A.J. Fuller, Jr., Introduction to Carburizing and Carbonitriding, *Steel Heat Treating Fundamentals and Processes*. Vol 4A, *ASM Handbook*, ASM International, 2013, p 505–521.

Quality Assurance

Because of the many variables that must be controlled during carburization, managing process variation is a constant challenge. Modern instrumentation and equipment makes it possible to produce repeatable results. However, proper operation and maintenance of carburizing equipment is essential to success. Due to the high temperatures employed and the chemical activity of carburizing gases, the equipment used to perform carburizing will deteriorate over time, so constant attention is necessary.

Numerous test methods have been developed to verify that the desired outcome has been obtained after carburization. Because the distinguishing characteristic of carburization is the high-carbon martensitic case, most specifications involve tests to verify the surface hardness, carbon and hardness profile, and microstructure.

The use of statistical process control (SPC) to monitor and control critical process variables has also been shown to be of great value in the successful operation of a carburizing process. An effective process control program using SPC can detect furnace maintenance and operational issues before they adversely affect product quality.

Surface hardness is the most basic and easiest test that can be performed to verify that carburization has occurred. Test methods such as the Rockwell, Vickers, and Knoop hardness tests have been in use since the early 1900s, and they are still relevant today (2013).

The hardness range for a carburized and hardened case will vary depending on the intended application, but it will generally range from approximately 55 to 65 HRC.

Core hardness is the hardness in the center of the component, usually in a noncarburized region. Core hardness is measured by the same methods as surface hardness. Core hardness is determined by the size and heat treatment method of the part and can range anywhere from 25 to 45 HRC. Unlike surface hardness, the testing of core hardness is a destructive test, because it usually involves cutting a component to gain access to the core. Core hardness will vary in a component as a function of section thickness. Depending on the geometry of the component, it may be necessary to define exactly where the core hardness will be evaluated.

The carbon gradient is the defining characteristic of a carburized component. While the surface carbon can be estimated by its effect on surface hardness and microstructure, this does not reveal anything about the depth and slope of the carbon gradient between the surface and the core. One method that can be used to confirm that the process has produced the intended result is to measure the actual carbon content at a defined depth from the surface.

The technique required to perform this test will depend very much on part geometry. One method that has been used on axially symmetrical parts is to chuck the component in a lathe and turn the surface down to the depth of interest, then turn down a bit further and collect the turnings for analysis. If this is done with the necessary precision, it is possible to collect the turnings at various depths of cut and analyze them using a combustion analyzer.

Case Depth. The designer is expecting the carburized case to extend to a certain depth into the component in order to provide the mechanical properties and load-carrying capacity that the component requires. This necessitates the determination of the carbon gradient. There are several ways to define this depth.

Total case depth is defined as the perpendicular distance from the surface of a carburized component to the point at which differences in chemical or physical properties of the case and core can no longer be distinguished. Total case depth is sometimes practically defined to be the distance from the surface to the deepest point at which the carbon content is 0.04% higher than the carbon content of the core. ally, the term *total case depth* is considered too vague for use in carburizing specifications because of the practical difficulty in determining the exact point where the carbon profile transitions between the case and the core.

Effective case depth or hardened depth is defined as the perpendicular distance from the surface of a

hardened case to the depth at which a specified level of hardness is obtained. This method is the most practical and most widely used for determining case depth. The industry standard hardness criterion is HRC 50. Defining case depth to other hardness values is occasionally used for special applications but is not common. When other criteria are used, they should be properly defined.

Carburized case depth is defined as the perpendicular distance from the surface of a carburized case to the depth at which a specified level of carbon is obtained. It is a hybrid of the total case and effective case methods. The specified carbon level is selected to approximately correlate to a particular depth of interest, such as the near-surface or the effective case depth. For medium-to-low-alloy carburizing steels, the depth to HRC 50 will correlate to a carbon level of 0.3 to 0.4 wt% C. Often, 0.35 wt% C is used as the specified carbon level for carburized case depth.

The depth of carbon is most easily measured indirectly by measuring the effect that the carbon has on the hardenability and hardness of the steel. Because it is the easiest method to perform and quantify, effective case depth is the predominant measurement method. A microhardness tester is useful for this purpose. To measure effective case depth, a specimen is cut with its face perpendicular to the component surface. A microhardness tester equipped with a Vickers, Knoop, or similar indenter is then used to place small indentations into the specimen at defined distances from the surface, continuing until the hardness drops below the hardness of interest. By determining the intercept of the defined hardness of interest (say, 50 HRC) with the hardness gradient, the effective case depth is easily determined (Fig. 17). Instruments for checking microhardness are available from a variety of manufacturers.

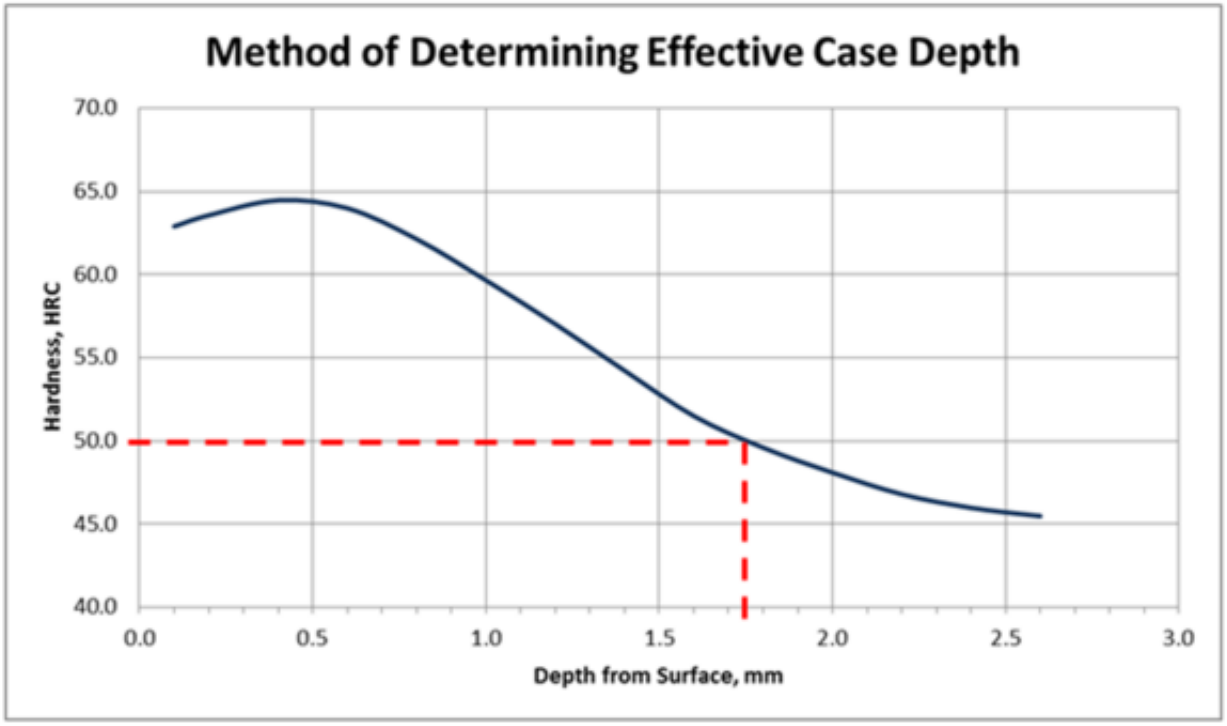

Fig. 17 Method of determining effective case depth at 50 HRC by means of microhardness profile (converted to HRC). In this example, the effective case depth is 1.75 mm (0.069 in.).

Case Microstructure. To achieve the mechanical properties necessary to take advantage of the carburizing process, a carburized component must be quenched to form martensite. Martensite exists in two major forms: lath and plate. These two forms, while identical in crystallographic structure, differ in morphology and mechanical properties.

Low-Carbon (Lath) Martensite. Lath martensite is the predominant form of martensite at carbon levels below approximately 0.6%, and it disappears altogether at carbon levels above 1.0%. As such, lath martensite is the form of martensite that is typically encountered in the core of a carburized component. Lath martensite is less strong than plate martensite, but has greater impact resistance (Fig. 18).

Fig. 18 Typical low-carbon (lath) martensite microstructure with some acicular ferrite. 8620-grade steel. Nital etch. Original magnification: 500×

High-Carbon (Plate) Martensite. Plate martensite begins to form when the carbon content is greater than approximately 0.6%. As the carbon content increases above 0.6%, the proportion of plate martensite increases until, at approximately 1.0%, lath martensite disappears completely and plate martensite becomes the dominant microstructure. Plate martensite is characteristically identified by the presence of large "needles," often accompanied by varying amounts of retained austenite. Plate martensite is stronger than lath martensite but also less impact resistant.

Retained Austenite. Depending on the case carbon content and the specific heat treatment process used, the component may contain a significant amount of retained austenite. Retained austenite is so named because it is a high-temperature phase that is retained at room temperature after quenching and tempering. Normally, austenite is not stable below the lower critical temperature (Ac_3) and is not normally present in ordinary alloy steels at room temperature. However, in many case-carburized applications, retained austenite is present due to suppression of the M_s temperature, nonequilibrium cooling, and the M_f being below the quench temperature. Retained austenite is metastable at temperatures below the lower critical temperature, so it is thermodynamically available to transform if sufficient provocation is offered by the environment. The driving force for the transformation of austenite to "fresh," untempered martensite can come from the application of shear stresses in service or from post-heat-treatment exposure to elevated temperatures.

Retained austenite can either be detrimental or beneficial, depending on the application. For instance, many gears and roller bearings are intentionally designed with certain levels of retained austenite in the case, because it has been shown to prolong service life in situations where rolling or sliding contact fatigue are a primary concern.

Retained austenite is almost exclusively a case microstructural feature and presents itself as indistinct, light-colored areas in the spaces between plate martensite plates (which appear as needles). Figures 19 and 20 show microstructures with two different levels of retained austenite.

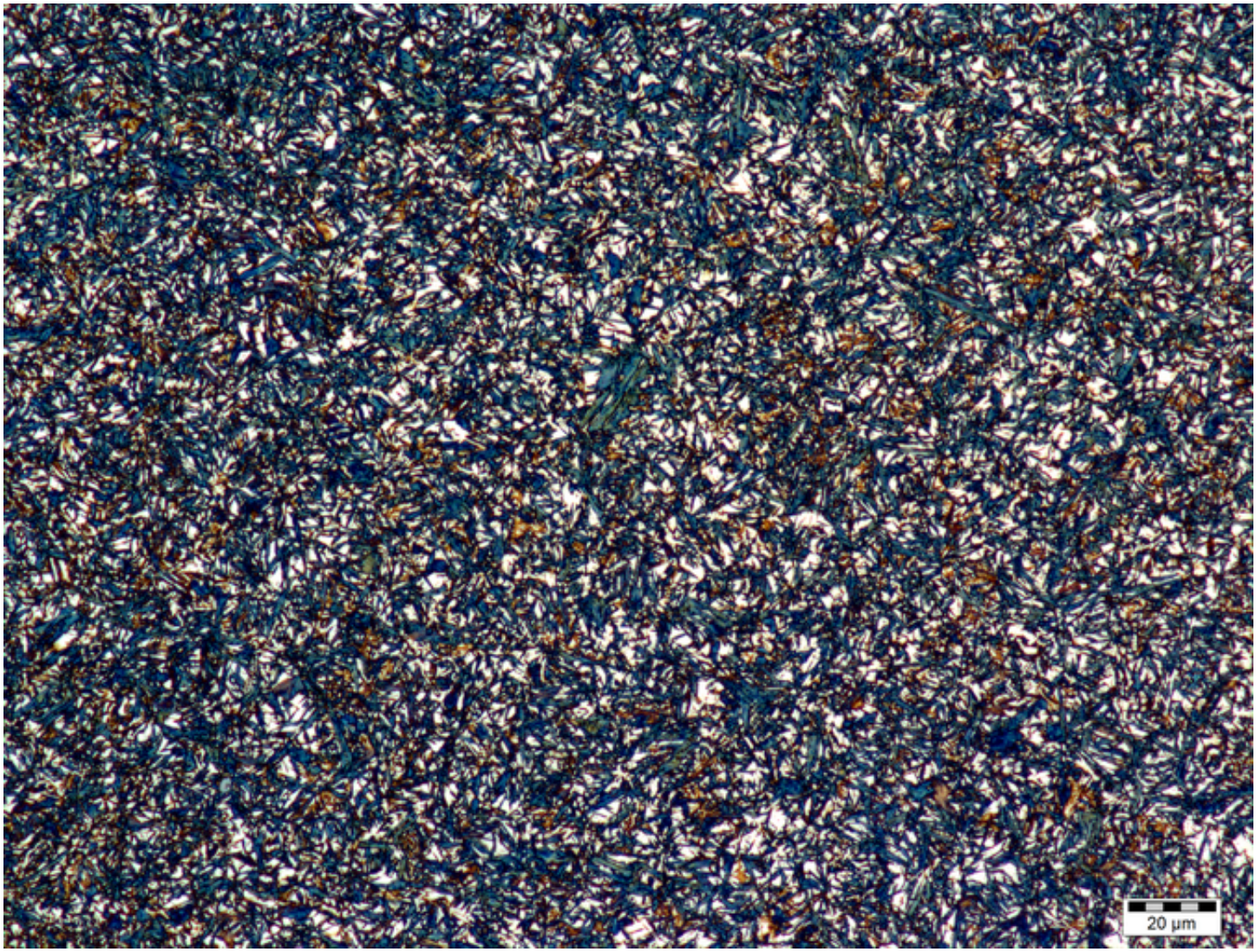

Fig. 19 Case microstructure of plate martensite and ~30% retained austenite (by x-ray diffraction). Nital etch. Original magnification: 500×

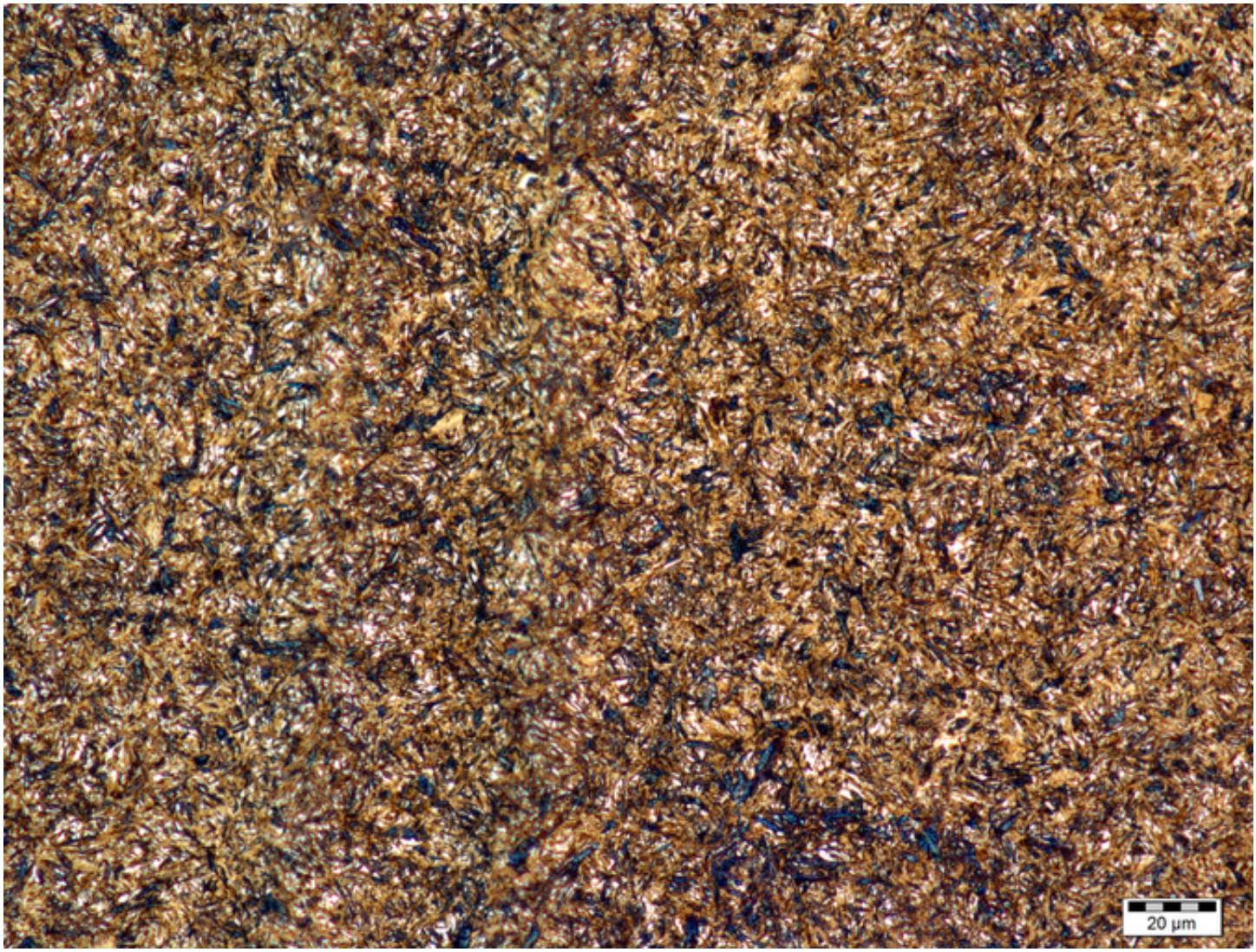

Fig. 20 Case microstructure of plate martensite and ~15% retained austenite (by x-ray diffraction). Grade 8620. Nital etch. Original magnification: 500×