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Interpreting Carburized Case Depths
(Part 1: Hardness Testing Methods)

The Internet is a wonderful place, full of invaluable information available, literally, at our fingertips. Did you ever wonder, however, how much of the information you're viewing is truly accurate? An intriguing question raised by a reader about hardness testing of carburized case depths is one such example. Let's learn more.

The Question

As part of suggested guidelines for designers, it was recommended that hardness on drawings be specified as Rockwell "C" with a minimum spread of 5 points or as a minimum hardness value, again in Rockwell C. The statement was then made that if total case depth is less than 0.76 mm (0.030 inch), an accurate reading cannot be obtained on "C" scale because a 150-kg load will drive the penetrator through the case and into core material, giving a false reading. Various Rockwell scales were recommended (Table 1) for use with minimum total case depths. The question was, "How accurate is this data?"

The Answer

There is indeed a minimum case depth that will allow its accurate determination by indentation surface hardness measurements using standard and superficial hardness tests (Table 2). Note that the values are listed for *effective* case depths in this table, which are different than the total case depth information in Table 1.

Understanding Hardness Testing of Case-Hardened Parts

In general, there are four controlling factors in the selection of the proper scale for hardness testing, namely type of material (chemistry and hardenability), thickness of the specimen, width of the area to be tested and scale limitations. It is this last factor that is often open to interpretation.

In the case of Rockwell C, typical applications (per ASTM E18) include "deep case-hardened steel." In the case of Rockwell A, its use includes "shallow case-hardened steel." These statements, while interesting, do not in and of themselves tell us if the data in Table 1 is correct.

The regular or superficial Rockwell scales are established such that an infinitely hard material will read 100 on the diamond penetrator scales (or 130 on the ball penetrator scales). Thus, one regular Rockwell number represents a penetration of 0.002 mm (0.000080 inch). Therefore, a reading of 60 HRC indicates penetration (from minor to major load) of 100 – 60 = 40 x 0.002 = 0.08 mm (0.0032 inch). By contrast, in Rockwell superficial testing, one superficial Rockwell number represents a penetration of 0.001 mm (0.000040 inch). Therefore, a reading of 90 HR15N indicates penetration from minor to major load of (100 – 90) x 0.001 = 0.01 mm (0.0004 inch).[2] However, Rockwell superficial testing, due to the lighter applied load, has a greater margin for error, which is why Rockwell C or Rockwell A testing is preferred.

Table 1. Rockwell scales as a function of total case depth

Total case depth, mm (inches)	Internet source recommended Rockwell scale
0.76 (0.030)	"C"
0.61 (0.024)	"A"
0.53 (0.021)	"45N"
0.46 (0.018)	"30N"
0.38 (0.015)	"15N"
< 0.38 (0.015)	File check

Table 2. Rockwell scales as a function of total case depth[1]

Effective case depth,[a] mm (inches)	Estimated total case depth[b]	SAE J423 recommended Rockwell scale
0.53 (0.021)	0.79 (0.031)	C
0.46 (0.018)	0.68 (0.027)	D
0.38 (0.015)	0.56 (0.022)	A
0.30 (0.012)	0.46 (0.018)	45N
0.25 (0.010)	0.38 (0.015)	30N
0.18 (0.007)	0.25 (0.010)	15N
<0.18 (0.007)	<0.25 (0.010)	Microhardness

Notes: Effective case depth defined as 50 HRC as determined by microhardness testing. Total case depth estimated using the formula (3/2) x effective case depth

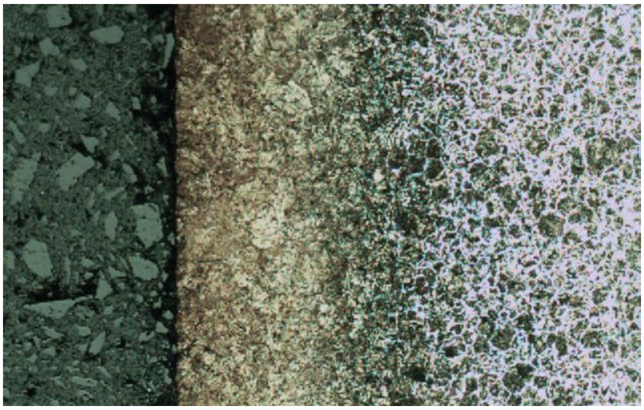

Figure 1. Total case-depth determination by Ms point method[4] *(courtesy of The Timken Company)*

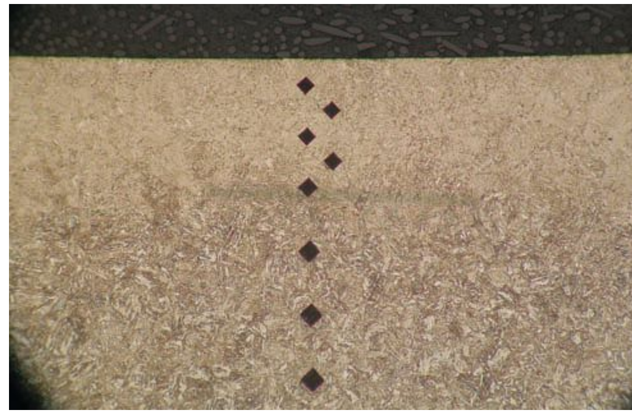

Figure 2. Example of effective case-depth determination by microhardness testing *(courtesy of Solar Atmospheres, Inc.)*

Understanding Case Depth[3]

Here are the most commonly accepted definitions for case depth in terms of carbon content.

- **Total case depth:** The depth at which the carbon content of the steel is 0.04% above the core carbon content of the steel. In other words, total case depth is the point at which differences in the chemical or physical properties of the case and core no longer can be distinguished (Fig. 1). Many metallurgists determine the total case depth by (nital) etching a steel sample and measuring the zone affected by the etchant.
- **Effective case depth:** The depth at which the carbon content of low-alloy steel is 0.40%, or approximately 0.30% for medium-alloy and high-alloy steels.

Since it is often time consuming to measure the carbon concentration as a function of depth in a carburized component to determine effective case depth, other techniques (such as microhardness) are commonly used. In certain situations involving very deep case depths, hardness is measured directly on the A or C scales. In these instances, the following definitions are used.

- **Effective case depth (U.S.):** The distance from the surface (in inches) to a point within the case where the hardness is 50 HRC (542 Knoop or 513 HV). This measurement is done on a cross section by microhardness techniques with a Knoop or Vickers indenter (Fig. 2). These values are then converted to Rockwell C hardness if a 500 gram-force load is used per ASTM E384 (latest revision). Interpolation is required to arrive at the proper case-depth value. The effective case depth depends on the carbon gradient and the case hardenability, but 50 HRC is typically equated to a carbon content of 0.40% in low-alloy steels and 0.30% in medium- and high-alloy steels.
- **Effective case depth (international):** The distance from the surface (in millimeters) to a point within the case where the hardness is 550 HV (approximately 52.5 HRC). This measurement is done by a Vickers microhardness method with a predefined load of 1 kg and is not converted to Rockwell C. The effective case depth still depends on the carbon gradient and the case hardenability. For highly alloyed case-hardening steels, the carbon content for 550 HV is typically in the range of 0.25-0.30%. For medium-alloy grades, it is approximately 0.30-0.35% C, and for low-alloy steels, it is approximately 0.35-0.40% C.

Case-Depth Callouts on Prints

Case depth on engineering drawings should be stated either as total case depth, effective case depth or finished effective case depth after a defined amount of material is removed from the surface. It is important to note that if neither total nor effective case depth is specified, one must *not* assume that total case depth is intended (although at one time many years ago this was a commonly held belief).

A "rule of thumb" to determine total case depth from the effective case depth is to multiply by 3/2, or to determine effective case given the total case depth is to multiply the total case depth 2/3. The steel grade, chemistry and hardenability of material (as well as case depth) can affect this percentage.

The following are several recommendations for writing clear specifications that unambiguously define the desired case.[3]

- Use wording and sketches, as needed, to define test locations and methods. However, do not use verbiage to define a hardened case.
- Specify the test procedure at each location and for each characteristic. State the maximum and minimum specification tolerance.
- Specify the condition of the part at the time of testing (as-hardened, after temper, after final grind).
- Show the draft print and specification to your test lab and part producer and check their interpretations of the specification against your requirements.

Next Time

We continue this discussion and focus on other methods of measuring case depth in August. **IH**

References available online

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Part 2: Methods for Measuring Case Depth

We continue our discussion on how to interpret carburized case depths by focusing on measurement techniques. These methods are also applicable to cases produced by nitriding, nitrocarburizing, boronizing, and induction or flame hardening. Let's learn more.

Methods used to determine the depth of case can be categorized as visual, chemical or mechanical in nature. Sample parts or representative test specimens are most often of the same grade of steel as that being case hardened and ideally from the same heat of steel. At the very least, one should know the chemistry and/or properties. Some companies, however, prefer to use a single steel (e.g., SAE 8620 for carburizing) and perform tests on it for comparative purposes with the added benefit of gaining insights into furnace performance over time.

Visual Methods

Visual interpretation falls in two broad categories: macroscopic and microscopic, and both are valuable.

Macroscopic Techniques

Macroscopic methods are often used on the shop floor for routine process control, primarily because of their simplicity and the short time required for determination. They are typically done using the unaided eye, a loop or with a stereomicroscope up to magnifications of 40X. Accuracy of results can be improved by correlation with other methods used to measure the case depth of the parts being processed.

Visual methods are normally applied to hardened specimens. Induction- and flame-hardened samples are prime examples since they usually have excellent contrast between case and core when macroetched (e.g., 10% Nital). Other methods include the use of fracture bars, which is an efficient and quick way to test every case-hardened load. The depth of hardening is well defined and easily interpreted by fracture methods. The outside has a flat but slightly grainy appearance associated with brittleness, while the inside has an irregular, rather fibrous appearance associated with toughness.

The important point is that the fracture changes from one to the other quite abruptly. Case depth can be measured by a Brinell scope or with a scale on a stereomicroscope. If the core is soft, the fractured surface will exhibit good contrast between case and core. If the core is hard, bluing the fracture on a hot plate[3] can enhance the contrast.

The M_s method[4] is another, but more involved, visual technique. It is based on the fact that the martensite-start temperature (M_s) varies with carbon content. Quenching (typically in a salt bath) and then holding the steel for a short time at the M_s temperature corresponding to a given carbon content tempers the martensite formed at all lower-carbon levels. Subsequent water quenching transforms austenite at all higher-carbon levels to untempered martensite. Polishing and etching reveals a sharp line of demarcation between tempered and untempered martensite (Fig. 1).

Microscopic Techniques

Microscopic methods are commonly used for determining case depth and have been described in detail by others.[3,5] What is often overlooked is that their accuracy depends on the nature of the case and core microstructures. For example, carburized depth is easier to evaluate in an unhardened sample while nitrided cases are, in general, difficult to estimate. It is important that the sectioning of

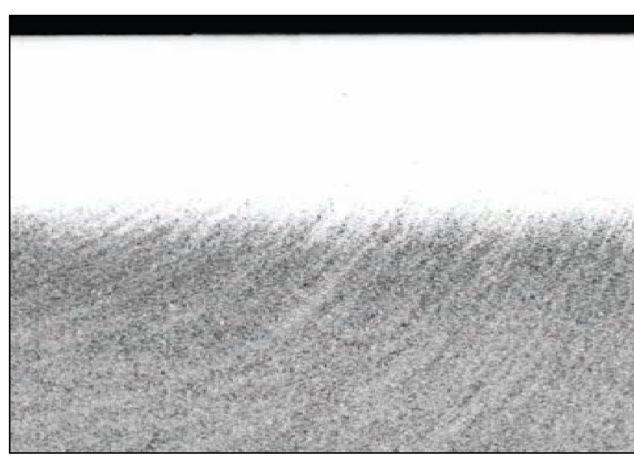

Figure 1. Example of demarcation line in the M_s method

the sample be perpendicular. Otherwise, the taper angle must be known. Perhaps the single-most overlooked step is to ensure good edge retention by use of proper mounting methods and procedures.

Microscopic techniques require that specimens first be given a full polish and etch before the evaluation, usually at 100X. Effective case-depth determination of hardened specimens relies on comparison to metallographic structures found to be equivalent to 50 HRC by other methods. A structure that is approximately 85% tempered martensite and 15% mixed transformation products often corresponds to 50 HRC. Total case depth is the demarcation line between the case and core (between dark and light regions after etching). This line is far from distinct for alloy steels.

Chemical Methods

These methods usually rely on analysis of chips from turned bars. Test specimens must be carburized with the parts or in a manner representative of the process. If the parts and test specimens are quenched after carburizing, the specimens should be tempered at approximately 595-650°C (1100-1200°F) and straightened to 0.04 mm (0.0015 inch) maximum TIR (total indicator runout) before machining is performed. The time at temperature should be kept to a minimum to avoid excessive carbon diffusion even at these low temperatures.

Machining intervals between 0.05 and 0.25 mm (0.002 and 0.010 inch) are typically chosen depending on the accuracy desired and expected depth of case. Chips from each increment must be kept separate and analyzed individually for carbon content in a carbon analyzer or other suitable device. In some cases, especially for deep-case carburizing, taper bars can be used. They are machined, and spectrographic analysis is performed along the length of the bars at a spacing of at least one turn diameter apart.

Mechanical Methods

These methods are preferred for an accurate determination of effective case depth and for determining total case depth in parts that have been shallow case hardened. The use of this method is based on obtaining and recording hardness values at specific intervals through the case. The sample is considered through-hardened if the hardness level does not drop below the effective case-depth value.

Considerable care should be exercised during preparation of specimens for case-depth determination by any of the mechanical methods. Serious errors can be introduced if the specimen has not been properly prepared. In the case of microhardness measurements, it is important to avoid cutting or grinding burns. It is always a good idea to use an etchant for burn detection as a general precaution, although this is almost never done in practice.

If the specimen is to be tested directly on a Rockwell scale, the cutoff technique done on it is critical. The hardness indentations must be made perpendicular to the surface, and in no case can the angle from parallel of the top and bottom surfaces be greater than 2 degrees. Otherwise, the readings will be erroneous.

When using microhardness methods, surface finish of the specimen is important and is a function of the indenter load. For accurate readings, the hardness impressions must not be affected by the surface condition. For example, a Knoop (500-gram) hardness profile can be performed on a specimen that was final polished on 600-grit (15-micron) paper. (Remember, the larger grit numbers correspond to smaller particle size and smoother surface finish with finer scratches.) The lighter the indenter load, however, the finer the polish necessary. Also, the hardness traverse should be started far enough below the surface of the case to ensure proper support from the metal between the center of the impression and the surface. A common error is to use too heavy an indenter load too close to the edge of the specimen, which results in deflection at the edge and a false (low) hardness value.

Another common error is to bunch the readings too close together. Making an indentation cold works the surface in the vicinity of the impression. If a subsequent reading is taken too close to a previous one, the resultant hardness value will be distorted (too high). For light and medium cases, up to 0.75 mm (0.030 inch), the indentations should be spaced along a 45-degree diagonal, a minimum of one indenter width apart. For deeper cases readings under one another are acceptable.

A typical Vickers or Knoop (500-gram) microhardness traverse would have an initial reading at 0.06 mm (0.0025 inch) and subsequent readings at 0.13-mm (0.005-inch) intervals to 0.75 mm (0.030 inch) and then at 0.25-mm (0.010-inch) intervals until readings above and below the 513 HV value are observed. Interpolation or additional indentations can be done to determine the exact value.

Summary

Regardless of the technique used to determine total and effective case depth in carburized components, it is important that the method be consistent, accurate and correlate to actual physical and mechanical properties as they relate to the performance and characteristics of the part in service. **IH**

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