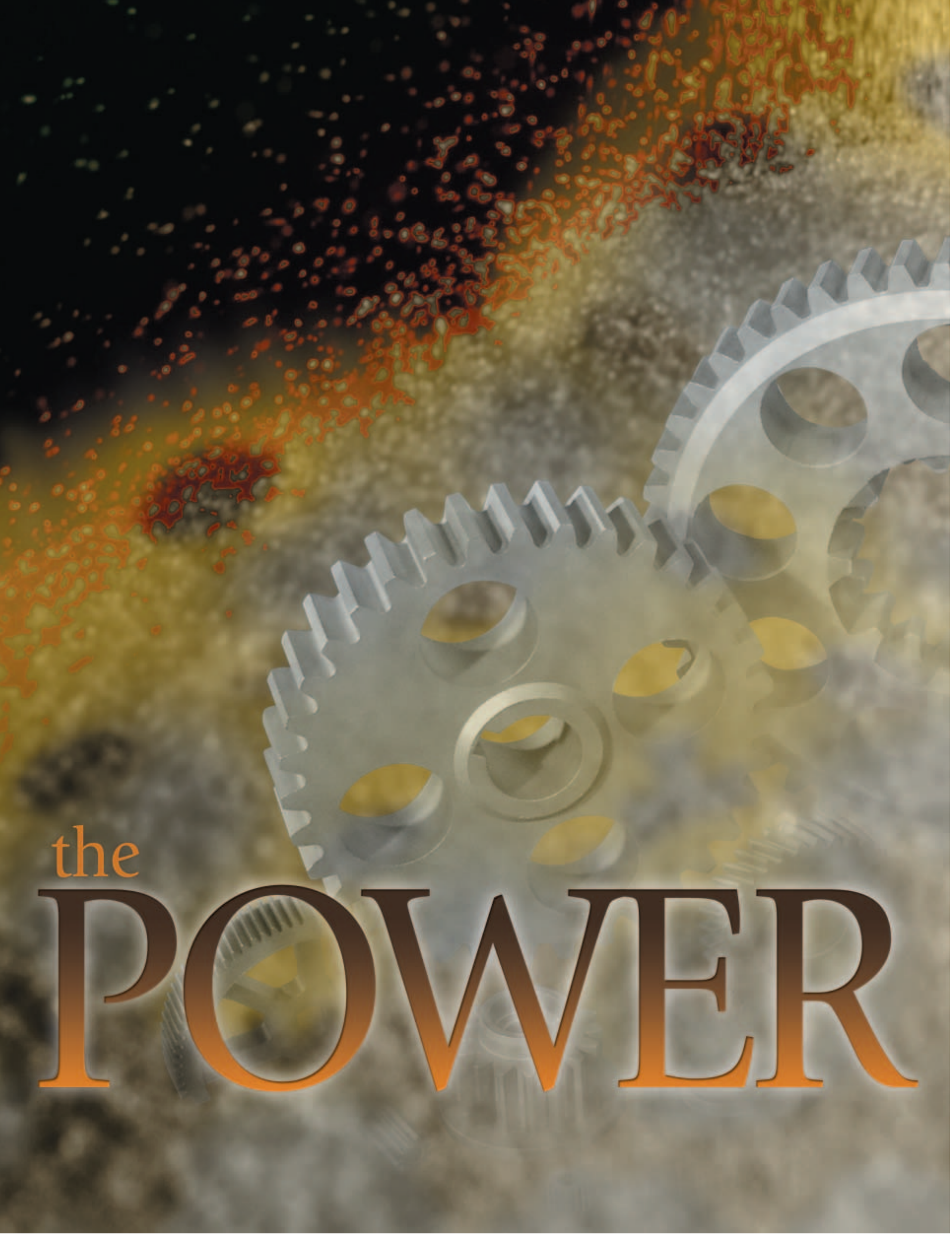
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Material and process advancements have powder metal poised to become a viable option for manufacturers seeking lower production costs and higher-precision gears.

by Tim Geiman

Market demand for more cost-effective processes to produce higher-performance product continues to increase. To meet this reality, manufacturers who often still consider gear-cutting as core technology are being forced to look hard at those processes capable of producing net-shape geometry. After all, a large percentage of the cost for manufacturing a gearbox is tied up in the capital and time required to machine the forms that create conjugate action. Powder metal forging is one manufacturing option that has served up some impressive results over the last quarter century in enhanced performance for the application, and reduced cost for the customer. With recent advancements in powder-metal materials and forming processes, powder forging is poised to become a process of choice for highly stressed products that also require precision for high-volume applications.

Historical Background

Gear manufacturing over the last 100 years has seen the development of various materials and methods of forming, machining, and heat-treating to improve precision, increase durability, and achieve desired geometry. Geometric forms, such as the epicycloid and the involute, were developed prior to the 19th century by mathematicians such as Albrecht Durer and Leonard Euler in order to solve the geometric problem of creating conjugate action. Methods for manufacturing these forms in high volume, however, were not developed until automobile manufacturing opened up new economic opportunities.

Powder metal manufacturing methods have been part of this continuing

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Want to learn more about powder metal technologies and applications? Then visit us online and read an article written by Stephen Baker and Mark Foster, of Allied Sinterings, Inc., and Howard Sanderow, who is president of Management & Engineering Technologies.

In addition to his work at MET—an independent consulting business specializing in powder technologies with a focus on product and process development, market development, and reducing process costs while improving process quality—Sanderow serves as chairman of the AGMA Powder Metallurgy Gear Committee, which recently issued a P/M gear specification standard and is close to completing a bending fatigue load capacity instruction sheet for P/M gears. He is also executive director of the Center for Powder Metallurgy Technology: a 50 member not-for-profit organization that promotes powder metallurgy and funds multi-year R&D projects in the field. MET is also a member of the Metal Powder Industries Federation (MPIF).

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advancement in the manufacture of gear components for a half century. Driven by the same economic incentives, and seeking to accomplish the same ends, powder metal manufacturers have faced unique challenges and have offered unique advantages over wrought manufacturing methods.

Powder Forging Meets Application Challenge

The biggest challenge for powder metal in automotive gearing applications continues to be material properties and density. Frequently, the perception among gear designers is that powder metal simply can't achieve the densities, material properties, and hardenability required for their applications.

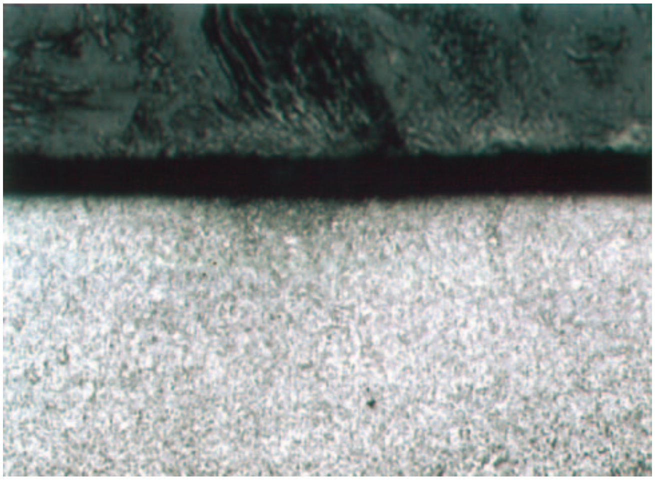
The simplest and most direct means of meeting this challenge is forging. For three decades, since the introduction of cleaner powder forging grade materials, manufacturers have developed and used the powder forging process to produce net and near net highly stressed structural components. These products have ranged from connecting rods for automobile engine applications to fins for guided missiles in the aerospace and defense industries.

Powder forging is used on a variety of components, including gears, differential sleeves and heavy duty clutch plates, as pictured above.

Viability from both a cost and performance standpoint continues to rely on the particular requirements of a given application, the potential sales volume, and the number of machining and heat-treating operations that can be displaced by a specifically designed powder forging process. The key, however, has been material development. Raw material cleanliness, greatly improved material properties, and higher hardenability have driven product development.

The Powder Forging Process

In its most basic form, powder forging consists of three manufacturing steps. The first step compacts a pre-alloyed, atomized steel powder with admixed lubricant and carbon into a predetermined shape optimized for the forging process. At this stage the component is referred to as a "green compact" and is held together by friction and the interlocking of powder particles from the pressing operation. As a next step, the green compact is sintered into a



Powder forged near-surface metallurgy illustrates full density of the powder forged part.

Powder forging net-shape gear teeth has been found to produce gears with better fatigue endurance, optimized fillet geometry, and better surface finishes than some established machining processes.

Historically, powder forging manufacturers have selected nickel molybdenum alloy steels in the development and manufacture of spur gears, pinions, and synchronizer rings for various applications. This material offers similar hardenability to SAE 4600 material, and close to that of SAE 4100 and 5100 steel grades. Powder metallurgy offers unlimited flexibility with respect to the carbon content, which can be optimized for each component depending on size, cross-section, heat treatment requirements, and application.

cohesive steel component. During sintering, the compaction lubricant is burned off and alloying occurs by solid-state diffusion. Metallurgical bonding develops where particle contact occurs.

Following sintering, the component is forged at pressures of approximately 65 tons per square inch utilizing heat from the sintering process, a reheat furnace, or induction heating.

Early Examples of Powder Forging

Powder forging has replaced cut wrought processes in several notable gearing applications. One of the first efforts to take advantage of powder forging occurred in the late 1970s, with a project conducted by a European automaker. This effort demonstrated that the homogeneity and isotropic nature of the powder-forged microstructure delivered superior results in fatigue durability over the comparable wrought gear, while reducing required machining by as much as 55 percent as measured using material utilization.

In the mid 1980s, a precision-forged products operation now owned by GKN Sinter Metals earned the "Fully Dense Grand Prize Part of the Year" from the Metal Powder Industries Federation (MPIF). The part was an internal ring gear transmitting 1,000 ft-lbs of torque for a class 7 and 8 truck automatic transmission (maximum gross vehicle weight of 50,000 lbs). During the subsequent two decades, GKN Sinter Metals continued refining its proprietary Sinta-Carb® process, which allows for a carburized case to be established during sintering. This process results in a desirable, gradual case-hardness gradient that provides higher case strength with lower induced stresses from subsequent quenching operations at the case core interface. Combined with an isotropic, homogeneous, fully dense microstructure, this results in the manufacture of a gear with greater resistance to tooth bending fatigue and excellent impact loading characteristics.

As recently as 2000, GKN Sinter Metals received an "Award of Distinction" from MPIF for a 64-tooth powder forged power take-off drive gear used in the transmission of larger gas and diesel pick-up trucks and utility vehicles.

Net or near-net shape P/M gears (shown above are various applications from GKN Sinter Metals) often offer a better cost-to-performance ratio than their cut-gear counterparts. Among GKN's capabilities are gear densities up to 7.4g/cm³ in single pressing through warm compaction; gears at density levels from 7.6 g/cm³ to fully dense through precision powder forging; and cleaner gears with reduced distortion and tighter dimensional control through sinter furnace hardening, as compared to cut gears with conventional (quench and temper) heat treating

Powder forged ring gear.

Powder forged gear set for manual transmission.

Future Developments

Today, new materials suitable for powder forging are available with greater hardenability, cleanliness, and reduced oxygen content than at any time in the last three decades. These material developments are important, since remaining product conversion opportunities require higher precision, helical forms, and greater hardenability than the nickel-molybdenum steels can achieve. Heat-treat processes such as high temperature quenching require steels with sufficient alloy to produce the desired microstructure without high rates of heat transfer that typically result in unacceptable amounts of distortion in gears. Fixture-quenching processes also either require high velocity oil flow resulting in undesirable temperature gradients, or higher alloy material less prone to distortion and requiring less oil flow to produce the same microstructure.

Materials currently available for powder-forged gears have reduced levels of nickel alloy while containing greatly increased amounts of other alloying elements to improve material hardenability without impacting formability or oxide reduction during sintering. Recent developments in prealloyed materials have resulted in renewed interest in gears produced with powder metal processes, in general, and powder forging, in particular. New processes developed to compliment powder forging integrate the most recent advances in material properties, tooling design and tooling materials, automation, heat treatment, hard machining, innovative post-processing, and the application of different modes and grades of powder forging. These advances promise to reinvigorate the use of powder forging for gear applications of all kinds. Combining superior material attributes with recent process developments positions powder forging to become the process of choice for highly stressed products that also require precision for high-volume automotive gearing applications.

Defining Suitable Applications

In defining suitable applications for powder metal forging, four things need to be considered. First, the module should ideally be greater than or equal to 1.0. The module has an impact on tool life, and therefore precision and cost. Second, the strength and endurance limits required should be equivalent to high performance wrought steel. Applying powder forging in low-stress applications may not provide the most cost-effective means of product manufacture. In this case, either GKN's traditional or advanced powder metallurgy methods may be a better solution. Third, precision and form need to be considered. Currently, net shape powder forging processes to economically manufacture spur gears up to an AGMA class 7 are well-established. Applications involving more complex geometries, as well as gears with AGMA classes greater than 7, are being sought. Finally, the annual production volume should be high enough to justify the tooling expenditure. Typical tool set costs vary depending on the size and complexity of the product, but can easily reach into the tens of thousands of dollars.

"Combining superior material attributes with recent process developments positions powder forging to become the process of choice for [many] highly stressed products."

For more information on GKN Sinter Metals, visit the company's Web site at [www.gknsintermetals.com].

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