THE HEAT TREAT DOCTOR

About the columnist . . .

Daniel H. Herring is president of The Herring Group Inc., Elmhurst, Ill., a business specializing in practical solutions to problems facing the heat treating and sintering industries (Web: www.heat-treat-doctor.com).

Dan Herring has spent more than 25 years working for furnace equipment manufacturers in a variety of roles, including senior management and new business development. Now an independent entrepreneur, Dan lectures, writes, teaches, and consults. A frequent speaker at local, national, and international conferences, he is dedicated to advancing the state of the art in thermal processing. He has published more than 75 technical papers, written three books, and contributes to Heat Treating Progress *and other industry publications.*

Dan's credentials include his appointment as a research associate professor at the Thermal Processing Technology Center, Illinois Institute of Technology, Chicago. He also serves on the ASM Heat Treating Society Board and is active on several HTS Committees.

Generic and practical information presented here is not intended to replace or supplement federal, state, and local codes, government standards, insurance requirements, company policies and procedures, or common sense. In addition, all equipment manufacturers' instructions and operating and maintenance manuals should always be thoroughly read and followed. Further, personnel training should be provided unequivocally to everyone who will be associated with operating such equipment.

Carburized Case Depth

Carburizing followed by quenching is a case hardening process used to produce a hard, wear-resistant surface layer, or case, on top of a ductile, shock-resistant underlayer, or core. Parts made from wrought and powder metallurgy steels are commonly heat treated using this process. In some instances, stainless steels are also carburized.

More formally, carburizing is the introduction of carbon into a solid ferrous alloy by holding above the temperature at which austenite begins to form on heating, the so-called critical, or Ac_1, temperature of the material, in contact with a suitable carbonaceous source in solid, liquid, gaseous, or plasma form.

The carburizing process has a great deal of variability induced by changes in process parameters over time. Thus, it is important to be able to properly interpret and measure case depth. This variability is compounded by the fact that no two furnaces carburize exactly alike. The process is dependent on material choice, equipment, and process technique. For each component there is an optimum material and process combination that must be empirically determined.

Interpreting case depth

The generic term "case depth" needs better definition in order to be useful to the heat treater. We talk instead about "total case depth" and "effective case depth." A quick rule of thumb is to multiply the total case depth by two-thirds to approximate the effective case depth.

The most common definitions in terms of carbon content are:

- **Total case depth:** The depth at which the carbon content of the steel is 0.04% above the core carbon content of the steel.
- **Effective case depth:** The depth at which the carbon content of the steel is 0.40%.

Since it is often time consuming to measure the carbon concentration as a function of depth in a carburized component, other techniques such as hardness measurements are common. These require alternative definitions:

- **Total case depth:** The point at which differences in the chemical or physical properties of the case and core no longer can be distinguished.
- **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). If the effective case is deep enough, this test can be performed using the Rockwell A or C scale. This is both fast and accurate in the hands of a skilled technician. More commonly, the measurement is done by microhardness techniques such as Knoop or Vickers and then the values are converted to Rockwell C hardness. 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.

Worldwide, other different definitions exist. For example:

- **Effective case depth (international):** The distance from the surface (in millimeters) to a point within the case where the hardness is 550 HV. 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 to 0.30%. For medium-alloy grades, it is approximately 0.30 to 0.35% C; for low-alloy steels, 0.35 to 0.40% C.
- **Total case depth (international):** The point at which the hardness of the material is equal to the core hardness plus 50 HV.

A good explanation of the new international hardness testing standards can be found in the July/August 2001 issue of *Härterei-Technische Mitteilungen* (in German). It includes 10 articles on various aspects of the standards.

Measuring case depth

Methods used to determine the depth of case are categorized as either chemical, mechanical, or visual. Test specimens or parts are normally of the same grade of steel as that being carburized or from a lot of material of known chemistry and properties. A heat of steel is typically purchased so that all test coupons will have a consistent and predictable performance. The test specimen may be subjected to these tests in either the soft or hardened condition. The measured case depth may then be reported as either

effective or total on the hardened specimen and as total case depth on the unhardened specimen.

Chemical 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 to 650°C (1100 to 1200°F) and straightened to 0.038 mm (0.0015 in.) maximum TIR (total indicator reading) 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 in.) 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, taper bars are machined and spectrographic analysis done along the length of the bars at a spacing of at least one turn diameter apart.

Mechanical methods are preferred for an accurate determination of effective case depth and for determining total case depth in parts that have been shallow case carburized up to 0.25 mm (0.010 in.). The use of this method is based on obtaining and recording hardness values at specific intervals through the case. The specimen or part 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 means. In the case of microhardness measurements, it is important to ensure against grinding or cutting burns. Serious errors can be introduced if the specimen has not been properly prepared. It is always a good idea to use an etchant for burn detection as a general precaution, although in practice this is almost never done.

If the specimen is to be tested directly on a Rockwell scale, the cutoff technique done on the specimen 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 5°, otherwise the readings will be erroneous.

When using microhardness test 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 g) hardness profile can be performed on a specimen that was fine ground on ANSI 600 grit (FEPA P1200 grit) paper. (FEPA = Federation of European Producers of Abrasives.) The lighter the indenter load 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, resulting 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 in.), the indentations should be spaced along a 45° diagonal, a minimum of one indenter width apart. For deeper cases, readings under one another are acceptable. A typical Knoop (500 g) microhardness traverse would have an initial reading at 0.06 mm (0.0025 in.) and subsequent readings at 0.13 mm (0.005 in.) intervals to 0.75 mm (0.030 in.), and then at 0.25 mm (0.010 in.) intervals until readings above and below the 513 HV value are observed. Interpolation or additional indentations can be done to determine the exact value.

Visual methods are generally used for "on the fly" checks of case depth since they are fast and can be used with or without the aid of magnification. They fall in two categories: macroscopic and microscopic.

Macroscopic methods are good for routine process control primarily because of their simplicity and the short time required for a determination. They are typically done using the unaided eye or with a magnification of 20X. 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. Procedures include fracture methods, with or without etching, grinding, and polishing. The depth of hardening is well-defined visibly 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.

The M_s method 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.

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. Often, a structure that is approximately 85% tempered martensite and 15% mixed transformation products 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.

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