LOW-PRESSURE CARBURIZING PROCESS DEVELOPMENT OF M50 NiL

With more aerospace customers looking for improved mechanical properties in bearing materials than offered in standard through hardened steel grades, New Hampshire Ball Bearings Inc. initiated a program to develop a low-pressure carburizing process that could provide the required properties in newer carburizable grades including M50 NiL.

Steve Carey*
New Hampshire Ball Bearings Inc.
Peterborough, N.H.

Dan Herring*
The Herring Group
Elmhurst, Ill.

**Member of ASM International and member, ASM Heat Treating Society*

HiTech Div., New Hampshire Ball Bearings Inc. (NHBB), manufactures precision bearings for use in aerospace and industrial applications, including various ball bearing and roller bearing configurations (Fig. 1). Historically, a majority of the materials used in aerospace bearing applications have consisted of through-hardened materials such as AISI 52100 alloy steel and M50 (intermediate high speed, molybdenum type tool steel) alloy steels. In the past several years, bearing manufacturers have seen an increase in the number of inquiries from aerospace customers who are challenged with bearing applications that require superior mechanical properties compared with those provided by standard through-hardened materials. To meet these ever-increasing requirements, carburizable grades of steel such as M50 NiL (a nickel-low carbon variant of M50 tool steel having the chemical composition 0.11-0.15% C, 4.1% Cr, 3.4% Ni, 4.2% Mo, 1.2% V, balance Fe) are now being specified for these applications. In doing so, wear resistance and fatigue strength properties (Table 1) are achieved on the case-hardened surfaces comparable to those of through-hardened materials, but with a higher level of fracture toughness in the core of the part. NHBB developed low-pressure carburizing technology to handle these materials.

Fig. 1 — Representative precision bearings.

Furnace Requirements

The first step in developing LPC technology at NHBB was to specify the requirements for the furnace design and operation. It was determined that one key feature of such a system would be its flexibility to perform both carburizing cycles and standard vacuum heat treatment. This required a furnace that would produce a minimal amount of sooting to avoid contaminating surfaces of non-carburized parts. Other features identified as being essential included:

- Ability to perform both oil quenching and gas quenching
- Optimum case uniformity
- Operator-friendly controls and programming
- Data acquisition capability
- Must meet all Aerospace Mate-

Table 1 — Typical Mechanical Property Data for Various Bearing Steels

Alloy	Tempering temperature, °F (°C)	Hardness, HRC	Fracture toughness (K_{Ic})*, ksi $\sqrt{in.}$ (MPa · $m^{0.5}$)	Fatigue life (L_{10} dynamic life factor)
440C	350 (175)	58-62	19 (20.88)	0.8
52100	375 (190)	60-64	18-20 (19.78-21.97)	1-6
M50	1000 (540)	60-64	18-20 (19.78-21.97)	10
M50 NiL	975 (525)	47 max.	50-52 (54.94-57.14)	12-16

** ASTM E399.*

Fig. 2 — Carburizing chamber of the low-pressure carburizing furnace.

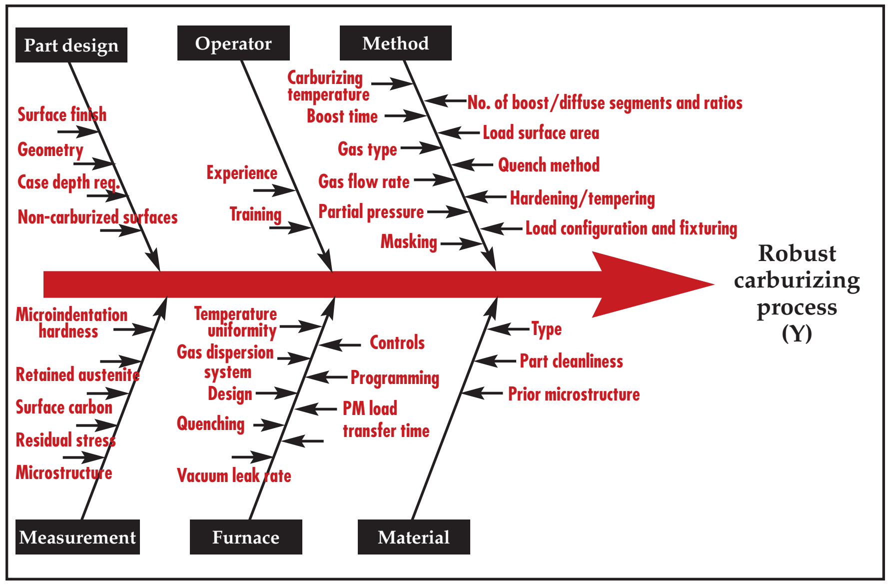

Fig. 3 — Cause and effect diagram outlining potential sources of variation in the low-pressure carburizing process.

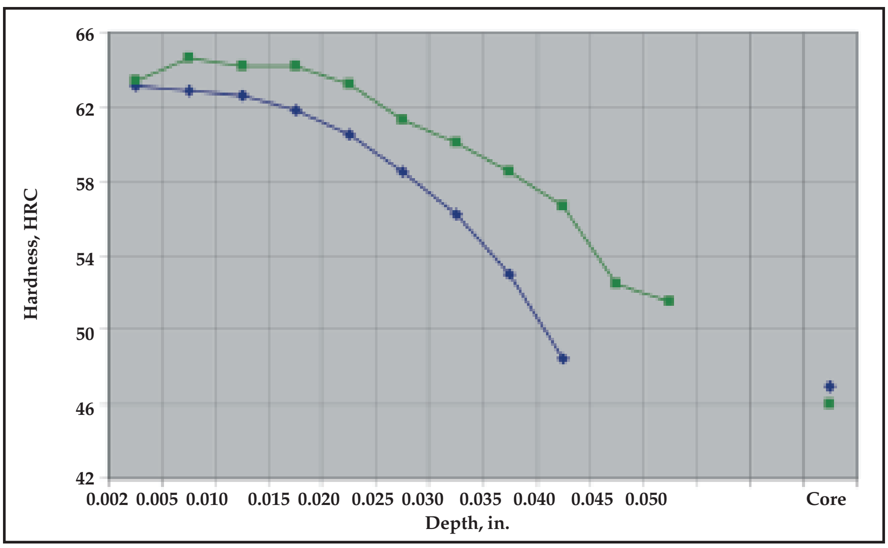

Fig. 4 — Case hardness profiles of two M50 NiL LPC development cycles.

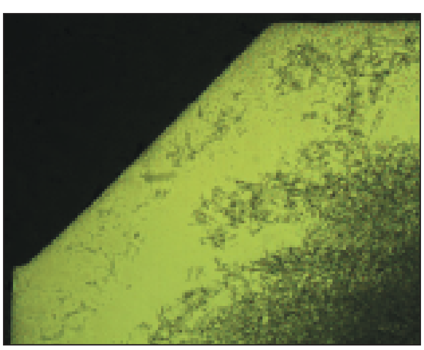

Fig. 5 — Photomicrograph showing very high level of retained austenite in the chamfer area of an inner roller-bearing ring; 3% nital etch. 200×

rial Specifications (AMS) pertaining to pyrometry (AMS 2750) and heat treatment of parts (AMS 2759)

It was determined that a LPC furnace would be best-suited to meet these requirements, and NHBB installed in 2005 an Ipsen International Inc. (Cherry Valley, Ill.) AvaC (acetylene vacuum carburizing) system (Fig. 2).

Process Development

After an extensive literature review on LPC and gathering information on LPC from various other resources, NHBB created a cause and effect diagram outlining the potential sources of inherent variability in the LPC process (Fig. 3). At the same time, carburizing simulation programs were developed to model the case profiles of M50 NiL and other materials. Several iterations of the M50 NiL simulation programs were conducted based on the results of the development cycles.

Initial carburizing cycles performed on the furnace were designed to verify the furnace would operate properly and produce the required carburized surface. These baseline cycles were completed using standard carburizing steels (AISI 1018 and AISI 9310). Carburizing parameters for these initial cycles were selected using values common to industry practices for these grades of steel.

While the required carburizing results were achieved in the furnace, results of initial test cycles indicated the need for modifications to the programming format for improved recipe flexibility (i.e., allow for additional boost/diffuse segments and provide the ability to program in minutes/seconds instead of hours/minutes) and modifications to the furnace hardware, both of which were handled on-site.

Following the initial tests, additional baseline test cycles on the standard carburizing steels were performed to verify the effects of several key process variables on resulting case depth, microstructure, and near-surface carbon content. Variables included:

- Carburizing temperature
- Boost/diffuse times and respective ratios

- Number of boost/diffuse segments
- Relationship between boost/diffuse cycles and surface carbon
- Partial pressures during boost and diffuse segments
- Relationship between part surface area and gas flow rate
- Carbon flux as a function of temperature

In all instances, resulting case depths, microstructures, and surface carbon measurements were consistent with expected levels.

M50 NiL Carburizing Development

NHBB used the results of the initial baseline tests to develop a robust carburizing procedure for M50 NiL (AMS 6278). M50 NiL is a carburizable grade of steel used in the aerospace industry in critical applications requiring higher core fracture toughness properties compared with the through-hardened (non-carburizable) M50 grade of steel. The relatively high level of chromium in M50 NiL (4.0-4.25%) presents a challenge when developing a carburizing process due to an increase in the effective carbon absorption of the material [1].

The first few M50 NiL test cycles were modeled to target an effective case depth of 0.030 to 0.035 in. (0.762-0.889 mm). Effective case depth is defined as the perpendicular distance from the case hardened surface to a depth equal to a hardness of 58 HRC. Initial carburizing temperatures in the range of 1600 to 1900°F (870-1040°C) were selected based on temperatures commonly used in the industry for LPC. In all cases, the parts were heated to the carburizing temperature, exposed to multiple boost/diffuse segments, cooled to below 200°F (95°C) in a protective atmosphere, then austenitized, oil quenched, and processed through multiple subzero/tempering cycles. Several short boost cycles were combined with progressively longer diffuse times to overcome the effective carbon absorption of M50 NiL material. For example, representative case hardness profiles (Fig. 4) from two of the development cycles where all processing parameters were identical with the exception of the number of boost/diffuse segments revealed that a much deeper effective case was produced with five additional boost/diffuse segments. While the case hardness profiles were promising based on targeted depths, metallurgical evaluation of the resulting case microstructures revealed high levels of retained austenite, particularly in the corner and chamfer areas of an inner roller-bearing ring (Fig. 5).

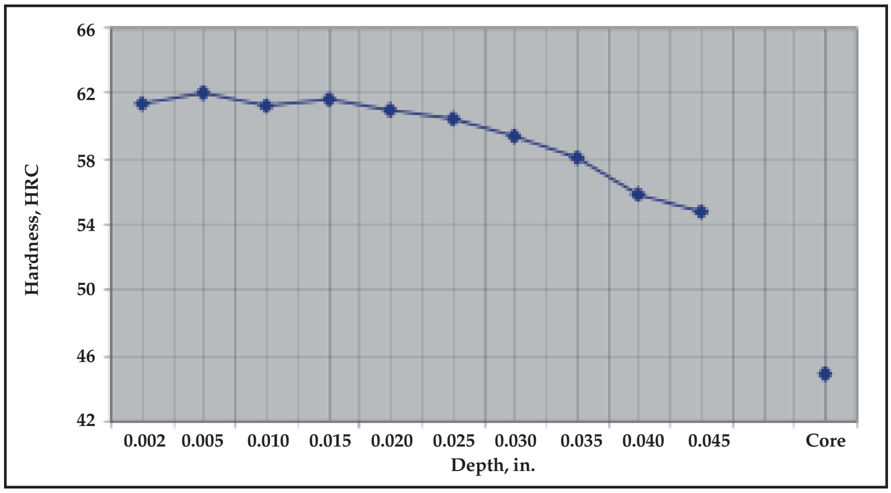

Fig. 6 — Case hardness profile of final M50 NiL LPC production cycle.

Surface-carbon results from test specimens included in the loads showed carbon levels in excess of 1.1%. It was necessary to lower the near-surface carbon concentrations to the 0.70% range to optimize the microstructure of the M50 NiL test pieces. "Leaning out" the surface carbon level was accomplished by lowering the carburizing temperature, shortening boost times, extending diffuse segments, and increasing the number of boost/diffuse segments. Resulting microstructures showed no evidence of retained austenite or excessive carbide formation in the corner and chamfer regions. However, the effective case depths of the test cycles were less than 0.020 in. (0.508 mm).

A carburizing process was developed to maintain the superior case microstructure of the previous cycle while extending the effective case depth to the required 0.030-0.035 in. range. The resulting case hardness profile (Fig. 6) for the modified cycle revealed the effective case depth to be approximately 0.035 in. Also, the corresponding case microstructure was uniform in depth around the entire cross section, consisting of tempered martensite with no evidence of retained austenite or excessive carbide formation (Fig. 7). Retained austenite content at a depth of 0.002 in. (0.051 mm) from the case hardened surface was measured using an x-ray diffraction method in accordance with ASTM E975 and was less than 2%. Near surface-carbon content was 0.74%.

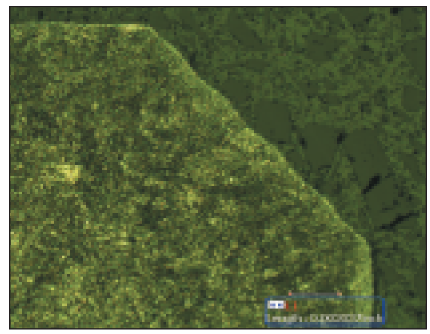

Fig. 7 — Photomicrograph showing a tempered martensitic microstructure in the chamfer area of an inner roller-bearing ring. There is no evidence of retained austenite or excessive carbide formation; 3% nital etch. 200×

Process Validation and Optimization

Validating process results was accomplished by repeating the cycle and examining load-to-load variation (Fig. 8), within-part variation (Fig. 9), and part-to-part variation within load (Fig. 10). The case-hardening profiles show that the LPC cycle developed using this analytical approach produces excellent case uniformity and reproducibility. In each instance, the corresponding microstructures, retained austenite levels, and near surface-carbon contents conformed to specified levels. *Continued*

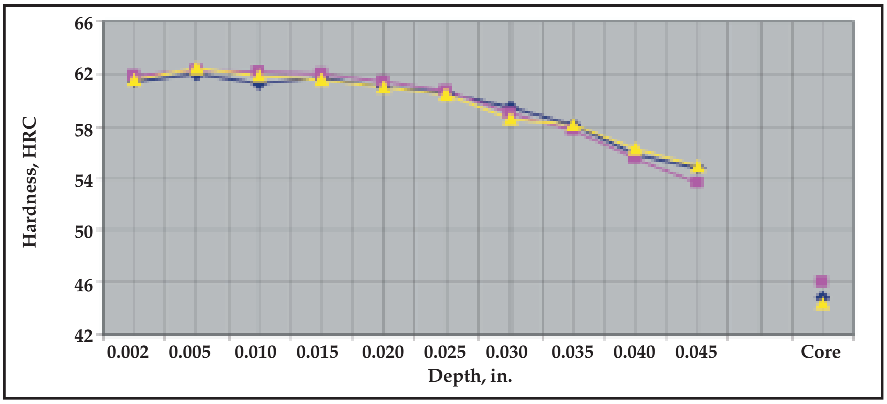

Fig. 8 — Case hardness profiles measured on the roller paths of M50 NiL samples processed in three identical test cycles show load-to-load variation.

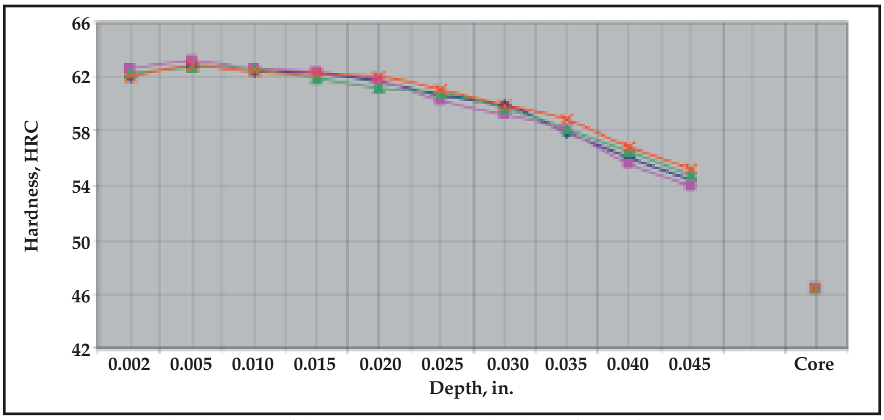

Fig. 9 — Case hardness profiles measured on multiple surfaces of an M50 NiL sample show within-part variation.

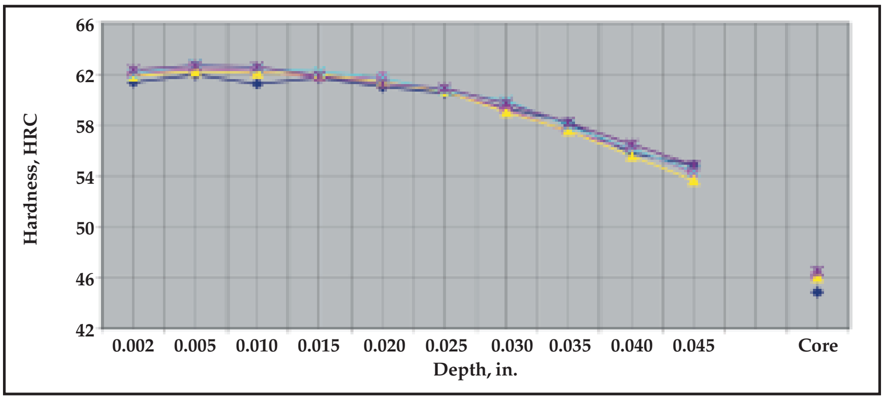

Fig. 10 — Case hardness profiles measured on multiple parts from one M50 NiL LPC production cycle show part-to-part variation within the load.

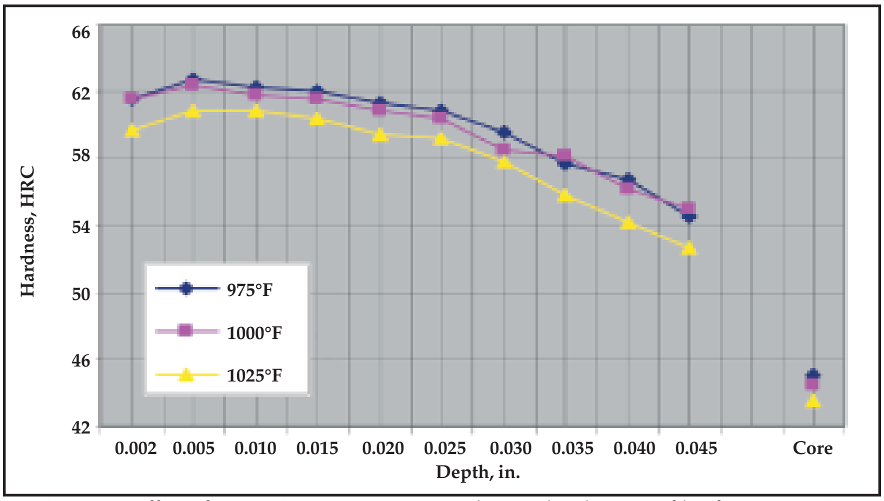

Fig. 11 — Effect of tempering temperature on the case hardness profile of an M50 NiL case hardened component.

Using standard industry temperature ranges, an optimum combination of austenitizing temperature and tempering temperature was determined based on results from a full factorial design of experiment. Variation in temperature for each of these operations has a significant impact on the resulting case hardness profile, particularly for the tempering operation (Fig. 11).

Qualification of Masking Process

Several test parts were copper plated in accordance with AMS 2418 to qualify a masking process for M50 NiL and other carburizing grades of steel. In all instances, the plating process was an effective way of masking surfaces to prevent case hardening at those locations.

Summary

NHBB developed an LPC process for M50 NiL material, providing a good knowledge base to enhance and apply the process to new materials and part configurations. Currently, effective case depths have been extended to 0.045 in. (1.143 mm). Future development work will be aimed at extending the process to achieve effective case depths in excess of 0.060 in. (1.524 mm) for M50 NiL and on the order of 0.100 in. (2.54 mm) or greater for materials such as 9310. Trials on Pyrowear 675 stainless steel (Carpenter Technology Corp., Reading, Pa.; www.cartech.com) are also planned.

References

1. D.H. Herring, Study of Vacuum Carburizing Process Parameters, *Ind. Heating*, p2, Sept. 1996.

For more information: Steve Carey is Manager of Materials Engineering, New Hampshire Ball Bearings Inc., HiTech Div., 175 Jaffrey Rd., Peterborough, NH 03458; tel: 603-924-3311, ext. 5522; fax: 603-924-9306; e-mail: scarey@nhbb.com; Internet: www.nhbb.com; Daniel Herring, The Heat Treat Doctor, is president, The Herring Group Inc., PO Box 884, Elmhurst, IL 60126; tel: 630-834-3017; fax: 630-834-3117; e-mail: dherring@heat-treat-doctor.com; Internet: www.heat-treat-doctor.com.