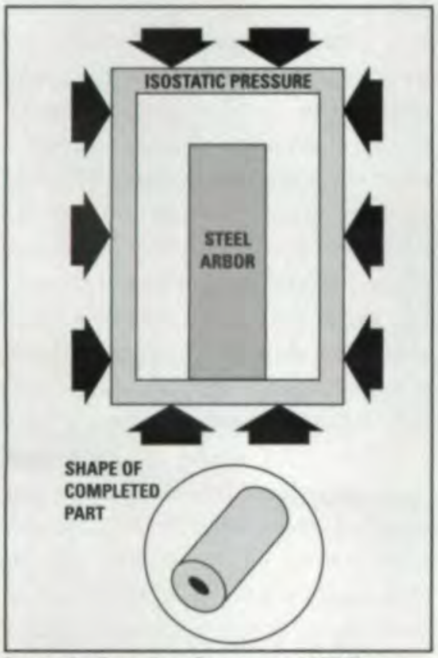
Powder Metallurgy Innovations

New materials, processes and standards are making powder metal a viable alternative to wrought metals in the gear industry. Here's what's new and what you can expect.

Charles M. Cooper

Powder metal. To gear makers today, the phrase conjures images of low power applications in non-critical systems. As powder metal technology advances, as the materials increase in density and strength, such opinions are changing. It is an ongoing, evolutionary process and one that will continue for some time. According to Donald G. White, the executive director of the Metal Powder Industries Federation, in his State-of-the-P/M Industry—1999 report, "The P/M world is changing rapidly and P/M needs to be recognized as a world-class process—national, continental and even human barriers and prejudices must be eliminated—we must join forces as a world process—unified in approach and goals."

According to Todd Olson, marketing manager for Burgess-Norton Manufacturing Co., this kind of unification is already happening. "Overall, the powder metal industry is moving toward consolidation. Historically, the industry has been very fragmented. However, the late '90s have witnessed a wave of mergers and acquisitions, which is allowing major powder metal players to optimize economies of scale and provide customers with a full range of products and services."



Isostatic Pressing. Courtesy of MPIF.

There is a greater use of powder metal in gear manufacturing, on both the tooling side and the workpiece side, today than ever before. In fact, a number of gear applications won awards in the 1999 P/M Design Competition (see sidebar, page 61). Major automakers are increasing the amount of powder metal they use in their transmissions and engines, and many of these gears are being made with new high speed steel alloy cutting tools. Part of the credit for this goes to new alloys being developed, while the rest goes to the new powder metal processing methods, which are designed to increase the material density to improve its mechanical qualities.

According to Philip Krupp, president of P/M Krupp Technologies, Inc., this drive toward heavier density in powder metal parts is of great importance to the powder metal industry because, as he said, "They've done all that can be reasonably achieved with varying chemistry and heat treat, and higher density is pretty much all that is left."

P/M Technology: The Quest for Density

According to Krupp, "Current P/M gear capabilities are very good in regard to shape complexity and tolerances, but fall short on high strength and hardness. For that, higher densities will be needed." This need for higher densities has led to the development of processing methods that promise near-fully dense powder metal products. Near-fully dense means that the part has less than 1% residual porosity. These processes also use different compacting methods, enhanced sintering techniques and work primarily with high alloy materials. Four of the most promising processes are powder forging, isostatic pressing, metal injection molding and spray forming.

Powder Forging. This method begins with the creation of a "green compact" (a workpiece that has been pressed into shape at room temperature) called a "preform." The preform is then sintered as usual, producing a near-net shape workpiece. This workpiece is then placed in the forge and restruck until the final density is reached. Powder forging is currently used in the mass production of powder metal steel parts with wrought steel properties. These parts are primarily used by the automotive industry and include gears, transmission parts and engine parts.

Isostatic Pressing. This method is primarily used to produce powder metal parts to near-net sizes and shapes of varying complexity. The biggest difference between isostatic pressing and other methods of compaction is that isostatic pressing is performed in a pressurized fluid. The powder mass is contained in a flexible, sealed container, which provides a pressure differential between the powder and the pressurizing fluid.

There are two types of isostatic pressing—hot and cold. Hot isostatic pressing is carried out using an inert gaseous atmosphere, usually argon or helium, contained within the pressure vessel. Usually, both the pressurized atmosphere and the part to be pressed are heated by a furnace within the vessel.

The powder being processed is hermetically vacuum-sealed within a shaped mold that will deform plastically at high temperatures. The powder metal is then simultaneously pressed and sintered within the heated vessel. Common pressure levels reach 15,000 psi at temperatures as high as 2,300°F. The mold is then removed from the finished near-net shaped part by chemical leaching, machining or some other mechanical method. Hot isostatic pressing allows densities in the 7.2–7.4 g/cm^3 range. While this is a notable improvement over the results of other methods, it is still not dense enough for many gear applications.

According to Krupp, "The tolerances are roughly equivalent to those of investment casting. It is suitable for more complex shapes that have the economic room for finishing operations to bring dimensions into line."

Cold isostatic pressing is carried out at room temperature and uses a liquid pressure medium rather than a gas. The pressures in this method often reach 60,000 psi. Packed into complex shaped rubber or elastomeric molds, the powder metal achieves a higher and more uniform density than could be obtained from regular cold die compaction. The resulting green preform is then sintered.

Metal Injection Molding. This method allows for the mass production of complex powder metal parts. Here, fine metal powders are mixed with thermoplastics, waxes or other ingredients, which serve as binding materials. The resulting feedstock is then fed into a conventional injection molding machine. Once the green preform is made, most of the binding material is removed either thermally or chemically, or by some combination of the two. The precise method is based on the binding material being used. The part is then sintered at temperatures that normally exceed 2,300°F, eliminating the remaining binding material. This process offers final relative densities in excess of 96% with interconnected porosity being less than 0.2%.

Injection molding permits parts with curved sides, external undercuts and threads. A wide variety of alloys can be processed with this method including alloy and stainless steels, soft magnetic alloys and tungsten carbide.

Spray Forming. This is not a process used to create a single workpiece. Rather, it is used to create billets, tubes and sheet/plate that are then used to make other products. The spray forming process consists of sequential stages of liquid metal atomization and droplet consolidation at deposition rates from 0.5 to 5.0 pounds per second. This produces a near-net shaped product that is close to full density with a fine, even grain structure and mechanical properties that meet or exceed those of ingot processed alloys.

P/M Technology: Alloys

There are a number of new powder metal alloys that will be of interest to gear manufacturers as both gear and tool materials. They include the various types of high speed steel bridge alloys as well as more exotic beryllium, titanium alloys and aerospace superalloys.

Bridge Alloys. When it comes to cutting tools, gear manufacturers have traditionally had a choice between high speed steel and carbide. High speed steel is economical and tough, but it is not hard enough for some of today's applications, such as dry cutting. Carbide allows dry cutting because it can take higher speeds and temperatures, but it is also far more expensive than high speed steel tools and far more fragile. Today, a third alternative is available, a material that many believe takes the best of both high speed steel and carbide and brings them together into one tool material.

In the cutting tool industry it is called Super High Speed Steel, a high speed steel tool material that provides many of the benefits of carbide but at a far lower price. To the powder metal industry, it is simply called a bridge alloy. "This is a new super high speed steel being developed that bridges the gap between high speed steel and carbide," said Robert Carnes, a staff specialist with the Technical Services division of Carpenter Specialty Alloys.

This material is made both possible and practical because of some of the unique properties of powder metals. "The material is much more uniform, without the segregation of the alloy material you often find in alloy ingots," said Carnes, who explained that with alloy ingots, you often find concentrations of different alloy components in different parts of the ingot. "Each particle in the powder metal mix is a microingot. That means you can create heavier, more consistent alloys with fine, uniform microstructures." This uniformity offers some specific benefits in terms of finishing and machining. According to Carnes, "The more uniform the alloy, the more uniform will be the response to heat treating and the more predictable will be the hardness and movement. Also, the material will be more readily machined." This means a tool material that is tougher than regular high speed steel and hard enough to handle jobs traditionally left to carbide tools.

Titanium and Beryllium. These lightweight metals are often alloyed and

A BRIDGE ALLOY IN THE MAKING

One example of the new bridge alloys being made today comes from Carpenter Specialty Alloys. Called Micro-Melt®, the material's manufacture begins with the nitrogen atomization of molten metal to produce prealloyed metal powders. These powders are then blended, screened, and poured into mild steel canisters. The powder is then hot isostatically pressed into ingots of 100% theoretical density.

The resulting powder metal ingots are then finished. This process includes forging on rotary forges, hot rolling and cold finishing into product forms, which include round or flat bar and plate.

Atomizing

Blending

Screening

Filling

Hot isostatic pressing

Hot working

Hot rolling

Cold finishing

1999 P/M DESIGN AWARDS

Gears and other power transmission products were big winners in the 1999 P/M Design Competition, sponsored by the Metal Powder Industries Federation. According to the MPIF, these "outstanding examples of powder metallurgy (P/M) eclipse competitive forming processes such as casting, extrusion and screw machining."

The Ferrous Grand Prize went to Stackpole Ltd. of Mississauga, Ontario, Canada, for the P/M steel helical balancer gears they make for DaimlerChrysler. The gear set, which replaced ductile cast iron, includes a balancer drive gear and a driven gear and operates at up to 13,000 rpm in a Chrysler 2.4L engine, twice the crankshaft speed. The AGMA Class 8/9 gears are selectively densified on the flanks to 7.8 g/cm^3 while the core region, which does not experience the high stresses of the tooth region, remains at 7.0 g/cm^3. The parts are vacuum carburized and hardened to 70 HRA. The mechanical properties include an ultimate tensile strength of 125,000 psi and a minimum yield strength of 120,000 psi. More than 2 million of these gears have been made.

The Stainless Steel Grand Prize goes to Keystone Powdered Metal Company of St. Mary's, Pennsylvania, for the AGMA Class 7 output gear they make for Eaton Corp., Lectron Products, Rochester Hills, Michigan. The output gear, used as an actuator in an automobile engine manifold, is a net-shape part that meets critical tolerances; inside diameter 4.80–4.85 mm and measurement over wires was 15.44 mm/15.31 mm. The part, which replaced a hobbed steel gear, has a density of 6.4 g/cm^3, an ultimate tensile strength of 43,000 psi and a minimum yield strength of 30,000 psi. Its hardness is measured at 61 HRB. More than a million such output gears have been produced.

Ferrous Awards of Distinction were given to two companies this year for entries from the gear and power transmission industries.

The first was given to the Burgess-Norton Mfg. Co., of Geneva, Illinois for a coupler assembly they make for Caterpillar, Inc., Peoria, Illinois for use in Caterpillar's backhoes. Made from MPIF material FLC-4608-80HT, the mating parts transfer power from the diesel engine to a high pressure hydraulic pump, which powers the backhoe loader as it digs ditches and trenches.

The adapter is formed to a minimum density of 6.9 g/cm^3 and has an ultimate tensile strength of 90,000 psi. The critical dimension over wires on the larger external spline is 107.1 mm/106.8 mm. The dimension between wires on the internal spline is 23.2 mm. The hub is made to a density of 6.7 g/cm^3 and has an ultimate tensile strength of 110,000 psi. It is machined and heat treated.

The second Award of Distinction went to Cloyes Gear and Products, Paris, Arkansas, for a reductor wheel they make for the General Motors Mark VI V-8 engine. The application is an assembly of two pieces brazed together during sintering. The 48-tooth part is produced as a net shape except for grinding to establish the separation groove, burnishing to qualify the bore and shot peening to remove grinding burrs. Necessary tolerances include holding the maximum total runout of both rows of teeth to <0.1295 mm to the bore; flatness of the mounting hub is held to less than 0.0787 mm. The teeth have a minimum density of 7.0 g/cm^3.

The Overseas Award of Distinction went to an assembly of a block crank, counterweight and eccentric gear for a jig saw made by MG miniGears S.p.A., Padova, Italy, for Porter Cable Professional Power Tools, Jackson, Tennessee. The complex parts are made from diffusion alloyed steel, MPIF material FD-0205-120HT. The parts are fabricated to a density range of 6.85–6.95 g/cm^3 and have a minimum ultimate tensile strength of 120,000 psi.

Grand Prize Winners. Courtesy of MPIF.

Award of Distinction Winners. Courtesy of MPIF.

used in aerospace applications including gears. Beryllium processing is usually begun with cold isostatic pressing followed by hot pressing or hot forging. Hot isostatic pressing can be substituted for the hot pressing step. However, titanium can be either conventionally processed or hot isostatically pressed, which for titanium means that the material will exceed the minimum wrought alloy specifications. Also, the near-net shape of the preforms makes the use of powdered titanium or beryllium more economical than cast, forged and machine processing.

Superalloys. Materials that fall into this category are found most often in the production of near-net shapes and forging preforms for aircraft turbine engines. Economic benefits have been the driving force behind the use of powder metal for the manufacture of these costly alloys.

Processing of these alloy powders is either through hot isostatic pressing followed by thermomechanical processing to enhance the mechanical properties and/or microstructure, or hot extrusion of the atomized powder. Lower costs are realized due to the alloy's homogeneous microstructure and near-net shape configuration. Today, over 10,000,000 pounds of superalloy components are in civilian and military aircraft worldwide.

P/M Technology: Gears

So what is driving all these advances? Look to Detroit. According to Krupp, "Automotive is probably the biggest driving force behind the quest for higher density, since the potential is very large. Transmission gears require higher strength and fatigue properties that are currently unavailable in conventional powder metal processing."

While that may be true, the trend toward the use of powder metal gears is certainly pointing to continued growth. "In today's marketplace, there are very few industries that don't take advantage of powder metal gear technology. Powder metal gears can be found in applications from automotive and agriculture to laser printers and lawn/garden equipment. As strength and tolerance characteristics continue to improve, we expect a continued proliferation of powder metal gear acceptance," said Olson.

Powder metal gears. Courtesy of Burgess-Norton Mfg. Co.

AGMA standards. According to Glen Moore, Burgess-Norton's director of engineering, those strength and tolerance characteristics are being addressed by AGMA, which is moving forward on classification standards for powder metal gears. Like the standards for their cut gear counterparts, these new standards will permit tighter tolerances and more uniform strength data, which will facilitate the overall design and product selection process. "This is important because it will allow customers of powder metal gears to easily make objective decisions about what product is best suited to their application," added Olson.

In November of 1998, AGMA published its first standards covering powder metal gears created by conventional powder metallurgy processes. *Specifications for Powder Metallurgy Gears*, ANSI/AGMA 6008-A98, gives the powder metal gear purchaser the detailed information that needs to be included in the gear specifications he submits to the gear producer. Detailed specifications for gear tooth geometry are described in the standard for external spur, helical and straight bevel gears. There are also discussions on the specifications needed for gear drawings and gear material data. "The powder metal people grossly lacked a way of communicating with their customers," said Charlie Fischer, manager of AGMA's technical division. "This standard allows them to do that. It's not a technical standard; it covers what needs to be communicated." Fischer then went on to say that AGMA's Powder Metal Committee is now working on developing an information sheet that deals with the strength of powder metal gears, as well as their materials and configurations, but added that the information sheet won't be out for a year or two.

The application suitability is going to become very important as powder metal gears become more economically competitive with traditional cut gears. "Through increased densification, powder metal gears have made their way into applications, which were once the sole domain of cut gears," said Moore. "Certainly, there will continue in the foreseeable future to be applications that can only be served by cut gears. However, because of the efficiency of the powder metal process, powder metal gears continue to offer economic advantages over cut gears."

According to Krupp, the benefit of a powder metal preform is its ability to eliminate manufacturing steps, since the more you can eliminate, obviously, the more economical the process becomes. "Near-net shape offers two key advantages over machining a blank," said Tom Stockwell, field sales manager for Burgess-Norton. "First and foremost, the density of the part will be "true." Second, the inherent physical properties of a near-net shape part will be much closer to the final production part. This eliminates surprises and facilitates the component finishing process."

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