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Experimental Investigations of Rockwell Hardness Test

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Abstract: The Rockwell hardness test is a widely used method for evaluating the hardness of materials, particularly metals. This research paper explores the principles, applications, and significance of the Rockwell hardness test in material science and engineering. The paper delves into the testing procedure, including the selection of scales, test loads, and indenters, as well as the interpretation of hardness values. It discusses the advantages of the Rockwell test, such as its simplicity, speed, and ability to provide reliable hardness measurements. Additionally, the paper examines factors that can influence Rockwell hardness results, such as material composition, surface finish, and testing conditions. Understanding the Rockwell hardness test's fundamentals and considerations is crucial for accurate material characterization and quality control in various industries, from manufacturing to aerospace engineering.

***Index Terms* - Rockwell hardness test, Material science engineering, Hardness, Evaluation, Quality.**

I. INTRODUCTION

The data collection period is ranging from January 2010 to Dec 2014. Monthly prices of KSE -100 Index is taken from yahoo finance. The Rockwell hardness test is a fundamental method used to measure the hardness of materials, particularly metals, by assessing their resistance to indentation. Developed in the early 20th century by Hugh M. Rockwell and Stanley P. Rockwell, this test has become a cornerstone in material science and engineering for evaluating the mechanical properties of various materials.

The principle behind the Rockwell hardness test is relatively straightforward yet highly effective. A standardized test procedure involves applying a minor load, often referred to as the preload or preliminary load, to set the indenter in the material's surface. Following this, a major load is applied, causing the indenter to penetrate the material to a predetermined depth. The major load is then removed, leaving the minor load to maintain the indentation depth. The Rockwell hardness value is determined based on the difference in indentation depths under the major load and minor load conditions.

The Rockwell hardness test holds immense importance in engineering and manufacturing industries for several reasons. Firstly, it provides a quantitative measure of a material's hardness, which is crucial for assessing its suitability for specific applications. For example, in the automotive industry, Rockwell hardness testing is used to ensure the durability and strength of engine components, gears, and bearings. Similarly, in the aerospace sector, this test helps evaluate the hardness of structural materials used in aircraft components.

Moreover, the Rockwell hardness test plays a vital role in quality control processes. By establishing standardized testing procedures and criteria, manufacturers can maintain consistent product quality and meet industry standards and regulations. It also aids in identifying material defects, variations in hardness across batches, and potential issues that could affect product performance and reliability.

In conclusion, the Rockwell hardness test serves as an indispensable tool for engineers, researchers, and manufacturers seeking to understand and characterize the mechanical properties of materials. Its simplicity, accuracy, and broad applicability make it a cornerstone in material testing and quality assurance across various industries.

Types –

There are several types of Rockwell hardness testing machines, each designed for specific applications and levels of precision. Here are some of the common types.

Regular Rockwell Hardness Tester: This is the standard type of Rockwell hardness testing machine. It typically includes a dial gauge for reading hardness values and is suitable for general hardness testing across a wide range of materials.

Superficial Rockwell Hardness Tester: This type of tester is designed for measuring the hardness of thin materials, surface treatments, and coatings. It uses lower test forces and shallower indentations compared to regular Rockwell testers, providing more precise readings for softer materials.

Twin Rockwell Hardness Tester: Also known as dual-scale Rockwell testers, these machines allow for testing on both the regular Rockwell and superficial Rockwell scales. They offer versatility in hardness testing, enabling users to assess a wide range of materials with varying hardness levels.

Digital Rockwell Hardness Testers: Replace traditional dial gauges with digital displays, providing more accurate and easily readable hardness values. They often include features such as automatic loading, data storage, and computer connectivity for data analysis and documentation.

Automatic Rockwell Hardness Tester: These testers automate the testing process, including loading and unloading test forces, making them ideal for high-volume testing environments. They offer consistent and repeatable results while reducing operator fatigue and errors.

Micro indentation Rockwell testers: Designed for testing extremely small and delicate samples, micro indentation Rockwell testers use very low test forces and specialized indenters to measure hardness at microscale levels. They are commonly used in research and development labs for studying thin films, coatings, and microstructures.

Portable Rockwell Hardness Tester: These testers are compact and light weight, designed for on-site or field hardness testing where portability is essential. They are often used in industries such as construction, aerospace, and maintenance to assess hardness without the need to transport samples to a lab.

Working principle-

The Rockwell hardness test is a widely used method to measure the hardness of materials, particularly metals, based on their resistance to indentation. Understanding its working principle involves exploring the test procedure, the role of test loads and indenters, and how hardness values are calculated and interpreted.

Figure 1. Rockwell Hardness Testing Machine. (front View)

Figure 2. Rockwell Hardness Testing Machine. (Side view)

II. Test Procedure

The Rockwell hardness test involves several key steps-

1. Preload Application: The test begins with applying a minor load, also known as the preload or preliminary load, to the material's surface. This preload is typically lighter and serves to set the indenter in the material without causing significant indentation.
2. Major Load Application: After the preload, a major load is applied to the material. This major load is much higher than the preload and causes the indenter to penetrate the material to a specified depth, typically measured in units of millimeters or inches.
3. Unloading: Once the major load is applied for a specific duration (dwell time), it is removed, leaving only the minor load to maintain the indentation depth
4. Depth-Measuring System: The indentation depth under the major load and minor load conditions is measured using a depth-measuring system integrated into the Rockwell hardness testing machine.

The Rockwell hardness test employs different combinations of test loads and indenters to accommodate various material hardness levels. The most commonly used scales are Rockwell B (HRB) and Rockwell C (HRC), each with specific test parameter.

5. Rockwell B Scale: This scale uses a 1/16-inch diameter hardened steel ball indenter and test loads ranging from 100 to 150 kilograms-force (kgf). It is suitable for softer materials such as aluminum, copper, and softer steels.
6. Rockwell C Scale: The Rockwell C scale utilizes a diamond cone-shaped indenter with a 120-degree angle and test loads typically ranging from 150 to 1500 kilograms-force (kgf). It is designed for harder materials like hardened steel, tool steel, and cemented carbides.

III. Calculation and Interpretation

The Rockwell hardness value (HR) is calculated based on the depth of penetration under the major load and minor load conditions. The difference in indentation depths is measured and converted into a hardness value using a standardized formula. This formula includes correction factors to account for variations in test conditions and material properties. Interpreting Rockwell hardness values involves understanding the scale used (e.g., HRB or HRC) and the material being tested. Higher Rockwell hardness values indicate greater resistance to indentation, reflecting a harder material. Conversely, lower values indicate softer materials.

IV. Working Principle in Depth

Indentre Design: The choice of indenter, whether a ball or a diamond cone, influences the test's sensitivity to material hardness. The ball indenter provides a broader contact area and is suitable for softer materials, while the diamond cone offers a smaller contact area and is ideal for harder materials.

Load Application: The test loads applied during the Rockwell hardness test are carefully selected to ensure adequate indentation without excessive deformation. The major load should be sufficient to penetrate the material to a measurable depth, while the minor load maintains the indentation for accurate depth measurement.

Depth Measurement: Modern Rockwell hardness testing machines feature precise depth-measuring systems, often utilizing optical or electronic methods. These systems ensure accurate and repeatable depth measurements, critical for obtaining reliable hardness values.

Standardization: The Rockwell hardness test is standardized by organizations such as ASTM International and the International Organization for Standardization (ISO).

Standardized procedures, test loads, indenters, and calculation formulas ensure consistency and comparability of hardness values across different laboratories and industries.

In summary, the Rockwell hardness test works by applying controlled loads and indenters to measure a material's resistance to indentation. Its versatility, accuracy, and standardized procedures make it a valuable tool for evaluating material hardness in various applications, from quality control in manufacturing to material characterization in research and development.

V. THEORY

Current practice divides hardness testing into two categories: macro hardness and micro hardness. Macro hardness refers to testing with applied loads on the indenter of more than 1 kg and covers, for example, the testing of tools, dies, and sheet material in the heavier gages. In micro hardness testing, applied loads are 1 kg and below, and material being tested is very thin (down to 0.0125 mm, or 0.0005 in.). Applications include extremely small parts, thin superficially hardened parts, plated surfaces, and individual constituents of materials.

1) Macro Hardness Testers Loads > 1 kg
- Rockwell
- Brinell
- Vickers

2) Micro Hardness Testers < 1 kg.
- Knop diamond
- Vickers diamond pyramid.

VI. EXPERIMENTAL DATA

A number of researchers have worked on the evaluation of the effects produced by the different definition parameters on the hardness measurement results, and the main contributions have been collected by F. Petik in a OIML publication8. One can observe that, mainly for questions involving the indentation pattern (velocities and loading times) the results are not always consistent. Many arguments were posed in the past on the effect of load increasing time and the relevant indenter velocity. Both parameters seemed to have very significant effect, so that the standard for hardness block calibration presented an alternative for standardizing machines: «constant velocity» machines, for which the velocity was defined, and «variable velocity» machines, for which was defined the load increasing time. It is clear that it is quite difficult to assign separately to the velocity or to the time the effect on measurement results, because, in general, the experimental variation of velocity involves a strongly correlated variation of time. The said correlation, together with other correlated effects can produce different patterns of results and, consequently, significant differences among the researchers can be expected. We have decided, therefore, to examine deeply these two parameters.

VII. WORKING PRINCIPLE IN DEPTH EFFECTS OF VELOCITY AND TIME INTERVAL

During a meeting for organizing a European comparison Marriner of NPL proposed a simple experiment for demonstrating that the main effect is due to the velocity of the indenter in the last part of major load application. He proposed to measure hardness on a very hard block (60 HRC) with a normal hardness tester provided with dashpot for the control of the load increasing phase. If, during that phase, one moves the operating crank by hand, accelerating or decelerating the movement, he will produce significant variations of velocity and, consequently, of time. When this is done only in the first part of major load application and the last part of indentation is performed with the natural movement of the tester undisturbed, one obtains consistent results with small variations. On the contrary, when the final velocity is changed, modifying the set point of the dashpot, even keeping by hand the time nearly equal as before, one obtains results with large, systematic variations.

The proposed experiment is based on a separation of the variations of velocity and of time. The natural, strong connection between velocity and time is such that it is not easy to separate the relevant variations. Probably the best in this direction can be done with the hardness standard machine developed at IMGC9, that has a feedback system to control the indenter velocity at any point of the load increasing phase.

The parameters describing the indentation cycle are many (Fig. 1), and very important are the approach velocity V0, the velocity during the preloading phase and the initial part of the loading phase V1, the velocity of the last part of the loading phase VLR, the preload dwell time TP, the major load increment time TL and the total load dwell time TM. Fortunately, it is possible to consider some of these parameter as independent from the others, so that they can be tested alone. For other parameters a correlation is possible, so they shall be tested together.

The experiments done were aimed to evaluate the effects of V0, tested alone, of V1 and TP, tested together, of VLR and TL, tested together, and of TM, tested alone. For the parameters tested together the experimental plans should be of the factorial type, but this is not possible even with the wide capabilities of the IMGC machine. The experimental plans are described

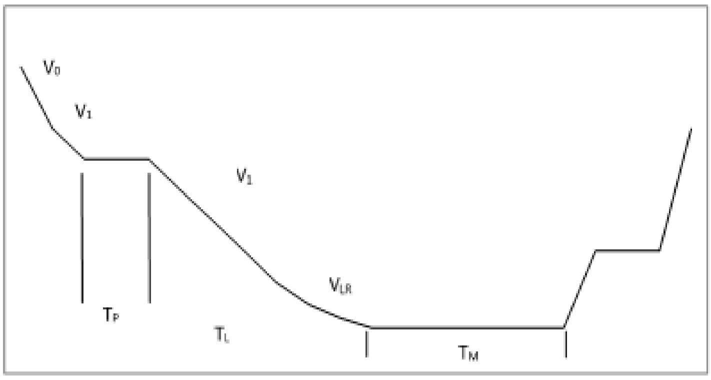
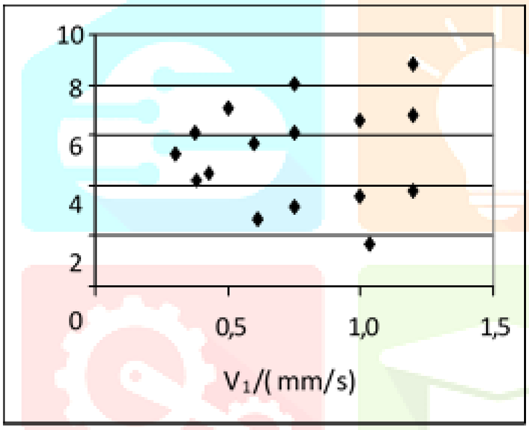


Figure 3. Main parameters describing the indentation cycle.



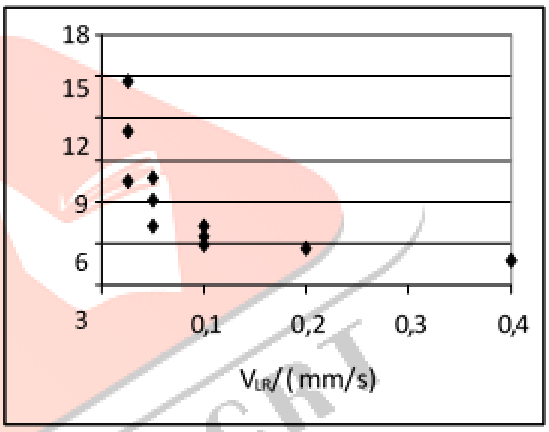


Figure 4.1 Plots of the experimental plans Figure 4.2 Plots of the experimental plans

Fig. 4.1 Plots of the experimental plans 1adopted for the evaluation of V1, VLR, TP and TL. in Fig. 4.2, which shows the position of the experimental points. It is evident that the measurement points for V1 and TP are practically uncorrelated, while the correlation level for VLR and TL is significant, mainly when the velocity is higher than 100 µm/s. Remembering that the interesting part of the velocity field is only up to 50 µm/s or at maximum 100 µm/s the situation is acceptable.

3.1 Approach velocity

The effect of approach velocity is very small. In the field examined, from 0,1 mm/s to 1 mm/s only at low hardness there is a significant effect with a slope coefficient of 0,14 HRC/(mm/s) (standard deviation 0,04 HRC/(mm/s)) as shown in Table 1. For medium and high hardness, the slope is not significant at all. In any case, the amount of expected variation for the specification tolerance (V0<0,5 mm/s) is negligible

3.2 Total load dwell time

The effect of total load dwell time is given in Fig. 3. It depends on the creep characteristic of the material tested, therefore should be checked during the test itself. This condition has been evaluated for different material10, and should, logically, require a tolerance depending on the material tested, as was established in a old ASTM standards (indicating to keep the load on until the gauge pointer stops). A proposal10 to define the dwell time in connection.

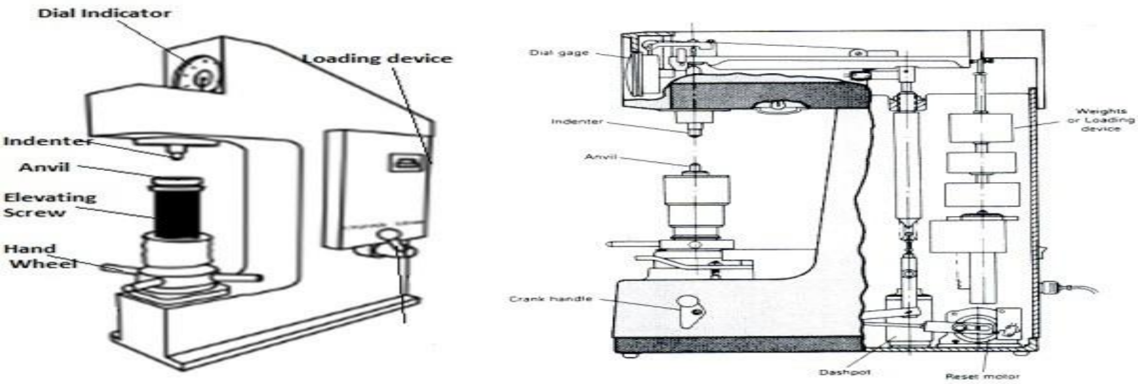
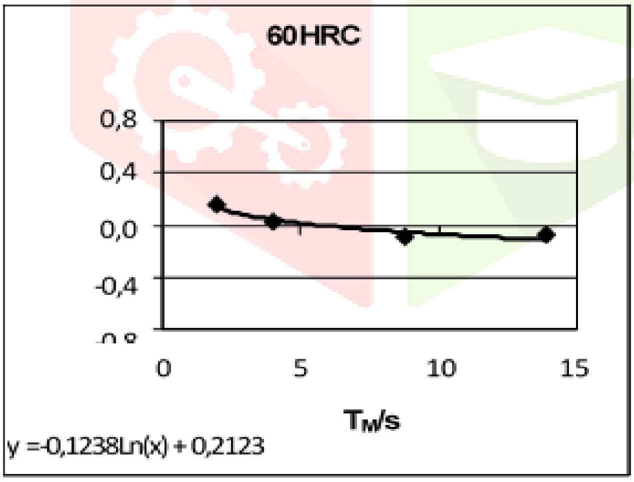


Figure 5. Block Diagram of Rockwell Hardness Test

With material creep and relevant measurement resolution could solve the problem of having good accuracy at the calibration level (machines with 0,1 µm resolution, dwell times of about 10 s) and good efficiency at workshop level (testers with 0,5 µm resolution, dwell times of about 4 s), keeping in the same time equal results within the relevant resolution of the different instruments used.

Table 1. Effect of approach velocity in the field from 0,1 mm/s to 1 mm/s

V_0	V_1	*VLR*	T_P	T_L	T_M	*Hardness*	HRC
[mm/s]	*[mm/s]*	*[mm/s]*	*[s]*	*[s]*	*[s]*	*[HRC]*	*[HRC]*
0,100	0,428	0,100	8,68	3,90	13,90	24,90	-0,07
0,500	0,428	0,100	8,02	4,01	13,79	24,99	0,02
1,000	0,428	0,100	7,25	4,06	13,84	25,03	0,06
					Mean	24,97	



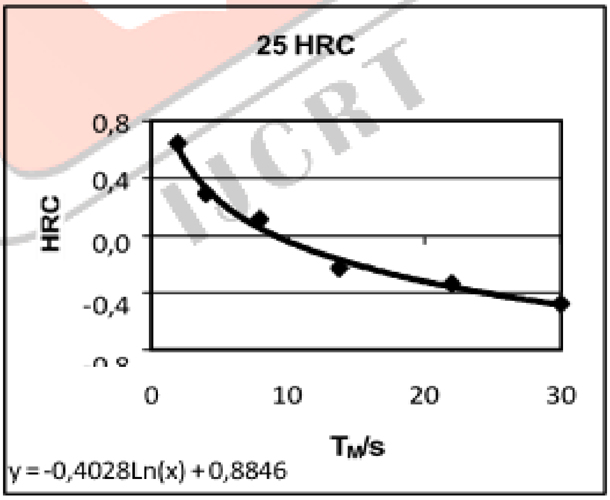


Figure 6.1 Plots of the measurement variation versus the dwell time. Figure 6.2 Single Effects

Fig. 6.1 Plots of the measurement variation versus the dwell time. Notice how the variations in the field of tolerance given by present ISO standard (2 s to 6 s) entrust variations up to 0,5 HRC and even much higher with some commercial hardness blocks.

These effects have been checked together with an experimental plan that significantly fills the sample space (1s to 9s and 0,3 mm/s to 1,3 mm/s, see Fig. 2). This allows to do a multiple variable analysis. The differences from the average have been fitted with different functions, showing for the level of 40 HRC the stronger correlation with both the velocity V1 and time TP as shown in Fig. 4 as single effects. The best fit, in this case, was obtained with logarithmic interpolation, adding the product of logarithms as mixed factor.

The same works for the level 25 HRC, but at 60 HRC both the time TP and the mixed factor loose their effect, variations being nearly totally justified by the velocity effect.

3.3 Total load dwell time

These effects have been checked together with an experimental plan that significantly fills the sample space (1s to 9s and 0,3 mm/s to 1,3 mm/s, see Fig. 2). This allows to do a multiple variable analysis. The differences from the average have been fitted with different functions, showing for the level of 40 HRC the stronger correlation with both the velocity V1 and time TP as shown in Fig. 4 as single effects. The best fit, in this case, was obtained with logarithmic interpolation, adding the product of logarithms as mixed factor. The same works for the level 25 HRC, but at 60 HRC both the time TP and the mixed factor loose their effect, variations being nearly totally justified by the velocity effect.

Table 2. Coefficients of the regression formula

Hardness level [HRC]	A	B	C	D	Standard dev. of residuals
25	-0,154	0,133	0,765	-0,429	0,13
40	-0,287	0,174	0,457	-0,326	0,07
60	0,023	0	0,062	0	0,06

3.4 Effects of VLR and TL

The most difficult problem was to separate the effects of loading time and loading velocity, as the operating conditions, even using a very versatile machine as the IMGC one9, cannot be forced in such a way to overcome the natural connection between time and velocity. Nevertheless, the experimental points showed in Fig. 2 can represent a good experimental base, at least if the velocity limit is kept within 0,100 mm/s. The tests made at a velocity higher than 0,100 mm/s are mainly intended to show eventually a tendency of the pattern.

The multiple regression analysis shows that the variation effect does not depend on the time: all the examined functions containing time fail to give a significant description, while the effect of velocity remains significant at least for the levels of 25 HRC and 60 HRC. The best fit is obtained using a logarithmic function, as shown in Table 2.

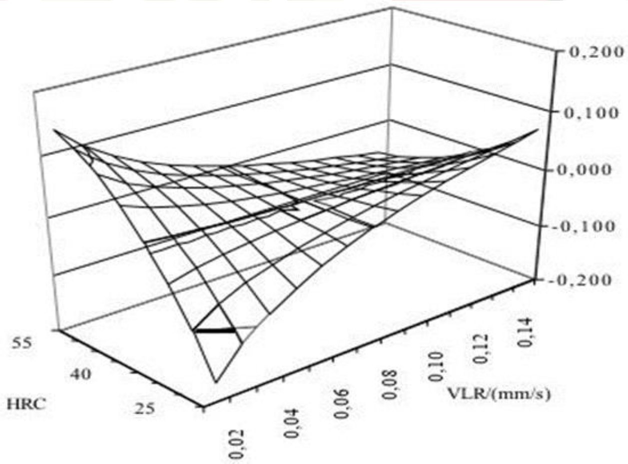


Figure 7. General pattern of the VLR effect

The effect producing variations connected mainly to the velocity VRL has not been explained until now. It seems that dynamic effects have to be rejected, as confirmed by the opposite pattern at low and high values of hardness. Taking this into account, one should infer an effect of the metallographic characteristics of the material tested. Note that the velocity effect, as already said for the effect of dwell times, depends on the material characteristics. The level of dependence could be not high, as tests previously made on blocks of different producers have shown good agreement.

VIII. Results & Conclusion

The results obtained could be useful for setting a number of problems, mainly the problem of having good metrological accuracy, at the level of block calibration, and high operation efficiency, at the level of workshop use. For the metrological accuracy it is necessary to operate with the working conditions that produce lower effects on the measurement variations. Two points are argued at present.

One point is the dwell times, that at metrological level are required longer, to avoid measurement during the evident creeping phase of the material, and at industrial level are required shorter, to save test time. Probably the proposal to give tolerance on the base of the measurement resolution can allow, all together, longer times for metrology, shorter times for industry, and measurement results significantly equal.

The second point is the velocity, but in this case an increment of indentation velocity is useful both for metrological reasons and for efficiency reasons. Other cycle parameters show lower influence, and can be considered only for establishing highly metrological test cycles for the comparison works of the Primary Metrological Laboratories

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