

Introduction to Carburizing and Carbonitriding

Possible Complications

Despite its many benefits, carburization is very process-sensitive. With so many variables to control, it is common to encounter certain types of conditions that may be detrimental to some degree, depending on the application.

Decarburization. The intent of the carburizing process is to create a carbon gradient into the surface of a steel component in order to achieve certain mechanical properties. However, process interruptions and equipment problems can lead to a reversal of the carbon gradient. By diffusion, carbon migrates from a region of high concentration to a region of low concentration. If, during heat treatment, the carbon potential of the atmosphere drops below that of the steel face, the carbon flow will reverse, and decarburization of the component will occur. This is obviously undesirable because if it progresses too far, decarburization will compromise the beneficial properties that the heat treater and designer intended.

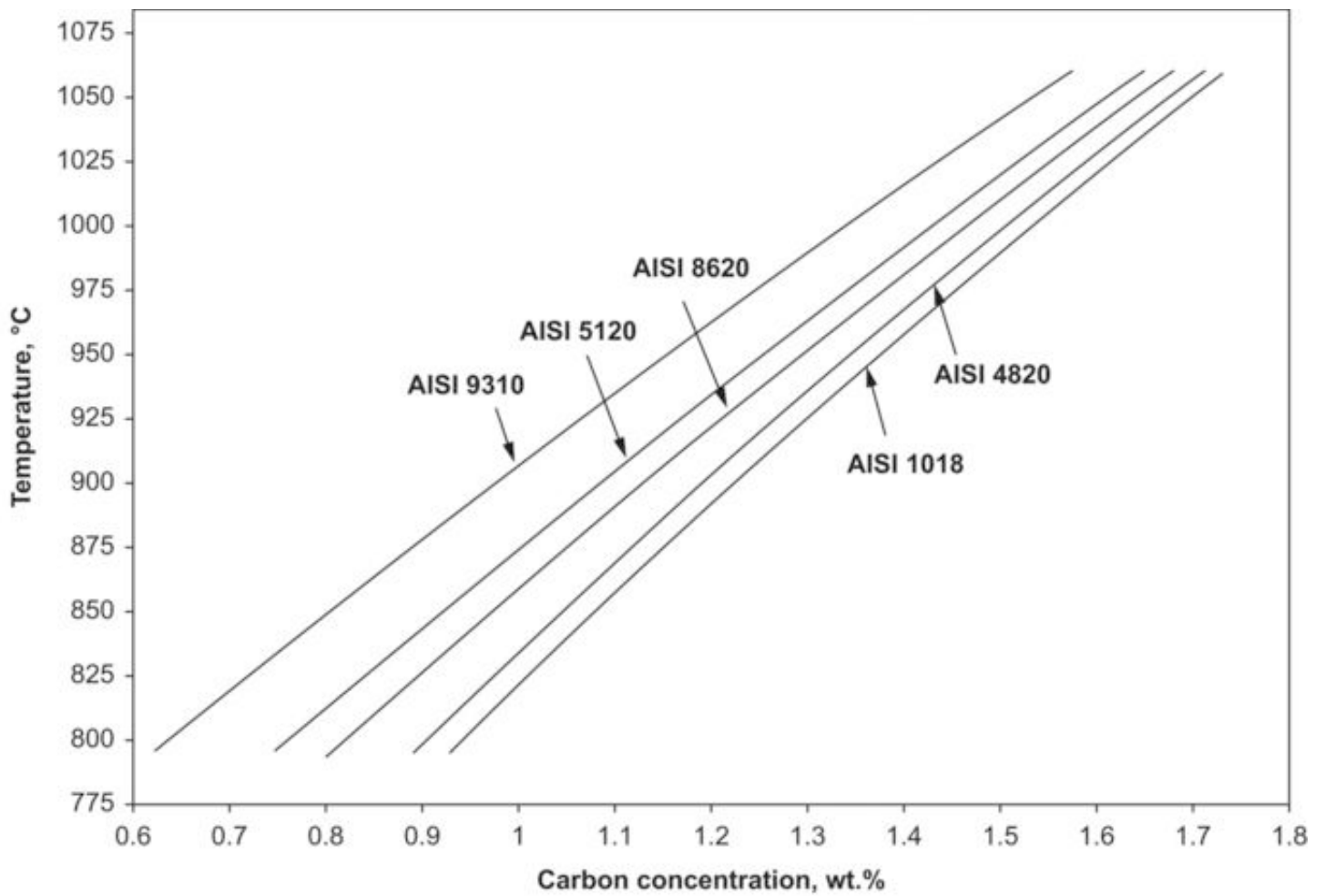
Common causes of decarburization in gas carburizing are outright furnace failures, that is, leaks, blown radiant tubes, open doors, and atmosphere generator problems. If the degree of decarburization is slight, it presents itself as a martensitic microstructure with a lower retained austenite content. This may not be a problem, but slight decarburization reduces the level of compressive residual stress near the surface. If decarburization is enough for the surface to revert back to ferrite, corrective action is required. Excessive surface decarburization can lead to low surface hardness and poor fatigue strength.

If the depth of decarburization is very shallow or less than the depth of metal removal from post-heat-treatment finishing operations, its impact may be negligible. Surface decarburization can be present even if the required case depth is achieved. This can make rework operations difficult because, in most cases, the processing required to recarburize the surface will drive the case depth even deeper, sometimes with undesirable consequences.

Carbides are relatively hard and brittle compared to carburized steel, so they are generally considered undesirable in a carburized component. Carbides are especially troublesome in rolling or sliding contact application, because they can act as fatigue crack initiation sites. Carbides tend to precipitate at grain boundaries, which can decrease the impact toughness of the material.

Regardless of the cause, carbides are typically seen near the surface of the carburized component, where the carbon content is at its highest. Carbides are typically caused by one of two conditions:

- *Excessive carbon content:* If the surface carbon of the carburizing medium is higher than the saturation carbon level of the steel ([Fig. 21](#)), it will begin to form iron carbide. There is no known benefit to carburizing at carbon levels higher than saturation. It is generally considered good practice to carburize at a carbon concentration just below the saturation carbon level, to maximize the increased diffusion rate achieved at higher carbon levels. The appropriate carbon potential can be easily controlled through the use of modern atmosphere-monitoring equipment and instrumentation. Maximum solubility limits of carbon in austenite are listed in [Table 4](#) at typical carburizing and quench temperatures for some common carburizing steels.
- *Slow cooling from the carburizing temperature:* When carburizing, it is normal for the carbon content at the surface to exceed the eutectoid composition of the steel. While the steel remains at carburizing temperatures, the carbon remains in solution, but as the component cools, it must pass through the austenite-Fe₃C field of the phase diagram. If the cooling rate is sufficiently fast, the carbon cannot precipitate out of solution. However, if the cooling rate is too slow, carbide will begin to precipitate as an equilibrium structure at the austenitic grain boundaries. This tendency can be minimized by cooling rapidly through the austenite-Fe₃C field to limit the time that the component spends in the austenite-carbide field.



Compositions used in calculations of saturation limits						
	1018	4118	4820	5120	8620	9310
C	0.18	0.2	0.2	0.2	0.2	0.1
Mn	0.75	0.8	0.6	0.8	0.8	0.55
Cr		0.5	—	0.8	0.5	1.2
Ni			3.5		0.55	3.25
Mo			0.25		0.2	0.1

Fig. 21 Carbon saturation limit in austenite for common AISI steel grades, calculated using Thermo-Calc. Source: [Ref 6](#)

Table 4 Carbon solubility limits in austenite at some typical temperatures for carburizing and hardening

Steel	Maximum solubility of carbon (wt%) in austenite (from Fig. 21) at:		
	925 °C (1700 °F)	845 °C (1550 °F)	800 °C (1475 °F) ^(a)
1018	1.3	1.07	...
4820	1.27	1.03	...
5120	1.17	0.91	...
8620	1.21	0.96	...

(a) Quench from 800 °C (1475 °F) applicable for 9310

Carbides present in an etched microstructure as distinct, light-colored, round-cornered features that can be present in a variety of morphologies ranging from discrete, individual carbides to a network around the prior-austenite grain boundaries (Fig. 22), also known as a continuous carbide network.

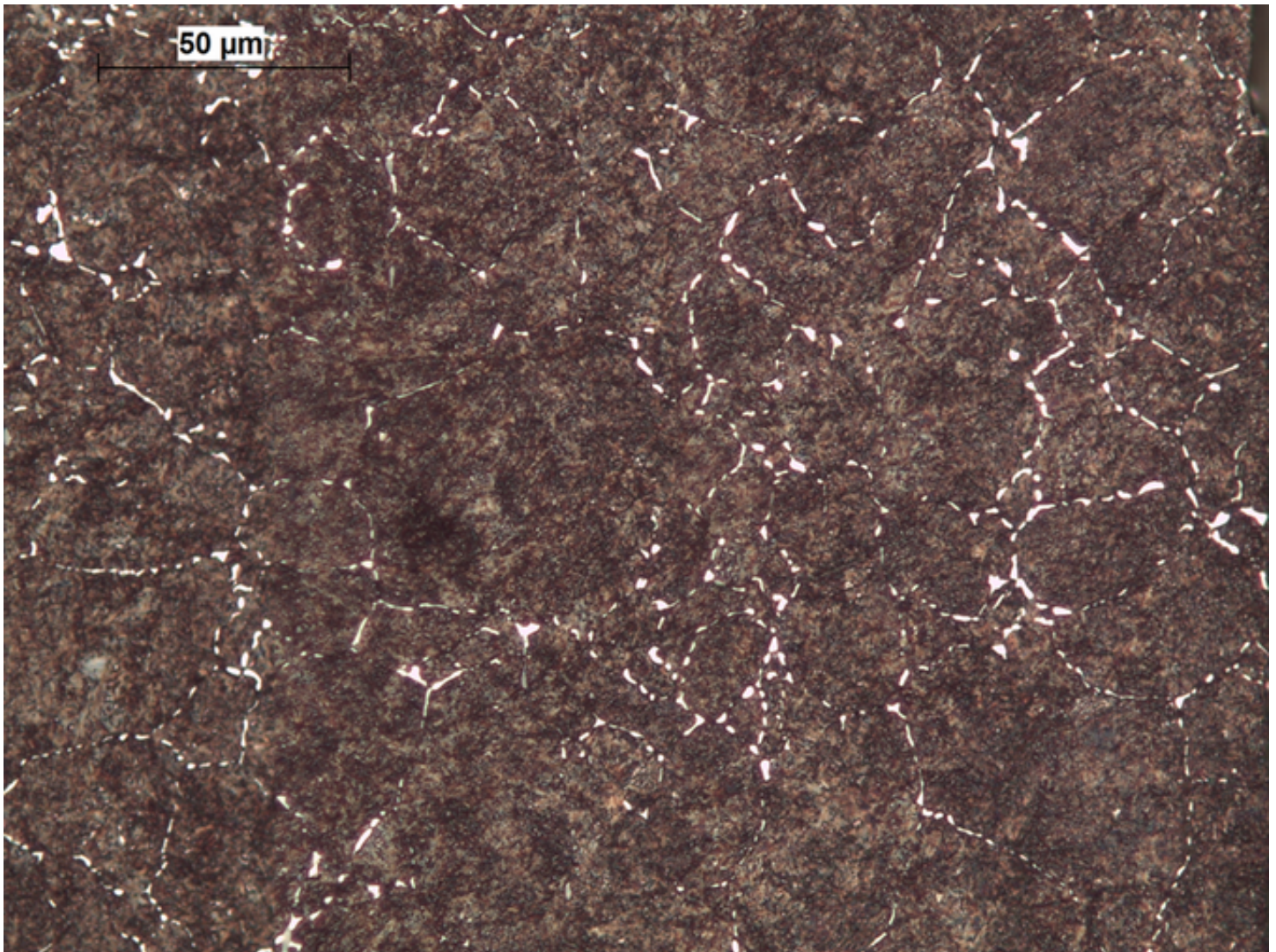


Fig. 22 Network carbides in a carburized case. Note how carbides outline the prior-austenite grain boundaries. 8620-grade steel. Nital etch. Original magnification: 500×

Masking is the prevention of carburization on a portion of the surface by means of a barrier. Masking can be either intentional or accidental.

Intentional masking may be employed when it is desirable to leave a specified area of the component soft for future processing (machining, drilling, etc.) or when having a hardened surface at some portion of the component is objectionable. This can be accomplished by plating with a barrier metal such as copper or by using commercially available stopoff coatings, which are formulated to act as a barrier to the transfer of carbon (see the article [“Stopoff Technologies for Heat Treatment”](#) in this Volume).

Unintentional masking results when carbon diffusion into the steel surface is accidentally inhibited, resulting in less surface carbon or case depth than intended. This can affect large or small regions of a component. Unintentional masking can be caused by chemical contamination of the surface or by physical obstruction of the surface by incidental contact between the component and other parts or fixtures during processing. This is often caused by residual fluids from previous operations that have dried on the surface or by surface corrosion. Unintentional masking is typically combated by selecting metalworking fluids that are compatible with carburizing or by washing parts prior to carburizing to remove residues. This condition is difficult to identify, but it can usually be detected by low surface hardness. Low case depth is

only detectable by metallographic sectioning of components.

Masking directly affects the carbon composition at the surface (and therefore the microstructure), so it can be detected on finish-ground surfaces by inspecting after the application of a suitable etchant. Unintentional masking will appear as a mottled or splotchy surface.

Intergranular Oxidation. The presence of internal oxidation at the surfaces of parts that are case hardened by pack or gas carburizing has been known for 50 years or more. The high-temperature transformation products, which can form as a direct consequence of internal oxidation, have subsequently been found to have adverse influences on certain strength properties of affected parts; therefore, these products are of some concern to metallurgists and engineers.

The use of oxygen-free gas carburizing atmospheres or vacuum carburizing processes is known to eliminate the oxidation process, and nitrogen-base atmospheres are said to reduce it. However, conventional gas carburizing using the endothermic carrier gas is still the most popular method of case hardening, and its use will continue for many years. Thus, the problems related to internal oxidation will persist as long as the conventional process lives ([Ref 7](#)).

Intergranular oxidation ([Fig. 23](#)) is unavoidable in gas-carburized steels, but it is predictable. In a normally operating furnace, intergranular oxidation typically develops at a rate of 0.0025 mm (0.0001 in.) per 0.25 mm (0.010 in.) of case depth, maxing out at a depth of approximately 0.013 mm (0.0005 in.). Intergranular oxidation penetration much greater than 0.013 mm (0.0005 in.) usually indicates that there is a significant atmosphere leak in the furnace.

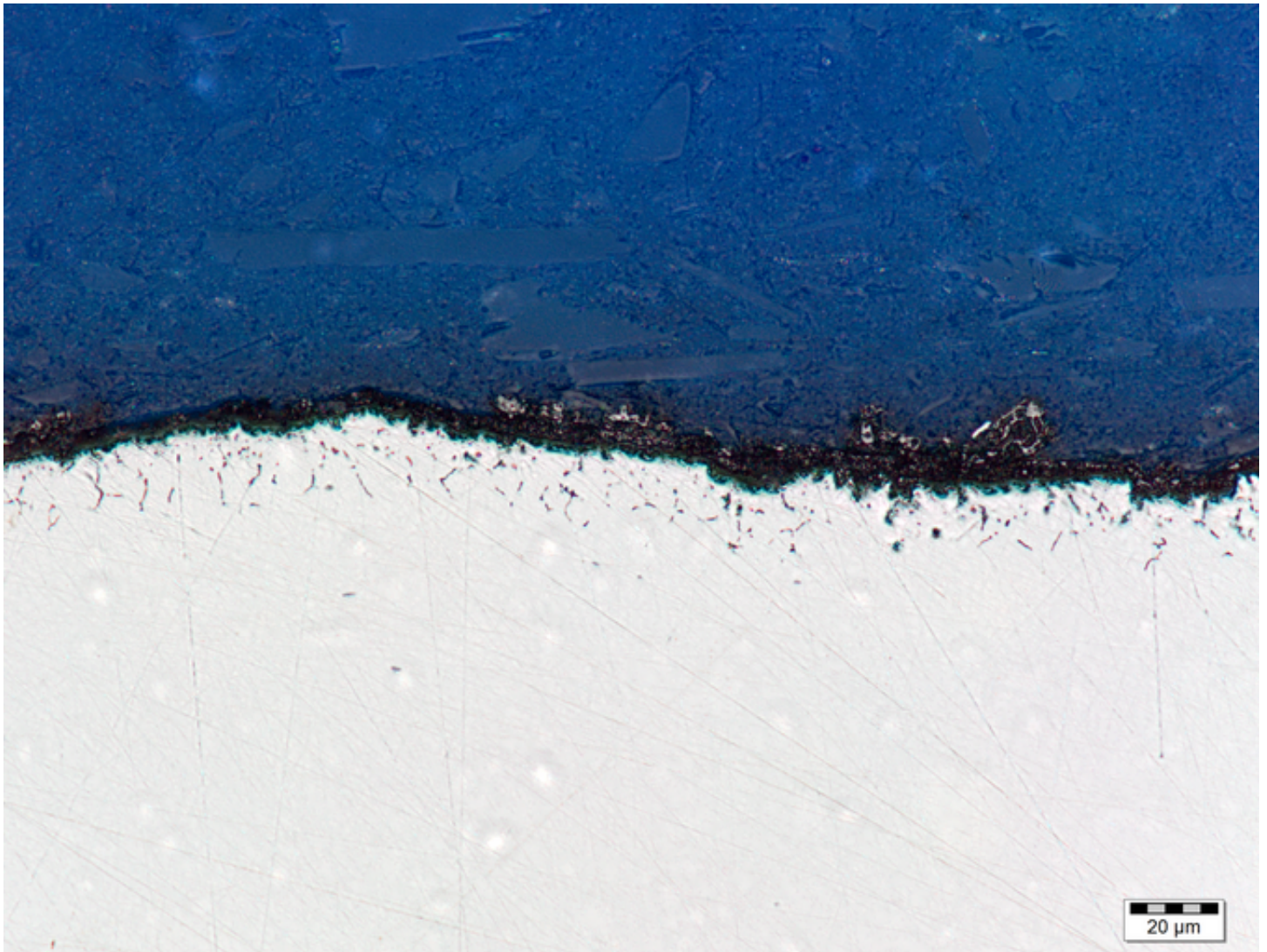


Fig. 23 Intergranular oxidation at the surface of a carburized component. Unetched. Original magnification: 500×

References cited in this section

6. Thermo-Calc Software TCFE7 Steels/Fe-Alloys Database, Version 7, Stockholm, Sweden

