Understanding Atmosphere in Carburizing Applications Using Simulation and Real-Time Carbon Diffusion

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Abstract

In gas carburizing, the source of carbon is a carbon-rich furnace atmosphere produced either from gaseous hydrocarbons or from vaporized hydrocarbon liquids. To predict the amount of carbon available to the steel surface, theoretical steps with anticipated process variable inputs can be applied, and diffusion can be simulated. Inputs are typically captured during a real-time run. After the real-time run, results can be compared with simulation data. In this paper, the following items will be covered with respect to simulated and real-time carbon diffusion:

- Principles of atmosphere carburizing, including sensor and control technology;
- Analysis of input variables;
- The effects of atmosphere, temperature, and time on results;
- Differences in analysis using three-gas measurement and measurement using oxygen probes; and
- Examples of real-time and simulated carburization data.

Introduction

Furnace atmospheres are critical to meeting metallurgical specifications defined by control processes. The makeup of a furnace's atmosphere in the heat treating process varies based upon the application. In order to produce proper metallurgical results, atmosphere and temperature need to be controlled to allow for the transformation of the surface. In carburizing, this process calls for the addition of carbon at the surface and to a certain depth that allows for an increased hardness. The atmosphere used to deliver carbon to the work pieces needs to be precisely controlled, as do the temperature and time the parts are exposed to the atmosphere. Measurements of atmosphere can be performed continuously using extractive or in-situ techniques, and modeling software can be used to predict the carbon profile. Taking this one step further, one can use modeling software to control the process by utilizing the atmosphere inputs and varying the time to achieve the desired carbon profile.

Atmosphere Control

At one time, carburizing was conducted by packing the work pieces in a thick layer of carbon powder. The temperature was elevated to a point at which diffusion of carbon into the work surface would take place. While the process was effective, it was extremely slow and very difficult to control. Innovation has led to a process utilizing a carbonaceous gas atmosphere. Initially, the only effective way of controlling this process was to establish a relationship between the enriching gas flow and measurement of the carbon potential using either periodic shim stock or dew point measurements. This basic technique persisted until the early 1970s, when the zirconia carbon sensor was introduced. This sensor provided continuous measurement of the carbon potential rather than discontinuous measurements from shim stock or dew point readings. The measurement has been subsequently refined; the sensor correction factor and accuracy can be adjusted automatically by using 3-gas (CO, CO_2 and CH_4) IR analyzers to calculate carbon potential. The technique of using scientific gas analysis in conjunction with oxygen sensors has advanced to including continuous, non-dispersive infrared analyzers which measure continuously rather than periodically. Additionally, true representation of atmosphere can be achieved using metallurgical evaluation of parts or through carbon saturation of shim stock or coil tests. From these results, proper correction to the carbon calculation can be derived yielding more accuracy on the in-situ control parameter from the oxygen probe.

For example, an oxygen probe used for carbon potential will factor in the mV reading, temperature and the COF (CO Factor, Process Factor or gas factor) to provide the %C control data.

Probe = 1100 mV
Temperature = 1700 °F
COF = 200
Calculated Carbon = 1.16

If the evaluation of the atmosphere or parts is yielding a 1.2 carbon result, the probe needs to be adjusted to compensate for this. This compensation is performed by adjusting the COF accordingly.

Probe = 1100 mV
Temperature = 1700 °F
COF = 209
Calculated Carbon = 1.2

Several factors may contribute to the atmospheric properties required for ideal carbon potential. Calculating carbon for gas carburizing requires assumptions which include part material, base atmosphere, temperature and atmosphere makeup. The composition of the base atmosphere and the way in which the gas is measured have a significant effect on the accuracy of the calculated carbon potential. This calculation above illustrates why bias or factors are used for measurement methods of carbon potential.

As shown in Figure 1, in order for carbon to be made available to the steel surface, the carburizing reactant gases (CO, CH_4, H_2) must get to the surface while carburizing product gases (CO_2, H_2O, H_2) must escape from the surface.

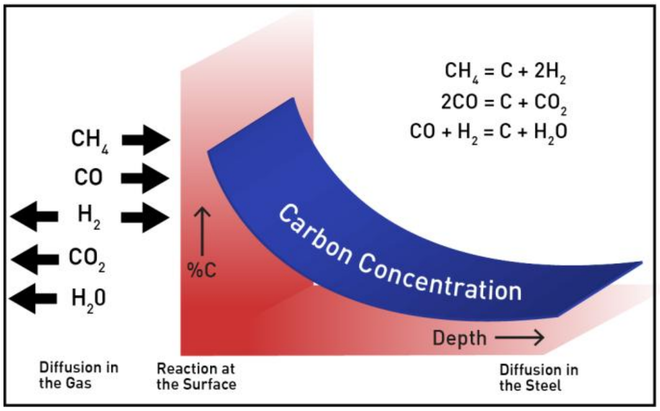

Figure 1: Movement of Gases in a Carburizing Atmosphere

Diffusion

Diffusion of the carbon can be calculated based on Fick's law of diffusion. With a carbon potential of the atmosphere greater than the carbon potential in the work piece, carbon concentration in the part can be predicted using the mathematical model represented by Fick's law. In Figure 1, the carbon concentration profile increases through the diffusion of the carbon.

Predictive Control

With a properly controlled and accurately measured atmosphere, the carburizing process can be predicted and controlled effectively. Historically, control methods are based on fixed time with a variance in the carbon and temperature setpoints. Using the fixed time does provide accurate control and consistency, but it is common to be conservative when providing a time for segments of the process.

When predicting the diffusion of carbon, the time variable can be replaced with the modeling of carbon to a desired carbon value at the surface or depth. The key to accurately predicting the procedure is to ensure that the atmosphere is measured precisely and that the time can be managed based on a model.

It is important to understand the model and specific variations caused by temperature, furnaces, agitation, fixturing, and part composition. Variations include alloying effects on the diffusion modeling based on certain alloy components, such as chromium and nickel.

The best way in which to utilize a predictive model in real-time control is to ensure that the variables accurately represent the conditions to which the parts are exposed, to build confidence by running data logged values through the modeling software, and to compare those values to metallurgical results. Using a three-step process of building, verifying and controlling allows for accuracy in method and confidence in results. The build process provides the simulation and "what if" analysis for the desired results commonly derived by case depth and surface carbon, but different methods such as time, temperature, and boost-diffuse steps can be explored. Verification accompanies the analysis of metallurgical results to determine whether desired results were achieved, allowing for adjustments of the process and mathematical model. When measuring gas atmosphere composition, it is important to ensure the control parameter (carbon potential) measured by the oxygen sensor accurately reflects the carbon content of the work piece. As discussed earlier, it is common for alternate methods of atmosphere verification to provide verification that the in-situ probe is accurate. Such alternate methods include three-gas analysis, shim stock, dew point, and resistance wire. When controlling with mathematical modeling, the variable that can be altered is the cycle time. The time is adjusted within certain parameters to meet the specific carbon profile characteristics that were defined initially.

Conclusions

Using gas atmosphere measurement and controls, it is possible to control a furnace to meet the specific carbon profile for the work piece. One should properly understand the variables in the measurement of the atmosphere and allow for mathematical modeling for determining the diffusion of the carbon into a specific material type. With proper techniques, the modeling and control can be used concurrently to provide a reduction in variation of surface and case carbon and to provide shorter cycle times.

References

[1] Super Systems, Inc. "CarbCalc II Theory: Theory of Operation," *CarbCalc II Carbon Diffusion Model for Atmosphere Furnaces* (2007), pp. 47-49.