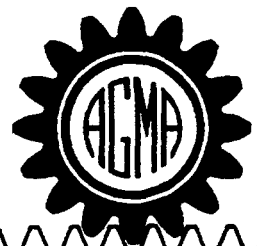


Powder Metallurgy Gears – Expanding Opportunities

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Management & Engineering Technologies

American Gear Manufacturers Association



TECHNICAL PAPER

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[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

Powder metallurgy (P/M) is a precision metal forming technology for producing simple or complex parts to net shape or near net shape. In most cases, little, if any machining is required. The mechanical properties of P/M materials are a direct function of density, composition, and microstructure. A systems approach to material and process selection permits the development of a microstructure suitable for the intended application.

A recently activated AGMA, Metal Powder Industries Federation (MPIF) work group has been established to develop standards and design guidelines for P/M gears. The current state of P/M technology as related to gear design and applications is reviewed. New materials and process technologies are discussed to demonstrate the comparability of P/M steel gears with cast or wrought steel components. The strengths and weaknesses of the powder metallurgy process, as pertaining to gear applications, is examined. Examples of P/M gears are presented along with the challenges facing the technology.

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American Gear Manufacturers Association
1500 King Street, Suite 201
Alexandria, Virginia, 22314

October, 1995

ISBN: 1-55589-662-6

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INTRODUCTION

The Powder Metallurgy Process

Powder metallurgy (P/M) is a precision metal forming technology for the manufacture of parts to net, or near net shape. The powder metallurgy process is illustrated schematically in Figure 1¹. There are three basic steps to producing parts; mixing, compacting, and sintering. Variations to these basic steps such as infiltration, double pressing/double sintering, and powder forging, may be used to achieve higher density parts. A sizing operation may be used to qualify critical part dimensions. Alternatively, a machining step may be added for the same purpose or to achieve a geometric feature not possible during rigid die compaction. P/M parts may be through hardened or surface hardened as required by the intended application.

Why P/M for Gear Manufacture?

The P/M process is particularly well-suited to the production of gears and spur, bevel, and helical gears may be made by powder metallurgy processing. The pressing cycle for a single level P/M part is presented in Figure 2¹. A charge of mixed powder is delivered to the die cavity by a feed shoe and the upper and lower punches are used to compact the powder. After the upper punch is withdrawn, the pressed compact is ejected by the lower punch and the feed shoe slides the part away from the die cavity. The cycle repeats as the feed shoe continues forward and refills the die cavity

with another charge of powder. P/M compacting tooling for a two-level cluster gear is illustrated in Figure 3¹. True involute gear forms are possible. Special features

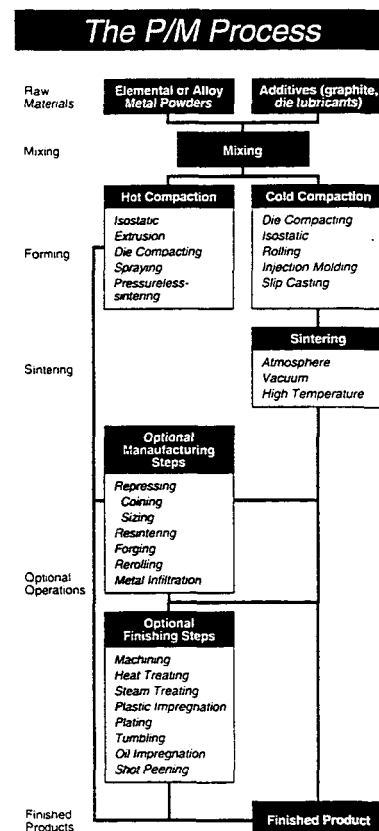


Figure 1 : The Powder Metallurgy (P/M) Process¹



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such as keyways, drive lugs, splines, and cam contours may be incorporated during the compaction process. Lightening holes may be added to reduce part mass and P/M gears can be made with blind corners eliminating the undercut relief that is needed with cut gears - see Figure 4 2. P/M tooling provides consistent tooth form accuracy and surface finish over long production runs. Generally, because of their porosity, good surface finish, and consistent tooth form accuracy P/M gears reduce noise levels. Additional information on the types of gears suitable for powder metallurgy and the advantages of P/M gears is presented in subsequent sections of this paper.

MATERIAL - PROCESS SELECTION

Alloying Methods in Ferrous Powder Metallurgy

The mechanical properties of P/M materials are directly related to their microstructure and the size, distribution, and morphology of the porosity they contain. Alloying additions are made to develop specific material performance characteristics. However, the manner in which the alloys are constituted has a significant effect on the porosity and microstructure of the final sintered product.

Ferrous P/M materials may be classified according to

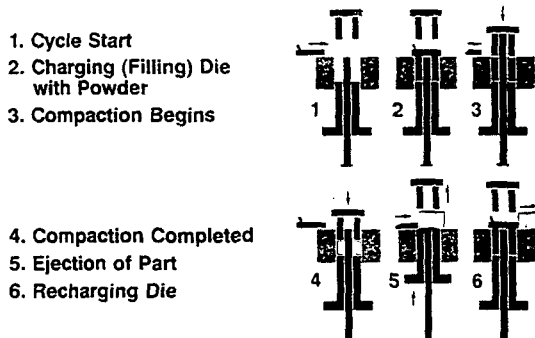


Figure 2 : Pressing Cycle for a Single Level P/M Part 1

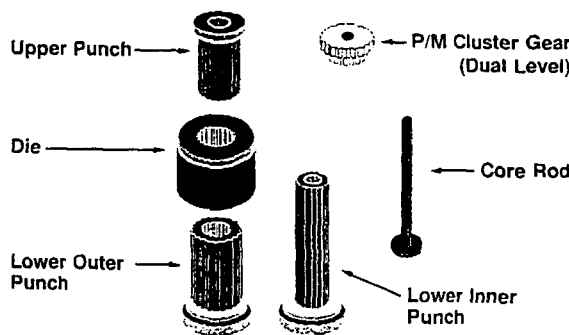


Figure 3 : Compacting Tooling for a Two-Level P/M Cluster Gear 1

the manner in which the alloy has been constituted :

- **Admixed** - The alloying additions are made to the iron powder base in the form of elemental or ferroalloy powders. This is the least expensive and most commonly used alloying method. Since the iron powder base is unalloyed when the mix is pressed, admixed materials retain most of the compressibility of the iron base. The degree of alloying is limited by the diffusivity of the alloying elements in iron at the sintering temperature, and the resulting microstructures are chemically heterogeneous. This type of material is also subject to powder segregation and dusting during handling and pressing.
- **Partially Alloyed** - The alloying additions are diffusion bonded to the base iron particles such that the compressibility of the base iron is essentially retained. These materials are often referred to as diffusion alloyed. The powders are highly compressible, and yield heterogeneous sintered microstructures consisting of lightly alloyed particle cores with a continuous network of more highly alloyed interparticle bonds.

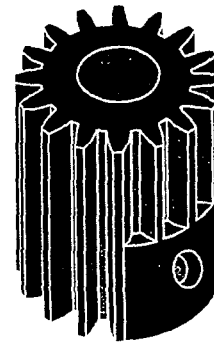


Figure 4 : P/M Gear Teeth with Blind Corners can be Pressed 2

- **Prealloyed** - The alloying elements, except for carbon, are added to the melt before atomization. This results in homogeneous microstructures and uniform hardness even on a microhardness level. Solution hardening of the powder particles by the alloy additions generally decreases the compressibility of the powders compared with admixed and partially alloyed materials. However, prealloyed powders that use molybdenum as their principal alloy addition have been developed with compressibilities approaching those of iron powders 3,4. Prealloyed powders have better hardenability than admixed or partially alloyed materials. The alloy additions must be in solution in order to contribute to hardenability.
- **Hybrid** - With the advent of highly compressible prealloyed powders, materials have been developed based on additions to these powders. For example, materials in widespread use are based on an

addition of 2 w/o (weight percent) nickel and 0.4 - 0.6 w/o graphite to a prealloyed powder with 0.85 w/o molybdenum as the principal alloy addition ⁵. Chrome-manganese steels have been introduced based on additions of high carbon ferrochromium and ferromanganese powders to a prealloyed steel (0.85 w/o Mo) ⁶⁻⁸. Recently introduced partially alloyed or diffusion alloyed powders have been based on a prealloyed base powder (1.5 w/o Mo) rather than a plain iron powder base ⁹.

The Mechanical Properties of Ferrous P/M Materials

The mechanical properties of P/M materials are directly related to:

- Density
- Composition
- Microstructure

P/M material designations, plus guaranteed and typical mechanical properties can be found in MPIF Standard 35 ¹⁰ and ASTM B 783 ¹¹. These standards contain information on tensile, compressive, impact, and fatigue performance. Young's modulus is listed also and is a linear function of density - Figure 5 ¹⁰. Poisson's ratio for P/M materials may be taken as 0.27 ± 0.02 .

It takes considerable time for standards to be developed. Therefore, currently, many P/M materials are not covered in the standards. Designers and fabricators should consult material suppliers during their selection process to ensure that they are aware of new developments.

In the unnotched condition, the fatigue strength of sintered steels is lower than that of wrought materials, and, in some cases, to nodular cast iron. Parts however, usually contain geometric discontinuities that act as stress raisers and an application-oriented comparison between materials needs to be made in the notched condition. For P/M materials with densities above 7.1 g/cm³, and notched specimens with notch factors above 2, the endurance limit data are largely comparable to those for wrought and cast materials - Figure 6 ¹².

The tensile and fatigue properties of a ferrous P/M material depend on density and microstructure. The effect of process variables is seen for prealloyed materials in Figure 7a and for partially alloyed materials in Figure 7b ¹³. Single compaction processing (1P1S) is compared with double pressing/double sintering (2P2S). The prealloyed materials (FL-4605) were tested in the quench-hardened and tempered condition (tempered at 450 °F for 1 hour), whereas the partially alloyed materials (FD-48XX) were tested in the as-sintered condition. The effect of increasing the sintering temperature is shown for both types of material.

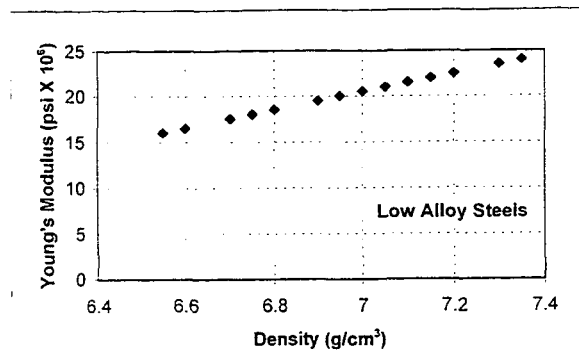


Figure 5 : Young's Modulus as a Function of Density for Prealloyed Low-Alloy P/M Materials

The macroindentation hardness of P/M materials is really a composite hardness; material plus pores. The measured macrohardness is termed the apparent hardness of the material. Microindentation hardness measurements may be used to measure the matrix or particle hardness of the material. Since sliding and surface contact take place on a microscopic level (surface asperities), the microhardness of a P/M material influences the scoring resistance more than the macrohardness ¹⁴.

A Systems Approach to Engineered P/M Materials (The Interaction Between Material and Process Variables)

A systems approach is required to optimize each stage in the production of a P/M part. There are a number of steps involved :

- Part Design
- Material Selection
- Mixing
- Compacting
- Sintering
- Post Sintering Operations

While many parts are developed using a process of trial and error, modern design techniques for load determination and stress measurement, computer aided design, and service load simulation, permit a systematic design procedure. The following steps are appropriate ¹⁵:

- Load assessment - This is often a difficult step. Measurement on similar parts may sometimes help. The anticipated loading influences the choice of material and the dimensions of the part.
- Geometric shape of the part - The shape and dimensions of the part are often constrained by the available design space. The part geometry will be dictated by the function to be fulfilled, the loading, and the selected material and process, but should be adapted where possible to improve the ease of part manufacture.