Vacuum Carburizing System for Powder-Metal Parts and Components

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Carburizing is one of the growing surface-hardening processes applied to sintered, low-alloyed steel parts in the automotive industry. While diffusion of carbon in wrought steel is well documented, this is not the case for powder-metal (PM) steel subject to carburizing in vacuum furnaces. In this paper we present results that show that the density of the powder metal is the main factor for the final carbon content and distribution. Also important is the state of the surface of the part – either sintered with open porosity or machined with closed porosity. The way the carburizing gas moves through the furnace might be of some influence as well.

Vacuum carburizing is a non-equilibrium process. Unlike atmosphere carburizing, it is not possible to set the carbon potential of the atmosphere and control its composition in order to obtain a desired carburized case.

Currently the boost-diffusion technique is applied to control the surface carbon content and carbon distribution in the case. In the first boost step, the flow of carburizing gas has to be sufficient to saturate the austenite while avoiding soot deposition and formation of massive carbides. To accomplish this goal, the calculation of the proper gas flow rate has to be made. In the case of PM parts, however, the amount of carbon absorbed by the part's surface can be a few times higher thanks to additional internal surface area created by pores present in the carburized case [1,2]. This amount will depend on the density of the part, the densification grade of the surface layer and the stage of the surface – "as machined" or "as sintered." It is believed that enhanced gas diffusion after initial evacuation of the PM parts leads to faster carburization from within the pores, especially when pores are open – surface "as sintered" and interconnected – with low density.

A serious challenge with vacuum carburizing is to deliver the carbon in a uniform manner to the workpieces. This led to the development of the different methods of carburizing gas circulation – pulse/pump method developed in 1960s or pulse/pause technique applied in most of today's vacuum furnaces [3,4]. In both cases each pressure change may deliver fresh carburizing atmosphere into the pores, leading to faster carburization from within the pores.

Since today's control of vacuum carburizing is based largely on empirical results, present experiments may lead to better understanding and improved control of the process [5,6].

Experimental Procedures

Using a powder-metal blend designed to simulate the composition of AISI 8620 wrought-steel chemistry, standard transverse rupture strength (TRS) bars were compacted at pressures ranging from 480 MPa to 1080 MPa at six different densities starting from 7.0 g/cm^3 to 7.5 g/cm^3 with a 0.1 g/cm^3 increment.

The basic iron powder was a QMP Atomet 1001 HP. Alloying elements were admixed as ferroalloys or elemental powders together with graphite and 0.2%

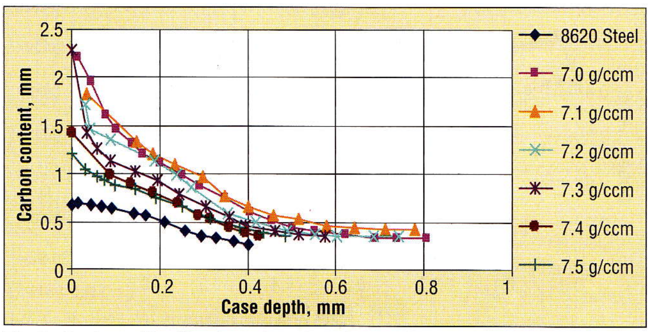

Fig.1. Carbon distribution showing dependence on density (as-sintered surfaces) - SECO/WARWICK pulse/pause process

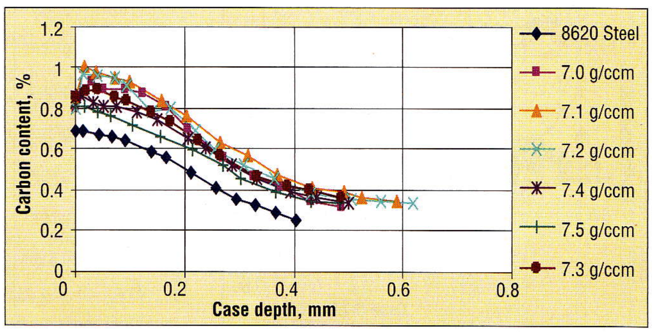

Fig. 2. Carbon distribution showing dependence on density (machined surfaces) – SECO/WARWICK pulse/pause process

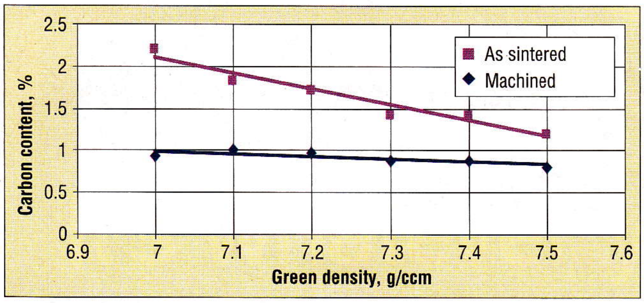

Fig. 3. %C on the carburized surface showing dependence on density – SECO/WARWICK pulse/pause process

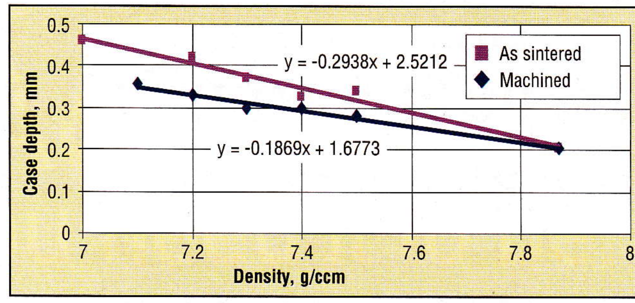

Fig. 4. Case depth at 0.5% C showing dependence on density for machined and as-sintered surfaces – SECO/WARWICK pulse/pause process

lubricant. Sintering was done at 1280˚C (2336˚F) in a 90% N_2 +10% H_2 dry atmosphere. As-sintered bars were vacuum carburized along with coupons of AISI 8620 wrought steel. Chemical compositions of the samples and reference coupons are given in Table 1.

Table 1. Chemical composition of the samples

Material	C	Si	Mn	Ni	Cr	Mo	Cu
8620 P.M.	0.19	0.21	0.84	0.52	0.51	0.21	0.21
8620 steel	0.21	0.323	0.81	0.57	0.54	0.20	0.20

To obtain machined surfaces, half of the samples were ground 0.1 mm with two passes. Carbon content was measured using a glow-discharge spectrometer – Leco GDS400. Typically, five runs were made for each depth level. Carbon profiling was achieved by subsequent grinding and spectral analysis.

Vacuum carburizing was performed using a furnace with a pulse/pause method and a furnace with pulse/pump method of gas circulation. In both furnaces process temperature was maintained at 900˚C (1650˚F) and the same boost and diffusion time of 16 minutes and 21 minutes, respectively.

In the pulse/pause furnace, the boost period consists of three pulses – 3 minutes + 1.5 minutes + 1.5 minutes – separated by 5 minute pauses. During each pulse, the pressure was fluctuating between 4.5 Torr and 8 Torr with the frequency of one fluctuation per 30 seconds. The carburizing atmosphere was SECO/WARWICK's patented mixture of acetylene + ethylene + hydrogen.

Boost in the pulse/pump furnace consists of three pulses separated by two pumping periods. Each pulse lasts 5 minutes and includes 8 injections, causing a pressure increase – up to 100 Torr. Pumping periods between pulses last 1 minute and pressure was reduced to 2 Torr before beginning the next pulse. Carburizing atmosphere consists of acetylene diluted with nitrogen in the ratio 1:7. Diffusion was carried on under vacuum of 0.2 Torr.

Results

Figures 1 and 2 show experimentally measured carbon distributions for different densities and sample surfaces ("as sintered" or "machined") for the pulse/pause carburizing process carried on in SECO/WARWICK's furnace.

Figure 3 shows a plot of surface carbon as a function of density for both sintered and machined powder-metal parts. Similarly, Figure 4 shows the variation of case depth as a function of density for sintered and machined samples.

Figures 5-8 show similar results obtained for the pulse/pump carburizing process. In both cases, the highest surface carbon content around 2.8% C is observed in "as sintered" samples, compacted at 7.0 g/cm^3. This amount decreases linearly to around 1.2% C for samples compacted at 7.5 g/cm^3. Based on high carbon absorption, the as-sintered, low-density samples produced a deeper case – up to 0.6 mm for pulse/pump process and 0.47 mm for pulse/pause process – as compared to 0.2 mm for reference pore-free material (AISI 8620).

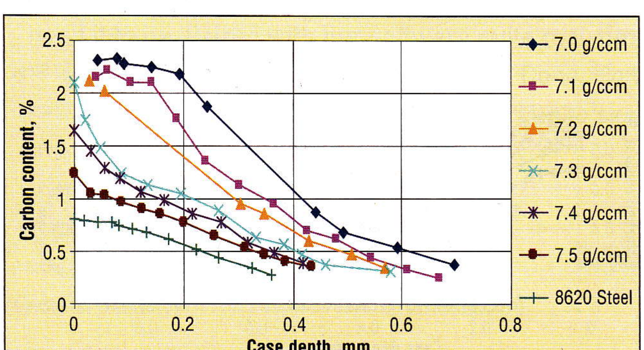

Fig. 5. Carbon distribution showing dependence on density (as-sintered surfaces) – Hayes pulse-pump process

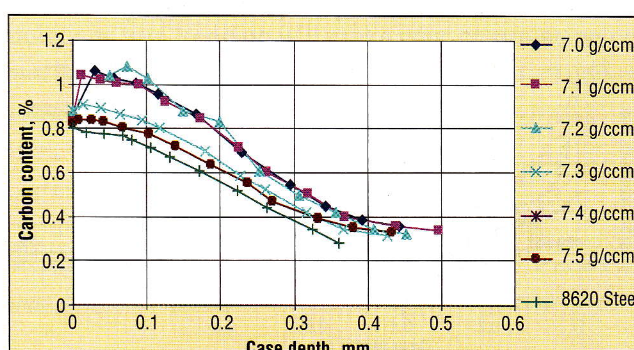

Fig. 6. Carbon distribution showing dependence on density (machined surface) – Hayes pulse-pump process

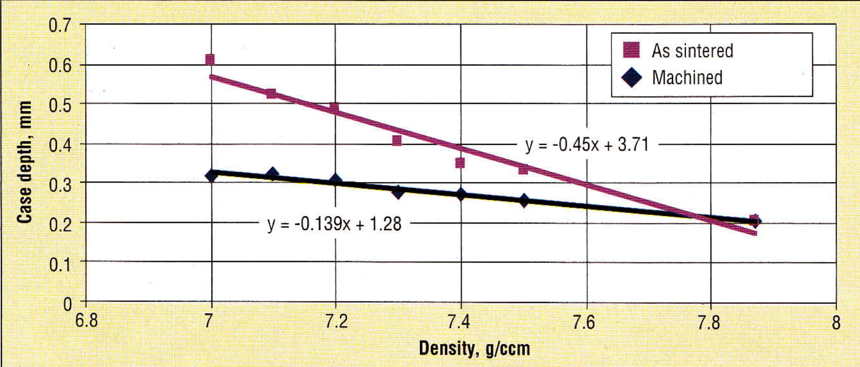

Fig. 7. Case depth at 0.5% C showing dependence on density for machined and as-sintered surfaces – Hayes pulse-pump process

As shown in these results, the closing of surface porosity by machining has a significant impact on both surface carbon absorption and case depth. At low density (7.0 g/cm^3), the surface carbon is reduced more than 50% by machining (2.8% vs. 1.1%). By increasing density to 7.5 g/cm^3, the machined samples absorbed almost the same carbon on the surface as pore-free material – wrought steel AISI 8620 (Fig. 6). Consequently, the case depth of high-density, machined powder-metal parts is very close to the case depth of pore-free wrought-steel material of the same chemical composition.

Conclusion

Vacuum carburizing of powder-metal material is much faster than of solid steel. The most important factor is open surface and porosity volume in powder-metal parts. By decreasing the amount of open porosity using a combination of high density and surface-pore closure modifications such as machining, the powder-metal parts can produce comparable case depth to wrought steel of similar chemistry.

In this work, it was shown that as-sintered, low-density powder-metal parts can produce dramatically abnormal surface carbon contents with massive carbides if carburized in the same conditions as pore-free wrought-steel parts. **IH**

References

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