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.

Advantages and Limitations

When deciding if carburization is the best process for producing a component, it is helpful to consider its advantages and disadvantages when compared to competing methods.

Advantages

Lower Material Costs. Carburizing steels are characterized by low carbon content. The low carbon content offers some benefits to the steelmaker, which can be passed on to the component manufacturer. The hardenability of most carburizing steels is low enough to avoid hardening during the rolling and finishing operations at the steel mill. This means that the steel can often be introduced into the manufacturing process in the as-rolled or hot-rolled condition without the need for annealing. This can save a significant cost by avoiding the necessity for annealing at the steel mill. By comparison, through-hardening uses medium-to-high-carbon steels. Steel grades with carbon contents greater than 0.30% can be too hard to be easily machined. These grades usually require some sort of anneal before leaving the steel mill, which adds significant cost. The use of low-carbon carburizing steels can avoid these additional costs.

Greater Ease of Machining. Compared to higher-carbon through-hardening grades, carburizing steels are typically easier to machine. This is because carbon content directly affects mechanical properties, such as strength and hardness.

As previously discussed, steels with a carbon range of 0.15 to 0.30% can often be machined directly after hot forming operations without the need for an intermediate annealing step, such as is usually required with high-carbon steels. This flexibility can be of significant financial benefit to the component manufacturer both in terms of energy consumption and cycle time.

The lower energy input required to machine carbon steels permits greater productivity and lower costs for consumables (such as machining inserts). Capital equipment costs can be reduced by the fact that lower machining effort permits the use of less rigid machine tools.

Greater Freedom during Forming. Carburizing steels tend to have lower yield strengths and rates of work hardening than medium- and high-carbon steels, which facilitates cold forming, and permits transfer directly to machining without subsequent annealing operations.

Tailored Mechanical Properties. The use of carburization gives the designer great flexibility. By controlling the carburizing process parameters, the engineer can choose the surface hardness, load-carrying capacity, and surface microstructure to suit various requirements.

Development of Compressive Residual Surface Stresses. The natural tendency of carburization to produce compressive residual stresses at the surface of components is a significant advantage that is often overlooked. Compressive residual stresses contribute to higher load-carrying capacity and greater resistance to damage. Compressive residual stresses can also provide greater fatigue life.

Widespread Use. Because carburization is such a commercially successful process, there are many commercial and captive heat treating facilities available that can provide heat treating services. Those wanting to bring carburizing in-house will find that the necessary equipment is widely available.

Limitations

Capital Cost. Heat treating equipment is costly, regardless of the method chosen. Procuring the equipment to carburize components will often require significant expenditures. Initial costs include furnaces and atmosphere generators. A small batch-type carburizing furnace can cost several hundred thousand dollars or more. A large continuous furnace line may cost well over a million dollars. The following additional expenses should be considered:

- With new installations, additional expenses should be anticipated for utility connections.

- Furnace racks or trays to hold the workpieces during heat treatment must also be purchased. Carburizing atmospheres will gradually degrade alloy fixtures and furnace hardware over time, so replacement will be an ongoing cost.

Energy Consumption. Carburization requires substantial time at temperature to achieve the required surface carbon content and case depth. This requires energy to heat and maintain equipment and components at the designated carburizing temperature. Competing processes do not require this step.

Distortion. The very nature of the carburization process creates the potential for changes in the geometry of the component. There are chemical, thermal, and microstructural effects that the designer must consider. To compensate for distortion, the designer may have to heat treat the component with additional stock that will allow the component to be finish-ground to the final size. This adds cost through the additional material that must be purchased and processed, as well as the cost of the final grinding operation.

Depending on the complexity and geometry of the component, some amount of fallout for dimensional nonconformance may need to be planned for. Some components may have a geometry that allows them to be hardened in what is known as a quench press. A quench press uses special tooling to hold and constrain the component while simultaneously flooding it with quenchant. The use of a quench press can greatly improve the dimensional stability of carburized components.

Time-delayed dimensional change can be caused by the transformation of retained austenite in a component. Retained austenite is metastable at temperatures below the lower critical temperature, so it is thermodynamically available to transform if sufficient energy is provided in the form of heat or shear stress. When transformation does occur, a portion of the austenite grains will transform into fresh martensite, causing the characteristic volume change that takes place when face-centered cubic transforms into body-centered tetragonal. This volume change can dramatically affect the residual-stress level of a component, which in turn can cause measurable changes in part geometry. This can be avoided by ensuring that the retained austenite content of the component is no higher than necessary.