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Introduction to Carburizing and Carbonitriding

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Introduction

There are many occasions when it is beneficial for a component to have the strength and wear resistance of a high-carbon steel on the outside while simultaneously possessing the toughness and ductility of a low-carbon steel in its center. A heat treating solution to provide such a composite was discovered centuries ago. This process has been known by many names, including cementation and later as case hardening. *Carburization* is the modern term used to describe the variety of processes that produce this case/core composite.

Carburization is the process of intentionally increasing the carbon content of a steel surface so that a hardened case can be produced by martensitic transformation during quenching. The steel is heated above the upper critical temperature (Ac_1), and carbon is introduced into the austenite phase as a solid solution. It is necessary that the steel be austenitized, because the solubility (and also, consequently, the diffusivity) of carbon in ferrite is very low compared to that of austenite. The carbon at the surface is then allowed to diffuse into the steel, so that a sufficient carbon profile or gradient is achieved below the surface. After a sufficient carbon profile is achieved, the steel is then quenched for transformation (martensitic) hardening of the high-carbon case.

Carburization has the ability to produce mechanical properties in steel that are markedly superior to those obtained from other methods of heat treatment, such as through hardening. Carburizing is particularly competitive in situations where fatigue resistance (especially bending, torsion, and rolling contact) is important. The primary characteristic that distinguishes a carburized component from one that is through hardened is the carbon profile or gradient. Through-hardened steels have uniform carbon content throughout the cross section of the component, whereas a carburized part has a higher carbon concentration at the surface that tapers down to the base carbon content of the steel at its core. It is this gradient that gives a carburized component its beneficial properties.

The unique properties of a carburized component are made possible by a combination of material properties (strength and hardness) that vary as a function of depth from the surface. These properties are the result of the complex interaction between the carbon content and the cooling rate. Because both the carbon content and the cooling rate vary across the section of a carburized component, different microstructures and properties are produced at different depths. The result is a component that delivers its greatest strength at the surface, where it is most effective. This has significant implications in terms of fatigue strength, because fatigue cracks typically originate at or near the surface of stressed components.

A closely related process is carbonitriding. Like carburizing, carbonitriding involves heating above the upper critical temperature (Ac_1) to austenitize the steel. In carbonitriding, however, both nascent (atomic) nitrogen and atomic carbon are added to the surface in solid solution with austenite. Nitrogen is a powerful austenite stabilizer, thus facilitating the formation of a solid solution with carbon in austenite. Nitrogen also speeds the rate of carbon diffusion. Like carburizing, case hardening is achieved by martensitic transformation during quenching. Because nitrogen is a powerful austenite stabilizer, the upper critical temperature (Ac_1) for any given steel is lower with nitrogen, thus allowing for lower transformation temperatures during carbonitriding as compared to carburizing. Nitrogen also increases the hardenability of the case so that many plain low-carbon steels respond to carbonitriding and oil quenching that would not ordinarily harden after being carburized and oil quenched.

This article introduces the basic fundamentals of carburizing, its advantages and limitations, and the methods of carburizing. Carbonitriding, as a method similar to carburizing but with important distinctions, is briefly compared to carburizing in the section "Methods of Carburizing and Carbonitriding" in this article. More details are in the article "Carbonitriding of Steels" in this Volume.