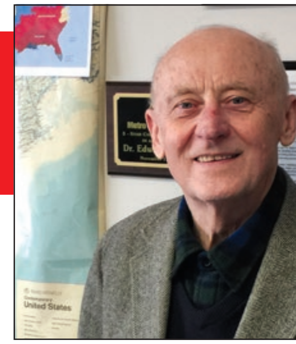
HOT SEAT

**EDWARD ROLINSKI**
SENIOR SCIENTIST
ADVANCED HEAT TREAT CORP.



# DISTORTION ENGINEERING OF GEARS

## Various thermal operations can be used to prevent distortion induced from any stage in the manufacturing process, whether it's before or after heat treatment.

**THE CAUSES FOR DISTORTION OF GEARS** are complex and the heat treatment process has been named as a main contributing factor [1]. However, the truth is, all the manufacturing steps prior to and after heat treating also make a contribution to distortion. Nevertheless, any thermal operations carried out on gears may trigger and reveal the hidden distortion potential induced by manufacturing. An interesting approach of "distortion engineering" was established by the Collaborative Research Center (CRC) at Bremen University [2]. The methodology concentrates on three levels of investigations. The first level shows potential causes of the distortion by analyzing the entire manufacturing chain. The second level deals with understanding the mechanisms responsible for the distortions, including "carriers of distortion potential" such as geometry of the component and metallurgical and mechanical characteristics of the material. These factors responsible for distortion can be introduced to the workpiece in the early production steps during the making of the steel or during the making of the semi-product and some, such as asymmetrical forging or machining, can be introduced during the final steps of manufacturing. The third level of the system-oriented approach addresses deliberate actions that prevent the existing potentials from causing distortion [1]. For example, this can be done by purposely applying counteracting inhomogeneous heat treat steps such as soaking or quenching for preventing distortion.

Case-hardening processes such as carburizing or carbonitriding are often used for surface hardening of the gears. They are carried out at high temperatures typically above 900°C for the diffusion step of carbon and nitrogen atoms and are followed by a vigorous quenching. This also happens during induction hardening of the gear teeth. Fast quenching is required for sudden temperature changes needed for the formation of martensitic structure in the steel. Therefore, when this process is applied to gears, it requires precise temperature controlling of all the steps to minimize distortion. To achieve that, a complex heating profile is typically used, which has a preheating step before carburizing to minimize temperature gradients as well as an additional step at a lower temperature before quenching. A new method of a quick low-pressure carburizing (LPC) process with a much-simpler temperature profile and adjustable high-pressure gas quenching was recently implemented [3]. The method offers optimal quality regarding temperature homogeneity and uniform quenching, and it results in good distortion control. The method shows excellent potential for processing gears, although sensitive part geometries, such as sliding sleeves, might still be a challenge. The LPC method is superior to much more expensive press quenching. Typical applications of this method are in the automotive, aerospace, and tool industries. When distortion is unavoidable, it is usually eliminated by bend straightening (BS) if permitted [4]. BS is an elastic-plastic operation applied typically to the drive and transmission shafts. It results in inhomogeneous deformation over the cross-section of the component. Because BS causes a plastic deformation of the material, components with the case-hardened layer can develop cracking during this operation. Such pre-existing cracks have a negative effect on bending fatigue properties of the case-hardened component. Also, the maximum residual compressive stress resulting from BS may be below the surface, nullifying the benefits of the case hardening.

Nitriding appears to be a distortion-free process when applied to ferrous alloys. Compared to other surface engineering or heat treating technologies, it can be applied to almost any low- or high-carbon or alloy steel, and it is characterized by a variety of applications based on the structure of the nitrided layer [5]. The process is typically carried out at a temperature range of 400-650°C, which is below Ac1-temperature for the iron-carbon system (transformation of pearlite to austenite). Therefore, there is typically no distortion if the process is carried out on the stress-relieved parts. Because there is no phase transformation in the steel, the only minor changes in dimensions of nitrided components can be caused by the formation of the residual compressive stress, which can result in distortion only if the stress is asymmetrical and the thickness of the specific area of the part is small compared to the layer depth. An insignificant dimensional growth of nitrided components is related to the formation of the compound layer consisting of $\varepsilon$-(carbo) nitride $Fe_2(N,C)_{1-x}$ and $\gamma'$-nitride $Fe_4N$ within the outer zone. The growth is typically small, not exceeding 60 percent of the compound layer thickness, and it is repeatable, predictable, and not exceeding a few micrometers. In situations when a limited surface area needs hardening, nitriding — especially in its plasma/ion form — offers a unique and effective method of local hardening by using mechanical masking.

Many of the small gears are made of sintered powder steels and alloys. Surface hardening of those gears should be carried out using plasma/ion nitriding methods to avoid distortion and dimensional changes. The porosity that exists in sintered products is a serious obstacle for conventional surface hardening processes such as salt bath and ammonia nitriding. Salt penetrates the porous structure and has to be removed in an additional post-nitriding operation, while ammonia used in the gas process penetrates the treated part, causing through-hardening and "swelling" as well as embrittlement. Ion nitriding hardens only the surface of the product without any of the adverse effects associated with the other surface treatment technologies, and it has proved to be a reliable technique for distortion-free surface


**Figure 1: Load of sintered powder metal (PM) hub synchronizers after ion nitrocarburizing**

hardening of many engineering components. The process can be used for a large quantity of small parts (see Figure 1).

The compound zone, shown in Figure 2 as a white layer (WL) in the structure, not only improves wear properties, but also increases corrosion resistance. Although a compound zone is the most important element of the nitrided layer in PM products made of iron-copper-carbon and similar alloys, there is always a diffusion layer below the surface with increased hardness reaching a depth of 0.010 to 0.050 inches (0.25 to 1.27 mm). This layer provides good support for a much-harder compound zone.

Unlike nitriding, even improved general heat treating such as quenching, tempering, and carburizing of gear components can cause significant distortion, which may not be easily controlled. Therefore, sensitive part geometries are still a challenge for general heat treating, and in this situation, nitriding should be considered as a primary surface hardening method.

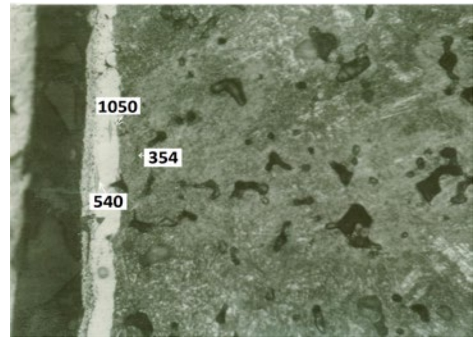



**Figure 2: Structure of the near-surface layer (the numbers denote hardness Knoop in three different locations of the structure [6])**

## REFERENCES


1. A. Olofsson, S. Johnson, and B. Brash, "Hardening Distortion Related to Segregations in Crown Wheels," HTM Journal of Heat Treatment of Materials, 2/2016 Volume 71 www.htm-journal.de. pp 68-74.
2. H.-W. Zoch, "Distortion Engineering" Interim results after one decade research within the Collaborative Research Center. Mat.-wiss. U. Werkstofftech. 43, 2012, 1-2, pp. 9-15, DOI:10.1002/mawe.20110081.
3. A. Schülerm, J. Kleff, V. Heuer, G. Schmitt, and T. Leist, "Distortion of Gears and Sliding Sleeves for Truck Gear Boxes – A Systematical Analysis of Different Heat Treatment Concepts," HTM Journal of Heat Treatment of Materials, 2/2016 Volume 71 www.htm-journal.de. pp. 90-98.
4. C. Schott, A. Ellermann, W. Zinn, and B. Scholtes, "Consequences of Bend Straightening Processes on Residual Stresses and Strength of Quenched and Tempered Steels," HTM Journal of Heat Treatment of Materials, 2/2016 Volume 71 www.htm-journal.de. pp. 75-82.
5. H.-J. Spies and A. Dalke, "Case Structure and Properties of Nitrided Steels," Comprehensive Materials Processing, Ed. G. Krauss, Elsevier Ltd., 2014, Vol. 12, pp. 439-488.
6. E. Rolinski and G. Sharp, "Ion Nitriding and Nitrocarburizing of Sintered PM Parts," Industrial Heating, Oct. 2004, 33-35.


**ABOUT THE AUTHOR:** Dr. Edward Rolinski received his M.S. in manufacturing technology in Warsaw, Poland, and received his doctorate for his research on phenomenon in the ion nitriding process. He has taught physical metallurgy and surface engineering and received his ScD (habilitation) for studying plasma nitriding of titanium. Rolinski is a senior scientist at Advanced Heat Treat Corp. in Monroe, Michigan, solving technical problems and developing technologies. For more information, contact him at doctorglow@ion-nitriding.com or visit www.ahtweb.com.