Intricacies of induction hardening powder metallurgy parts

PROFESSOR INDUCTION

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Professor Induction welcomes comments, questions, and suggestions for future columns. Since 1993, Dr. Valery Rudnev has been on the staff of Inductoheat Group, where he currently serves as group director – science and technology. In the past, he was an associate professor at several universities, where he taught graduate and postgraduate courses. His expertise is in materials science, heat treating, applied electromagnetics, computer modeling, and process development. He has 28 years of experience in induction heating. Credits include 15 patents and 118 scientific and engineering publications. He also is coauthor of the 800-page Handbook of Induction Heating *(published in 2003 by Marcel Dekker, www.dekker.com). Contact Dr. Rudnev at Inductoheat Group, 32251 North Avis Drive, Madison Heights, MI 48071; tel: 248/585-9393; fax: 248/589-1062; e-mail: rudnev@inductoheat.com; Web: www.inductoheat.com.*

An important emerging application of induction heating is for surface hardening of ferrous powder metallurgy (P/M) parts, such as gears (figure), splined hubs, and cams. Induction hardening of P/M parts has several peculiarities compared with hardening wrought steels and cast irons.[1,2] First, when using induction, remember that the results of induction hardening are more sensitive than those of alternative processes to chemical composition, the microstructure of the part before hardening, and the part's physical properties.

Density, porosity

Electrical resistivity, thermal conductivity, and magnetic permeability are strongly dependent on the amount of porosity in the sintered compact. This helps explain why the induction hardening response of P/M parts is more sensitive to variations in material properties than that of castings or forgings. For example, variations in electrical resistivity and magnetic permeability lead to variations in the amount of power induced within the P/M workpiece and the depth of eddy current penetration, resulting in heat-pattern variations. The effects of a density reduction (porosity increase) on some properties and induction hardening parameters are given in the table.

Low density (high porosity) negatively affects hardenability. Therefore, when induction hardening P/M parts, good practice requires a density of at least 7.0 g/cm^3. This will help ensure consistent heat treat results, particularly when hardening internal surfaces that have undercuts, teeth, splines, sharp corners, slots, and other stress risers.[1] (*Note:* Although it is strongly recommended that P/M parts to be induction hardened have a density of at least 7.0 g/cm^3, there are applications where OD hardening is successfully performed on parts having a density as low as 6.8 g/cm^3.)

Low-density P/M parts also are good candidates for cracking. Interconnected pores contribute to decreased part strength and rigidity compared with wrought materials. In addition, the poor thermal conductivity of porous P/M parts encourages the development of hot spots. And very fast quenchants are required, which results in severe thermal gradients that also increase the tendency for cracking.

In addition, highly porous P/M parts have a greater tendency to corrode and to take on an unsightly appearance. Causes of both can be traced to residual water-based quenchant trapped in subsurface pores.

Bottom line: Inconsistent results often are observed when induction hardening highly porous (low-density) P/M parts. These may include cracking and variations in surface hardness and case depth.

Composition, homogeneity

Density and porosity are not the only factors that affect the induction hardening of P/M parts. Material composition is another. Copper, nickel, and molybdenum are the most commonly used steel powder alloying

A selection of P/M gears suitable for induction hardening. Other candidates include splined hubs and cams. (Photo courtesy Inductoheat Inc.)

How density reduction (porosity increase) affects some P/M part properties and induction hardening parameters (Ref. 1)

Property	Change	Influence on induction process
Thermal conductivity	Decrease	Less soaking action from high-temperature to low-temperature regions. Larger temperature gradients and thermal stresses during heating. Slower cooling during quenching.
Electrical resistivity	Increase	Larger current penetration depth.
Magnetic permeability	Decrease	Larger penetration depth and lower coil electrical efficiency.
Hardenability	Decrease	More severe quench is required to provide the same case depth.
Structural homogeneity	Worse	Inconsistency of hardening; variations in surface hardness, case depth, hardness scatter, and residual stress data. Tendency for cracking during hardening.

elements. Depending on their specific composition, some parts may have a greater tendency to crack. For example, special attention must be paid when developing induction hardening recipes for P/M copper steels.

Other factors that affect the heat treat quality of a P/M part are the homogeneity of its microstructure (material segregation), surface condition, and parameters of the heat treating process, as well as specifics of prior processing operations such as sintering of the green compact.

In the case of sintering, factors include the process sequence, atmosphere used, pressure, temperature, degree of sintering, and graphite segregation. High-temperature sintering is preferred because it improves microstructural homogeneity and ensures good diffusion. However, decarburization of the surface prior to induction hardening should be avoided.

Alloying technique: The alloying method used to produce the powder also can have a marked effect on heat treat results. Among alloying techniques are admixing, diffusion alloying, prealloying, hybrid alloying, and the MIM (metal injection molding) method. The technique used can affect material segregation and chemical and microstructural heterogeneity, due to different areas of the part undergoing abnormal phase transformations during cooling. For example, large inclusions may form that can serve as stress risers, increasing the potential for cracking of the part and/or inconsistent hardness readings.

I have observed cases where microstructural heterogeneity in a copper alloyed steel powder metallurgy part was so severe that when examined under a microscope it almost looked like copper had been electroplated on the surface of the part. This was the result of incomplete copper diffusion during alloying.

Quenching, distortion

Oil quenching is often specified when hardening powder metallurgy parts, particularly for those with stringent dimensional stability requirements and those having a pronounced tendency to crack. It is quite common for P/M parts to absorb 2% oil by weight. Therefore, steps must be taken to ensure that quenching oils remain clean.

Concern about fires and environmental restrictions are obvious drawbacks to using oils and oil-based quenchants. Other media frequently used include water-based polymer quenchants and water (containing appropriate additives). Note that oils typically require higher hardening temperatures than polymer quenchants and water.

Shape/size distortion and warping due to heat treating are usually less for powder metallurgy components than for their wrought steel counterparts. The degree of shape deformation strongly depends on part/coil geometry and hardness pattern, and usually is determined experimentally.

Material, process selection

P/M steel parts considered ideal for induction hardening have a variable "surface-to-core" or "OD-to-ID" density. The density at the surface to be hardened typically is 7.5 g/cm^3 or higher. This gradually decreases to a base density of 7.0 g/cm^3 at the center of the part.

When determining process parameters for induction hardening of P/M parts, energies and frequencies higher than those used for wrought alloys of similar composition often are chosen. Closer process control also is required. And preheating is sometimes needed to avoid cracking and obtain the required heat treat pattern for parts having significant stress risers.

Summary: The P/M industry continues to improve its technology. In the past, P/M parts sometimes were tagged "low strength." And the low strength and high porosity of P/M parts held back the widespread adoption of induction hardening. Not anymore. Improvements in P/M parts manufacturing, a better understanding of induction hardening of P/M parts, and a greater awareness of induction heating's features all have emerged during the past five years. The tools are now available to develop intelligent process recipes that will ensure success in induction hardening of P/M parts. **HTP**

References

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