GalvInfoNote	Hardness Measurement of Coated Sheet Products
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Introduction

> "The hardness of a material is a poorly defined term which has many meanings depending on the experience of the person involved." [1]

In general, hardness implies a resistance to deformation, and for metals it is a measure of their resistance to permanent or plastic deformation. Metallurgists, including those working in the coated steel sheet industry, are concerned with the mechanics of testing, and define hardness as a measure of the resistance of the base steel to indentation by an indenter of fixed geometry under static load. The quotation preceding this paragraph alludes to the fact (contrary to what many people may believe) that "indentation hardness is not a fundamental property of a material" [2]. This is the case even though relationships have been developed between hardness values and other material properties, such as tensile strength. To a design engineer such a relationship could be important; because hardness would mean an easy and specified quantity that indicates the strength of the material. Certainly, much information can be derived from a hardness test, although it requires intelligent appraisal of hardness test results using knowledge of the steel's composition and condition when tested. Factors influencing the accuracy of the test must also be understood. This GalvInfoNote offers guidance in the use of hardness values as they relate to coated steel specifications, and its suitability for the intended end use.

Usefulness of Hardness Testing

Process control and inspection – Many processes that steel undergoes, e.g., heat treatment and cold working, result in changes to its hardness. Hardness testing is therefore an excellent method of rapidly and nondestructively monitoring the product in order to assist in process control. Specification limits for hardness are established at key processing locations in the product stream, and periodic tests are conducted to ensure the product of the process is within defined limits. These tests can be done rapidly, allowing quick confirmation that the process is under control, e.g., that a galvanizing line is achieving, to a high degree of probability, the proper degree of annealing of the base steel. The hardness control limits enforced in such a process are developed for the specific coating line and product, and are not necessarily taken from an industry product specification. They may, in fact, not be representative of the product hardness when it is eventually consumed because, with time, some steels "age harden". Age hardening is a natural phenomenon with many low carbon steels, and while a hardness test on aged steel may show a higher value, the steel may still be suitable for its intended end use

Other properties of coated sheet estimated from hardness – While it is possible to use hardness to estimate the approximate tensile strength of heat treated low carbon steel, a hardness test is no substitute for the tensile test. In the coated sheet production industry, hardness testing is used mostly as verification that processes that alter steel properties are within broad control limits. For many of these products, it is necessary to further verify suitability for end use using more time consuming and complex tensile and formability tests. Hardness testing alone cannot supply reliable information about how steel behaves during forming. A hardness test can easily distinguish amongst full hard, ½ hard, ¼ hard, and fully annealed sheet steel. It can also discern the difference between commercial and drawing grades of annealed sheet, but provides no dependable information about the stretchability and drawability properties of these grades.

For heat treated high carbon and/or alloy steel parts, hardness testing is a very reliable quality control test that can discern small differences in hardness [3]. For soft low carbon annealed steel sheet, it is an "in the ballpark" test, that in cases where formability is critical, must be backed up by more extensive mechanical testing, as a small difference in hardness could, or could not, be significant. The hardness of many heat treated high carbon and/or alloys steels has been correlated with their tensile strength, but it is significant that published hardness conversion charts (available from equipment suppliers – see reference 2) do not show approximate tensile strength for hardness values less than Rockwell B 72. Below that hardness value the relationship is considered to be inexact.

Types of Hardness Tests

While there are three general methods of hardness testing, viz., scratch hardness, indentation hardness, and rebound or dynamic hardness; for all intents and purposes, indentation hardness testing is the only method used on steel products. There are numerous indentation hardness methods. The most common are: the Brinell hardness test, the Rockwell hardness test, the Vickers hardness test, and the micro hardness test. For most steel products, the Rockwell hardness test is used. It has a series of scales capable of covering the range of hardness encountered in these products. This article deals only with Rockwell hardness testing, focusing on the scales used for annealed steel sheet.

Rockwell Hardness Testing of Steel Sheet

The Rockwell test is the most widely accepted hardness test, not only for steels, but many other metals. It is a very rapid test, taking only about 5 to 10 seconds and can be used on sheet as thin as 0.006 in. [0.15 mm]. A Rockwell test is based on measuring the penetration depth of an indenter, with the result displayed directly on a dial gauge or digital display. Specifically, it measures the additional depth to which a carbide ball, or diamond penetrator is forced into the material by a heavy (major) load, beyond the depth of a previously applied light (minor) load [4]. High Rockwell hardness numbers represent hard steels and low numbers soft steels.

There are two main types of Rockwell tests – Regular and Superficial. While there are over 30 different Rockwell hardness scales between these two categories, for steel sheet only three or four scales are suitable. These are the Regular Rockwell B scale and the Superficial Rockwell 45T, 30T and 15T scales.

- The Regular Rockwell B test uses a 1/16" ball, a minor load of 10 kgf (kilograms force), and a major load of 100 kgf
- The Superficial Rockwell 45T test uses a 1/16" ball, a minor load of 3 kgf, and a major load of 45 kgf
- The Superficial Rockwell 30T test uses a 1/16" ball, a minor load of 3 kgf, and a major load of 30 kgf
- The Superficial Rockwell 15T test uses a 1/16" ball, a minor load of 3 kgf, and a major load of 15 kgf

From this it is obvious that the latter two scales would penetrate the steel less, so are used on thinner sheet. The 45T scale is sometimes used on thicker sheet steel as an alternative to the B scale.

To fully understand why the use of 4 scales is required, it is necessary to understand what happens during a penetration hardness test. The material around a Rockwell indentation is "cold worked", which means it is permanently deformed. While the degree of cold work depends on the material and any previous cold work hardening of the steel, investigations have found that the thickness of steel affected is about 10 times the depth of the indentation. Therefore, if sheet thickness is less than 10 times the depth of the indentation, an accurate hardness result cannot be expected because the underlying support anvil can affect the result. On the other hand, it is always desirable to use the heaviest load possible so as to produce a larger indentation that tests more of the material, making the result more accurate and representative. Choosing the correct scale for the material involved is a careful trade-off. It is advisable to refer to ASTM specification E18 Standard Test Methods for Rockwell Hardness and Rockwell Superficial Hardness of Metallic Materials (available at www.astm.org) for detailed procedures on how to select the proper scale.

From the above it can be seen that the Rockwell B test is used on thicker steel sheet. In most cases, at 0.040" [1 mm] and above, the Rockwell B test is used, although the 45T scale is an option. Below this thickness, the B scale can be used down to about 0.026" [0.66 mm] if the steel is hard enough. Below 0.026" the Rockwell 30T scale is used, down to about 0.014" [0.36 mm] depending on hardness. Below this thickness, the Rockwell 15T scale is used, and is required for soft steels 0.016" [0.41 mm] and thinner. Refer to specification ASTM E18 to obtain exact thickness break points between scales as a function of sheet hardness. To visually check if a sheet is too thin for a given scale, examine the test piece directly beneath the indentation to determine if the metal is disturbed, or a bulge exists. If this is the case then the sheet is not thick enough for the load used. The “anvil effect” is present and the next lowest scale should be used. *It is not acceptable to test multiple thicknesses of sheet in an attempt to avoid the anvil effect.*

For annealed steel sheet, it is the usual practice to convert readings obtained using the Superficial Scales back to the Rockwell B scale. While it is best if Rockwell results are reported in the same scale that was used for testing, converting results to the B scale helps avoid confusion, albeit at the risk of losing some accuracy in the conversion process. For sheet steel the conversion chart used should be based on Table 2 in ASTM E140.

In addition to choosing the proper scale to avoid the anvil effect, it is important that a number of other simple precautions be observed in order to ensure useful and reproducible test results [5, 6]. These are:

- The indenter and anvil should be clean and well seated
- The surface to be tested should be clean, dry, smooth and free from oxide
- The surface should be flat and perpendicular to the indenter
- It is important for accuracy that the test sample is held securely and the test piece be centered over the anvil. It is easier to accomplish this if the sample size is not too large, e.g., 4” x 4” maximum
- If a diamond anvil is used, ensure it is not cracked
- If a steel anvil is used, ensure it is flat with no indentations

The definition of what consists of one hardness result varies throughout the steel industry. Some laboratory procedures require 5 individual readings for each test, with the high and low discarded, and the remaining 3 averaged to obtain a final result. In any case, most test procedures avoid relying on just a single reading.

Rockwell Testing and ASTM Coated Sheet Specifications

As much as hardness testing is used to monitor the production of steel sheet, it is not possible to order coated sheet to ASTM specifications using hardness ranges. Many grades of coated sheet are sold on the basis of meeting specified mechanical properties, or a guarantee of being able to be fabricated into a specified part. When being sold to mechanical property specifications it is necessary to use fundamental measures such as yield/tensile strength, or elongation. To guarantee to be within a certain range for a non-fundamental property such as hardness would mean that such a range would be too wide to be meaningful. There could also be the risk of making a product that would not fabricate into the intended end use.

On the other hand, attempting to produce a product to an overly restrictive Rockwell hardness range runs the risk of unnecessarily rejecting material that might well form into the intended end use without difficulty.

Coating on versus coating off – given that ASTM specifications for coated sheet are silent on the topic of hardness values, it follows that no information is provided on whether tests should be performed with the coating on or off. **It is the usual practice in coated sheet producing mills to strip the metallic coating off before hardness testing.** Since it is the steel substrate that governs the mechanical properties of the sheet, it is the steel substrate that should be directly measured. Some laboratories test hardness with the coating on in the interest of time, or because they may not have the means to properly and safely strip the metallic coating off. Performing the test in this manner is known to affect the result, although the degree has not been quantified. Hardness testing done with the coating on is less reliable – the more so the heavier the coating.

Summary

The Rockwell hardness test is a quick and very useful tool in the metals industry. On hardened steels, it can easily and nondestructively discern small differences in properties. In the annealed low carbon steel sheet industry, the test is useful for production control, and sorting amongst distinct hardness classes of sheet. However, ASTM coated sheet specifications do not contain hardness range limits, for the basic reason that it is not a fundamental property, and cannot be reliably used to predict the behavior of annealed product in forming operations.

References:

1) Dieter, Jr, George E., Mechanical Metallurgy, McGraw-Hill, New York, 1961, p. 282.
2) Wilson Instruments, Fundamentals of Rockwell Hardness Testing, WB1226, www.wilsoninstruments.com
3) Dieter, Op. Cit. p. 290.
4) Wilson Instruments, Op. Cit. p. 7
5) American Society for Metals, Metals Handbook, 1948, pp. 93-105.
6) McGhee, Douglas B., Common Problems in Rockwell Hardness Testing, Heat Treating Progress, May/June, 2004.