

A Review Study of Materials Testing in Hardness

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Abstract:

The main purpose of hardness testing is to evaluate a material's suitability or treatment history, taking into account factors such as the indenter type, geometry, and applied load. Hardness tests are frequently used in quality control to ensure materials conform to client specifications and industry standards, which typically define acceptable hardness ranges.

In engineering, achieving a balance between hardness and other material properties is vital, as harder materials can resist wear but may also be more brittle and less ductile. This consideration is especially critical in the aerospace sector, where materials face extreme conditions.

Ultimately, in manufacturing, a material's hardness significantly influences product quality, including its durability, functionality, and overall performance.

Keywords: Brinell Hardness Test; Rockwell Hardness Test; Vickers Hardness Test; Functions and Errors in the Hardness Testing; Quality Control; Material Selection; Failure Analysis.

1. Introduction

Hardness refers to a metal's resistance to scratching or penetrating by other materials. It reflects a material's capability to scratch others or its resilience to being scratched. The hardness of a material is assessed by comparing it to ten well-known minerals ranked on a scale from 1 to 10. Each mineral can scratch the one below it in sequence and can be scratched by those above it.

In terms of physical properties, hardness signifies the degree to which a metal can resist scratches and wear. It can be evaluated by noting how readily or difficulty a metal can be scratched by a sharp object, such as a pin or knife blade. Hardness levels in metals vary significantly; for instance, talc has a low hardness that can be scratched by a fingernail, while diamond ranks at the top as the hardest known natural and synthetic material. Hardness is a vital physical characteristic for metals because it can be quickly assessed, aiding in metal identification.

The hardness of metals is comparatively defined through the Mohs hardness scale, which ranks ten minerals from the softest (talc) to the hardest (diamond). The following is the standard Mohs hardness scale: Talc (1); Gypsum (2); Calcite (3); Fluorite (4); Apatite (5); Feldspar (Aluminosilicate) (6); Quartz (7); Topaz (8); Corundum (9); and Diamond (10).

To assess the hardness of various materials, they must be compared with minerals on this scale. A basic understanding of the hardness of metals can be gained using everyday items such as a fingernail, copper coin, knife blade, or piece of glass. Their hardness ratings are as follows: Fingernail (2); Copper coin (2.5 to 3); Knife blade and glass (5.5).

In precise testing environments, like manufacturing facilities that create tools and gears, a device known as a sclerometer is employed. This instrument measures the force required to scratch a test material using a diamond or equivalent borazon, the hardest known substances.

To ascertain the hardness of a metal, one might begin by scratching it with a fingernail or pencil point to gauge its position relative to other metals. Testing its surface with adjacent metals can help clarify where it lies on the hardness scale. For example, if pyrite scratches orthoclase (level 6) but does not scratch the mineral following orthoclase, its hardness is understood to be between orthoclase (6) and quartz (7), approximately (6.5). If two minerals have the same hardness, they will scratch each other equivalently. It is essential to differentiate between actual scratching and the resulting scratch mark, as the latter is simply the powdered residue from friction as the trace of a chalk on a blackboard (one would not claim that chalk is harder than the

blackboard). Scratching is a permanent characteristic that cannot be erased from the surface of the metal, while the scratch mark can be easily removed. Also, the length of scratches should be minimized to no more than a quarter of a centimeter to maintain the integrity of the metal sample.

It is important to note that the numbers assigned in the Mohs hardness scale indicate relative hardness; it is inaccurate to claim that diamond is ten times harder than talc, as the difference is much more significant. Additionally, the disparity in hardness between adjacent metals on the scale varies; for example, the hardness difference between corundum (9) and diamond (10) is considerably greater than that between talc (1) and corundum (9).

Rough approximations of hardness can be determined using the following: Fingernail: up to 2.5; Window glass: up to 5.5; Copper coin: up to 3; Scratching board: up to 6.5; Knife blade: up to 5.5; Hard files: 6-7.

Since most metals have a hardness rating below 7, this straightforward method allows for a quick assessment of a metal's hardness in both laboratory and field settings.

When selecting gemstones, jewelers often start with a hard file. If the file makes a scratch on the tested material, its hardness is deemed to be below 4. Many imitation stones, particularly those made of glass, typically fall below a hardness of 7, whereas most genuine gemstones have a higher hardness. This simple test using a hard file is effective in distinguishing between imitation and genuine gemstones.

Hardness testing, as one of the cornerstones of Materials Engineering, is a fascinating area you should delve into. It's an essential quality control process that aids in determining the suitability and sustainability of materials for various applications. Let's start by comprehending what hardness testing truly means.

In more in-depth terms, hardness testing evaluates the hardness level of a material by measuring the depth or area of indentation left by an indenter of a specific shape, with a specific force applied to it for a specific time. There are also dynamic methods where the sensitivity of the rebound of a defined impact body is measured.

The determination of material hardness is not a fundamental property like mass or length, but a material's response to a specific test method. It's fascinating to note that the result can be related to properties such as strength or wear resistance.

Numerous interesting methods have been developed for hardness testing, from techniques that suit large, rough castings to methods that provide extreme precision needed for tiny components or delicate surfaces. Below is a

list highlighting a few of the most common methods used in hardness testing:

Rockwell Hardness Testing: Measures the permanent depth of indentation.

Brinell Hardness Testing: Involves applying a known load to the surface of the test sample via a hardened steel or carbide ball.

Vickers Hardness Testing: Utilizes an optical measuring system to measure the area of the impression [1] – [15].

2. Engineering Materials Testing

The main objective of hardness testing is to evaluate a material's suitability or the specific treatment it has received. When interpreting the hardness value, it's essential to take into account the type and geometry of the indenter used, as well as the load applied to it.

Hardness tests are frequently performed in a field setting as part of quality control to ensure that a material complies with client specifications, material standards, or codes. These specifications typically define a minimum acceptable value, a maximum limit, or an allowable range.

In engineering contexts, it's vital to find a balance between hardness and other material properties. For example, while harder materials generally offer enhanced wear resistance, they can also become more brittle and less ductile. This balance is especially critical in the aerospace sector, where materials must withstand extreme conditions.

In manufacturing, the importance of a material's hardness in production processes cannot be overstated. The level of hardness directly influences product quality, affecting aspects like durability, functionality, and overall performance.

Mechanical testing encompasses a wide array of tests that can be broadly categorized into two types:

- i. Tests aimed at determining the mechanical properties of the material, independent of engineering considerations.
- ii. Tests that assess how a structure responds to specific actions, such as testing composite beams or aircraft structures until failure.

Numerous tests, many of which are standardized, exist to evaluate various mechanical properties of materials. Generally, these tests are intended to yield properties that are intrinsic to the bulk material and not influenced by engineering factors. However, in practice, this can be challenging since certain properties in tensile tests, for instance, may be affected by the sample's size or geometric shape. Below is a list of some of the most commonly used hardness tests [1] – [20].

2.1 Brinell Hardness Test

In this test, a hard ball is pressed against the surface of the metal being evaluated, and the hardness is determined using the Brinell factor. This factor is based on the load applied during the pressing and the size of the indentation made by the ball in the metal, as follows [1] and [2]:

$$\text{Brinell hardness number} = \frac{2W}{\pi (D - \sqrt{D^2 - d^2})}$$

Where:

WW is the load used in kg.

DD is the diameter of the ball used in mm.

dd is the diameter of the impression left by the ball in the metal in mm.

Figure 1 below illustrates the mechanism of the Brinell hardness test.

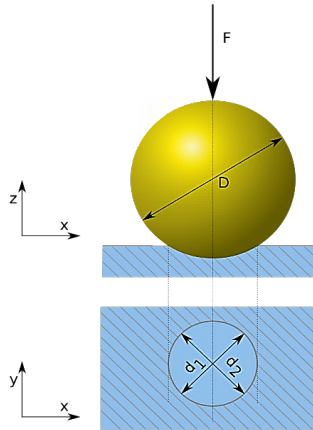


Figure 1 The Mechanism of the Brinell Hardness Test

Figure 2 below shows a schematic diagram of a Brinell hardness testing machine.

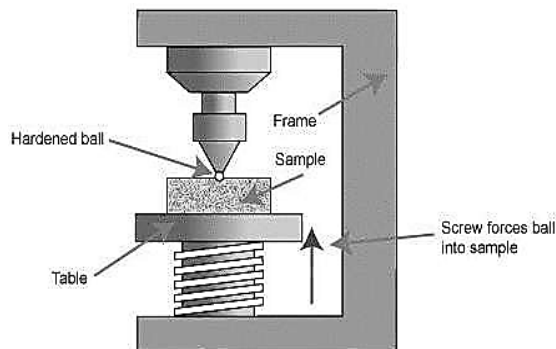


Figure 2 A Schematic Diagram of a Brinell Hardness Testing Machine

2.2 Rockwell Hardness Test

In this test, a diamond cone with a vertex angle of 120 degrees is pressed into the material being evaluated, and the hardness is determined by measuring the depth of penetration of the cone under a load that varies according to the hardness of the material being tested. Generally, the load and the testing methodology can be categorized into the sections outlined in Table 1 below [1] – [5]:

Table 1 Types of Loads and the Methods used in Rockwell Hardness Test

Test Type	Initial Load	Total Load	Test Tool Shape
RHA	10 kg	60 kg	Angle Cone (120 degrees)
RHB	10 kg	100 kg	Ball (2.5 mm diameter)
RHC	10 kg	150 kg	Angle Cone (120 degrees)

Figure 3 below illustrates the Rockwell hardness test for the bolt.

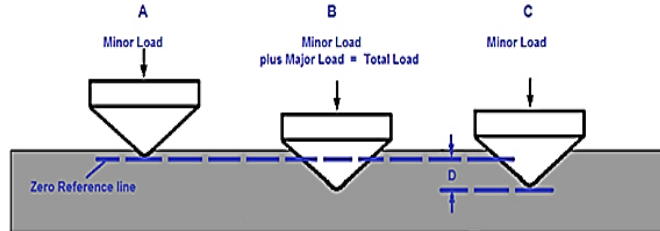


Figure 3 The Rockwell Hardness Test for the Bolt

Figure 4 below illustrates a Rockwell hardness testing device.



Figure 4 A Rockwell Hardness Testing Device

2.3 Vickers Hardness Test:

This technique is mainly utilized to assess the hardness of the thin surface layer of metal produced by specific heat treatments. Additionally, it is suitable for evaluating the hardness of extremely hard materials and components with small cross-sections. The hardness measurement involves pressing a tetrahedral diamond pyramid, which has a vertex angle of 136 degrees, into the material under loads varying from 5 kg to 140 kg. The area of the resulting indentation is subsequently measured with a microscope, and the hardness is calculated using the following formula [1]- [10]:

$$\text{Vickers Hardness Number, } H_v = \frac{\text{load}(W)}{\text{area of impression}}$$

It should be noted that the pressure on the sample being tested should be maintained for a duration of at least 15 seconds.

Figure 5 below illustrates the Vickers hardness testing device.



Figure 5 The Vickers Hardness Testing Device

The Vickers hardness test, introduced by Smith and Sandland in 1924 at Vickers Ltd, serves as an alternative to the Brinell method for assessing the hardness of various materials. This method is often more user-friendly compared to other hardness tests, as the calculations are not influenced by the size of the indenter, allowing it to be applied to materials of any hardness level.

The fundamental principle behind the Vickers hardness testing apparatus, similar to other widely-used hardness scales, is to evaluate a material's resistance to plastic deformation caused by a standardized force. The Vickers hardness tester is suitable for all metals and boasts one of the most extensive scales among hardness testing methods. The hardness measurement obtained from this test is referred to as the Vickers pyramid number (HV) or diamond

pyramid hardness (DPH).

To meet the requirements of the Vickers hardness test, the indenter must be designed to produce geometrically consistent impressions regardless of its size, creating well-defined measurement points, while also exhibiting high resistance to deformation. A square pyramid diamond fulfills these criteria. Below, Figure 6 illustrates the Vickers hardness test procedure [1] – [15].

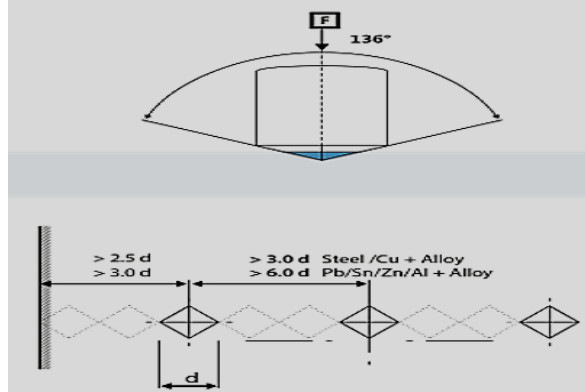


Figure 6 The Vickers Hardness Test

3. Common Errors in the Hardness Testing Process

Although hardness testing may appear simple, several common mistakes can compromise the accuracy of your results. Here are a few to watch out for:

3.1 Insufficient Surface Preparation

Proper surface preparation, including grinding and polishing, is crucial. Minor imperfections can significantly influence the hardness reading.

3.2 Incorrect Test Force

Any variation in the applied test force, whether it's the preload or the main load, can lead to erroneous outcomes. Regular calibration is vital to maintain accuracy.

3.3 Relying on a Single Measurement

A frequent mistake is depending on a single reading. It is advisable to take multiple measurements from various locations and compute the average for more reliable results.

3.4 Using the Wrong Indenter or Tester

Employing an inappropriate indenter or tester for the specific scale can result in inaccurate readings.

By steering clear of these common missteps, hardness testing can serve as a reliable and insightful method in materials engineering. It is essential to follow the prescribed procedures meticulously to ensure accuracy in hardness testing [1] – [15].

4. The Importance and Function of Hardness Testing

Contrary to popular belief, the main purpose of hardness testing extends beyond merely measuring a material's hardness. Its true value lies in offering a comprehensive understanding of the material's characteristics and insights into its mechanical performance.

Consider the advantageous traits that hardness tests can uncover:

- i. Wear resistance
- ii. Resistance to plastic deformation
- iii. Elasticity level
- iv. Fracture tendency

More generally, hardness testing serves as an indicator of various other material properties [1] – [3].

5. The Essential Role of Hardness Testing in Engineering Materials

Hardness testing is vital across various phases of a product's life cycle in engineering materials, including selection, production, quality control, and failure analysis. Assessing the hardness of a material provides critical insights into its appropriateness for specific applications. This information helps engineers determine whether a material can endure the anticipated forces without deforming, wearing out, or failing. Additionally, hardness testing contributes to:

5.1 Quality Control

Hardness testing is routinely employed to monitor product quality during production, ensuring that items conform to established hardness specifications.

5.2 Material Selection

In the early stages of material selection, hardness testing assists in identifying appropriate materials that fulfill the necessary functional criteria for parts, components, or structures.

5.3 Failure Analysis

Analyzing indents from hardness tests can aid in failure analysis by pinpointing brittle areas or anomalies resulting from improper heat treatment or surface hardening.

In summary, hardness testing significantly reduces the time and costs associated with trial and error in material selection and production, all while guaranteeing optimal performance of products or structures. It is a vital tool in materials engineering with the potential to make a significant impact [1] – [20].

6. Conclusions

Hardness testing offers several advantages, such as requiring minimal specimen size and the ability to perform tests on-site without damaging

materials. It provides valuable information on surface quality, wear resistance, and heat treatment.

However, there are notable drawbacks to hardness testing:

- i. **Limited Insight:** It primarily assesses resistance to deformation, lacking insights into other mechanical properties like toughness and ductility.
- ii. **Surface Sensitivity:** Results can be affected by surface conditions (e.g., roughness and coatings), potentially leading to inaccuracies.
- iii. **Scale Variability:** Different hardness scales yield varying results, complicating material comparisons without standardization.
- iv. **Size Restrictions:** Some tests require specific sizes and shapes, limiting their applicability.
- v. **Destructive Nature:** Many tests can alter or damage small or delicate samples.
- vi. **Operator Dependency:** The skill of the operator can impact accuracy, resulting in inconsistent outcomes.
- vii. **Calibration Needs:** Regular equipment calibration is necessary for precise measurements.
- viii. **Temperature Sensitivity:** Hardness can change with temperature, requiring controlled testing conditions.

In conclusion, while hardness testing is effective for material characterization, its limitations suggest the need for complementary methods to fully understand material properties.

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