidence. To evaluate a surface hardness gradient (e.g., due to carburizing or alloy depletion), a specimen should be tested using the microhardness method, METAL-520.

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 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minor load prior to the major load being deployed and the depth associated with the minor load after the major load is withdrawn.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

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, prevents contact between the component and any part of the indenter other than its tip, and presents a perpendicular surface to the indenter tip.

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 need to be more for unfavorably oriented material. Adjustment of the test loads or indenter type can be made during testing to accommodate these requirements when needed.

5 EQUIPMENT

- 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 as required by the hardness scale being used.
- Certified reference material (CRM) test block(s) appropriate for the hardness scale(s) in use
- Various geometries of platens and specimen holders
- Lint-free wipes

6 STANDARDS AND CONTROLS

Adequate instrument performance is verified using at least one CRM test block(s) every time the instrument is powered up for use or the indenter or test scale 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.

Additional CRMs near, or bounding, the hardness of the specimen(s) may be used during the procedure.

7 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.

8 PROCEDURE

8.1 Specimen Preparation

A. Clean all loose debris and scale from both the test surface and the support surface of the specimen.

B. Small components may be mounted in polymer molds to accommodate polishing. Follow steps for specimen mounting, grinding, and polishing in METAL-450. Mounted samples that rely on the mounting material to provide the support surface must be tested using a superficial hardness scale.

C. Ensure the specimen size is compatible with the test load.

1. Consult 9.1 Required Thickness for minimum thickness guidelines to select the appropriate Rockwell test scale.

2. For convex cylindrical surfaces, consult ASTM E18 for minimum cylinder diameter guidelines for the different Rockwell test scales.

8.2 Instrument Operation

8.2.1 Indentation Placement

A. Align a debris-free region of the test specimen beneath the indenter.

   1. Flat test surfaces must be perpendicular to the axis of load application.

   2. Curved test surfaces must be aligned so that deformation will be uniform on opposite sides of the indentation. That is, the plane tangent to the part curvature at the indentation point must be perpendicular to the load axis.

   3. Assure that the indentation will be placed not less than two and one half diameters from any edge or change in part geometry.

   4. Assure that multiple indentations on a single surface are separated by at least three indentation diameters to avoid interference by any plastically deformed or damaged material.

B. Support the specimen with a platen or gripping fixture in a manner that will support the applied test load perpendicular to the load axis and not allow the specimen to move during the load application.

8.2.2 Data Acquisition

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

B. Apply the major load. The instrument will indicate the end of the appropriate dwell time.

   1. For manual machines, release the major load. Read the Rockwell Hardness Number (HR) from the correct scale on the analog dial face.

   2. For an automatic tester, the major load is removed without intervention. The HR will appear in the electronic readout.

C. When testing on the Rockwell B scale, if the HR value of an indentation exceeds 100 points, change the indenter ball. Make one indentation on a test block to seat the indenter and continue the measurement series on the specimen. If additional HR values in the test series exceed 100 points, a different scale will be used (e.g. Rockwell C scale).

8.3 Verify Instrument Performance

8.3.1 Verify Calibration

A. Set up the instrument to use either the Rockwell B or C scale:

   1. Set the appropriate major and minor loads. (On an automated Rockwell tester, select the test sequence.)

   2. Install the appropriate indenter.

   3. Select a CRM test block within ±15 hardness points of one of the nominal test values on the most recent calibration certificate. 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.

B. Make one indentation to seat the indenter. (Do not record this value.)

C. Perform three indentations and record the values in the instrument logbook. Adjust the test position away from the center of any previous indentations by at least three indentation diameters to avoid interference by any plastically deformed or damaged material.

   1. If all three HR values are within the hardness range reported on the CRM certification sheet, record the PASS status in the instrument logbook.

   2. If any of the three HR values fall outside of the hardness range reported on the CRM certification sheet:

      i. Wipe the platen surface and the back of sample with a clean cloth to remove any debris from the standard and retest to verify.

      ii. If any of the retest values fall outside of the hardness range reported on the CRM certification sheet, replace the indenter and re-verify.

      iii. Calculate the average of the final three HR values.

         a. If the average falls outside of the hardness range reported on the CRM certification sheet, the instrument must be serviced and recalibrated by a service provider that meets the FBI Laboratory requirements. Record the FAIL status in the logbook.

         b. If the average falls within the hardness range reported on the CRM certification sheet, calculate the error, E, and repeatability, R, for comparison to the maximum tolerances allowed per ASTM E18.

1) If E and R are within the ASTM E18 tolerance, record the PASS status in the logbook.

2) If either E or R are outside of the ASTM E18 tolerance, record the FAIL status in the logbook. The instrument must be serviced and recalibrated by a service provider that meets the FBI Laboratory requirements.

8.3.2 Verify Range of Testing

A. Select an appropriate combination of indenter type and load (scale) for the evidentiary specimens to be tested. Some of the available tests are listed in Table 1. 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 indentations produced would be too destructive. The A scale is used primarily for testing tungsten carbide and other very hard materials. The list in Table 1 is not inclusive, and other Rockwell tests are available.

Table 1. Commonly Used Rockwell Hardness Scales

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

B. Select a CRM test block for the test scale and hardness range of interest.

1. The HR values of the verification test block and evidentiary specimen should fall within +/-15 Rockwell points for test scales that use carbide ball or diamond brale indenter. If this condition is met by the initial calibration verification, no further verification is required.

2. 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.

C. Perform 8.3.1 Verify Calibration on the selected test blocks with the appropriate scale and indenter. PASS/FAIL status for a scale or range other than that previously verified is limited to the tested scale and range.

8.4 Specimen Testing

A. Align the prepared specimen in the instrument and acquire a minimum of three hardness measurements.

1. Inspect the support surface of the specimen. If this back surface exhibits any deformation zone beneath the indentation, the specimen thickness is insufficient for the test load. Select a scale that uses a lower applied load and repeat 8.3.2 Verify Range of Testing on the new scale.

2. If the measured hardness is outside of the range initially verified, re-verify the instrument at the range of interest using the appropriate scale with appropriate test block(s).

3. 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 statistical comparisons.

B. Record the HR values and scale in the case notes.

9 CALCULATIONS

9.1 Required Thickness

The deformation zone beneath a hardness indentation must not penetrate through the specimen. Required specimen thickness can be determined from tabulated values or by calculation.

C. Interpret required thickness from a table that relates maximum allowed hardness for a given thickness on a specific scale, ASM Handbook vol. 8

D. Calculate required thickness as 10 times the depth of a hardness indentation as (HR = Rockwell Hardness Number):

1. For a diamond indenter:

   Depth (mm) = (100 – HR) x 0.002 mm

2. For a ball indenter

   Depth (mm) = (130 – HR) x 0.002 mm

3. For Rockwell superficial tests, regardless of indenter used:

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

9.2 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 measurements, collect at least five values. Calculate and report the mean and expanded measurement uncertainty.

   1. 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.

   2. Estimate measurement uncertainty as detailed in CHEM-100. Include the repeatability component of the evidentiary specimen.

9.3 Comparative Analysis

Where quantitative data from two specimens are being compared, a pooled, two-tailed Student's t-test statistic of the sample means will be used for the comparison, as detailed in METAL-210, Calculations section. Typically, five to ten measurements per sample are used for performing comparisons.

9.4 Hardness Conversion Estimate

ASTM E140 provides tables correlating hardness values between scales. The tables are material specific. To report an estimated conversion, report the original measurement and scale used, as well as the converted value and scale. Reference ASTM E140 and the table in the report.

9.5 Tensile Strength Estimate for Steel

ASTM A370 provides tables correlating steel hardness values to estimated tensile strength. The tables are material specific. To report an estimated tensile strength, report the original measurement and hardness scale used, as well as the estimated tensile strength value. Reference ASTM A370 and the table in the report.

10 Measurement Uncertainty

Quantitative data from this procedure are often used for comparative purposes. Expanded measurement uncertainty should not be used for these inter-comparisons because it increases the probability two samples will appear to be analytically indistinguishable and therefore increases the likelihood of type II errors (false inclusion). Instead, the variances associated with the samples and with data acquisition are accommodated by the statistical comparison.

When quantitative data are compared to a particular specification or when quantitative measurements are reported, the estimated measurement uncertainty will be calculated in accordance with CHEM-100. Measurement uncertainty is expected to be significantly influenced by composition, heat treatment, part geometry, and other factors. Since these factors are specimen dependent, the measurement uncertainty will include the repeatability of the evidentiary specimen HR values and will be calculated on a case-by-case basis.

Measurement uncertainty will not be calculated for converted hardness values or tensile strengths due to the approximate nature of the conversions.

11 ACCEPTANCE CRITERIA

11.1 Calibration

The system is calibrated annually by a service provider that meets the FBI Laboratory certification requirements. Calibration is demonstrated by the service provider for the Rockwell C (HRC) and Rockwell B (HRBW) scales.

11.2 Performance Check

A. Prior to the first use of the Rockwell hardness tester to make a significant measurement on a given day, the user will verify the calibration on either the HRC or HRBW scale and enter the verification results in the instrument logbook. See 8.3.1 Verify Calibration. 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. 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 service provider that meets the FBI Laboratory requirements.

B. If the evidence requires the use of a different scale than that used for the daily performance check, or if the measurements are on the same scale, but fall outside of the range verified, the user will verify the instrument performance using one or more CRM test blocks of the appropriate scale and range. See 8.3.2 Verify Range of Testing.

11.3 Quantitative Analysis Conclusions

Variability in hardness measurements may be metallurgically significant (i.e.., resulting from grain size differences, heat affected zones, or cold worked regions.). If this is observed, the hardness results should not be averaged but should be reported individually or as a range for the area tested.

11.4 Comparative Analysis Conclusions

When evaluating whether sets of test readings from different locations on a single specimen or from different specimens are statistically distinguishable, a Student’s t-test of the local means will be employed.

12 LIMITATIONS

A. Measurements made on convex or concave surfaces will be affected by additional material constraint, or lack thereof. Even after applying correction factor(s), such measurements should be considered approximate.

B. 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 the microhardness method, METAL-520.

C. Conversion tables relating hardness values measured on different scales, including those in ASTM E140, are only approximate due to the difference in cold working response of a material to the indenter shape and load applied. Nevertheless, conversion is of considerable value when comparing different hardness scales in a general way.

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

13 SAFETY

A. Wear safety glasses when making hardness indentations.

B. Wear personal protective gear and use engineering controls that are appropriate for the task being performed when preparing specimens.

14 REFERENCES

- CHEM-100, Quality Assurance and Operations Manual, FBI Laboratory, Chemistry Unit, latest revision
- METAL-210, Examinations for Association or Origin, Chemistry Unit, latest revision
- METAL-450, Metallography, Chemistry Unit, latest revision
- METAL-520, Microhardness Testing, Chemistry Unit, latest revision
- ASTM E18: Rockwell Hardness of Metallic Materials, ASTM International, West Conshohoken, PA, latest revision
- ASTM E140: Standard Hardness Conversion Tables for Metals Relationship Among Brinell Hardness, Vickers Hardness, Rockwell Hardness, Superficial Hardness, Knoop Hardness, and Scleroscope Hardness, ASTM International, West Conshohoken, PA, latest revision
- ASTM A370: Standard Test Methods and Definitions for Mechanical Testing of Steel Products, ASTM International, West Conshohoken, PA, latest revision

- ASM Handbook Volume 8: Mechanical Testing and Evaluation, ASM International, Materials Park, OH, latest revision

15 Revision History

Revision	Issued	Changes
05	09/30/2022	Revised to comply with new formatting requirements. Distributed information from previous Instrumental Conditions and Decision Criteria sections into Acceptance Criteria and Procedure sections. Removed informational references. Added operational references.