Injection-molded gear manufacturers like ABA-PGT are at the leading edge of plastic gear manufacture.

Plastic gears are getting stronger—and smaller—for a variety of applications. (Photo courtesy DuPont/Winzeler Gear)

Plastic Gears—

A Growing Industry Still Seeking Respect

Jack McGuinn, Senior Editor

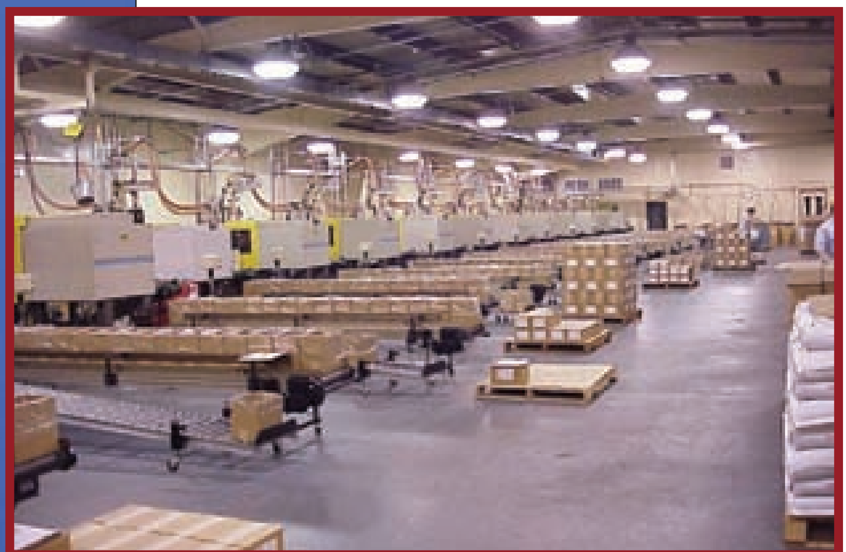
Mr. McGuire: *I want to say one word to you. Just one word.*
Benjamin: *Yes, sir.*
Mr. McGuire: *Are you listening?*
Benjamin: *Yes, I am.*
Mr. McGuire: *Plastics.*

—From the 1967 film, The Graduate

Forty years ago, the plastics industry was practically in its embryonic phase when that classic movie line was delivered to Dustin Hoffman's befuddled, just-graduated, in-search-of-a-career character, Benjamin Braddock. Today, although still in its infancy, plastic gear manufacture has made significant gains in the gear industry, with plastic gears now being used in applications never thought possible. And yet, while envelope pushing by plastics suppliers, gear manufacturers and end-users alike guarantees that plastic gear market share will continue to grow, there nevertheless remains a level of skepticism. A number of product designers and parts specifiers with industrial applications remain unconvinced that gears produced from plastic are capable of matching the high-temperature, high-power functionality of metal gears. But talk to any number of relevant players in the plastics industry—gear molders and suppliers—and they will tell you that when decisions are made regarding gear materials for high-capability, high-performance applications, plastic gears are getting a bad rap.

Zan Smith, an engineering associate with Florence, KY plastics supplier Ticona, says the plastic industry must at times overcome misperceptions, in relation to other materials.

"I think sometimes the use of plastic is avoided because there is a lack of understanding about its effectiveness," he says. "There are some applications where plastic would probably be the preferred material, but OEMs fail to consider it because they are unfamiliar with its performance capabilities." He adds that, in recent years, the plastics industry has done a good job of promoting the benefits of plastic and shifting



"Lights Out" manufacturing provides cost-effective packing and shipping at ABA-PGT's Vernon, CT plant.

attitudes about the use of plastics in challenging situations, such as in gears.

Over the years, plastic gears have indeed proven themselves time and again, and are certainly here to stay in significant numbers. While estimates vary and are—at best—just that, industry experts point to some very healthy numbers regarding the size of the plastic gear market.

"On a sales revenue basis, we believe approximately 10% of gears sold are plastic," says Thomas E. Grula, account manager for DuPont. "On a number of gears sold basis, the figure is much higher; but we have no good estimate."

Richard Wheeler, president of Manchester, CT-based plastic gear molder ABA-PGT, Inc., breaks down the data a bit further.

"According to a market survey completed in 1997 by the market research firm Freedonia Group, the demand for plastic gears in the U.S. was projected to grow more than 10% annually, to roughly $1.5 billion in 2000 and to $2 billion in 2005," he says. "Plastic gears are produced by OEMs (captive molders), custom molders and gear molders. Based upon rough estimates, the gear molders produced approximately $100 million in 2000, or less than 7% of the $1.5 billion in plastic gears shipped in 2000."

What's in a Name?

Generating those numbers are a variety of applications in which plastic is the gear material of choice—including, but by no means limited to—office and lawn equipment; automotive interior, exterior and under-the-hood components; and pumps. The list grows with each new advancement in plastics engineering. But before going further, perhaps a primer in plastics terminology would be helpful. While there is no shortage of names out there for what in the end is universally known as "plastic," there are distinctions to be made.

"'Plastic' is a good term to use, and the most convenient," says Grula. "However, a better term may be polymer-based materials. The term 'plastic' is short for thermoplastic, which implies that the material is melt-processable. Some key material in the growth of gears produced from polymer-based materials may not be melt-processable; they may require other fabrication techniques, such as sintering. This is especially true in the area of materials with improved heat resistance."

Ticona's Smith relates a humorous experience he had at his local optometrist that lends some perspective to the confusion in terminology.

"(The optometrist) asked me if I wanted polycarbonate or plastic lenses,

continued

and I said, polycarbonate is plastic….he said, 'No it's not.' And I asked, Well, what is plastic? And he gave me some spec number or something he thought was plastic, but he insisted polycarbonate was not plastic. And it was much better than having glass or plastic."

Automotive Inroads. And More.

Funny anecdotes notwithstanding—and whatever one calls it—the use of plastic gearing is growing.

"Any opportunity where operating environment permits the use of plastic gears, the conversation is being made," says Edward Butler, vice president of engineering for Seitz Corp in Torrington, CT. "Temperature, stress, and chemical attack, which may be present in the application, need to be design considerations for plastic gears. Plastic gears are an inexpensive solution to steel gears, and offer such benefits as reduced noise generation as well as improved lubricity, which can be added to plastic material."

Grula echoes Butler's optimism for expanded application opportunities.

"Automotive applications are a high-growth area for plastic gears, and the continued development and proliferation of power-actuated accessories is a key driver."

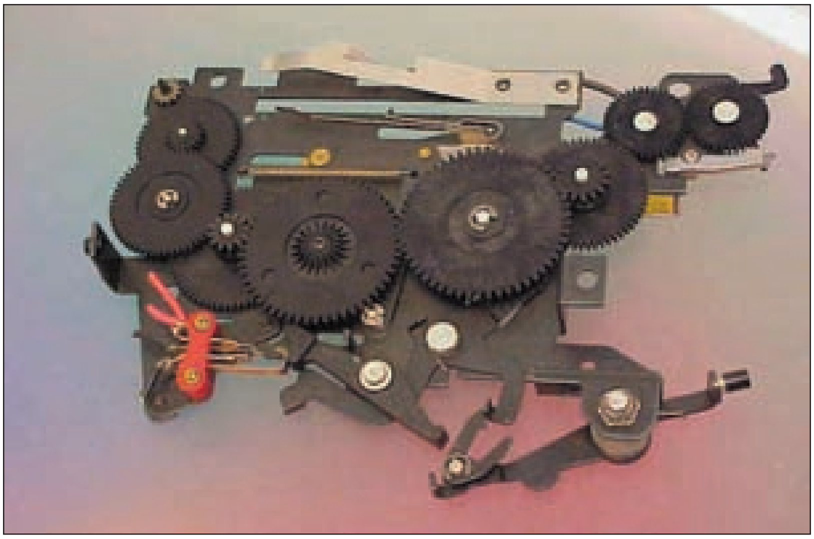
He adds, however, that those opportunities will also require more than newly engineered plastics. "Greater penetration in under-the-hood applications will require continued advances not only in materials technology, but in gear design and processing technology as well."

Ticona's Smith supports that statement, pointing to fundamental design changes in how automobiles are built. Those changes are leading to the increased use of plastic gears that will be required to function in an extensive temperature range.

"Power steering is getting away from hydraulics, and you're beginning to see electric power steering with plastic gearing being involved there," he says. "And there's movement towards electric in the braking system, and there may well be an opportunity for plastic gearing in that area."

There are, according to Smith, efforts already underway in that regard in both Europe and the U.S.

Too, the home appliance market has for years been fertile ground for plastic gears. What is new is the fact that plastic gears are now being seen in heavy home appliances such as washing machines.



Plastic gears are found in all kinds of applications. Shown here is an ABA-PGT gear set for a device that makes change for paper money in vending machines.

Plastic gears are now common in automotive applications such as this seat position sensor from ABA-PGT.

Lack of True Benchmarks a Standard Complaint

If there is one thing that retards further expansion of plastic gears in higher-performance environments, it is the lack of well-defined global or even North American standards. Considerations such as load and stress conditions, tolerances, inspection, calculation software, fatigue testing and other due diligence common to gearing—both plastic and metal—are all areas that will require more clarity and consistency in order to enable expanded acceptance of plastic gears.

David Sheridan, senior design engineer for Ticona, is one of many in the industry who believes such clarity is long overdue. And it must allow for the apples-and-oranges differences from metal gears inherent in injection-molded plastic gears.

"There is definitely a need for something different from what is out there, specifically in the plastic gear industry. But the issue really is that gear feature tolerances—within a certain quality level—were originally established by the metal gear machining capabilities.

And injection molding is really a different beast, and it has different capabilities and properties. So for some features you can get tighter tolerances for molded plastic gears, and for some features you get worse tolerancing."

The nature of the "different beast" that is injection-molded gearing does indeed require outside-the-box calculation by gear designers that goes beyond, for example, available standardized ISO testing data for materials. Even the most promising, leading-edge thermoplastics may go unused for gears if the need for effectively precise standards is not realized.

"For gear designers to get the precise data that they require to optimize plastic gear design and functionality—and, thereby, expand into new markets and end-use applications—the gear industry needs to develop an agreed upon method to test molded plastic gears under specific load and stress conditions," says Grula. "This is true even for existing materials, where much of this data does not exist. It is likely even more important as newer, higher-performing materials are developed."

He goes on to say that plastic-specific gear testing is "difficult" due to the many different variables facing gear designers in the interpretation and implementation of the test data. "This is an area in which the AGMA Plastic Gearing Committee is working," he adds.

Grula's frustration with this dilemma serves to support Zan Smith's thoughts regarding the skepticism plastic gears must overcome. He points out how that skepticism adversely affects not only plastic gear manufacturers, but also end-users' bottom line.

"Today, gear designers typically have to rely on material performance data derived from standardized (ISO) testing, provided by material suppliers to be used across all applications," he says. "The problem is that this data is not specifically relevant to gears, so the resultant gear designs and material selections are often unnecessarily conservative, leading end-users to reject plastic-based gear systems that may offer the best, most cost-effective solution."

Much of the need for new standards derives from the physical properties of plastic, especially in the injection molding process. Seitz Corp.'s Butler is another who maintains that more robust, plastic gear-specific calculation standards are a must for optimal gear design.

"The ability to calculate contact stresses, bending stresses and tooth deflection is essential to good gear design," he says. "Approximation of these calculations from 'cookbook' calculations is still widely used; however, actual modeling of the gear meshes in an FEA package allows better evaluation of the dynamics of the gear mesh, resulting in better feature design."

For ABA-PGT's Wheeler, test-and-verify is a good way to prevent costly, uninformed assumptions in plastic gear design, especially when a newly engineered plastic is part of the equation. A trap designers often fall into, for example, is in extrapolating narrowly derived performance standards to plastic gear design.

"Plastics don't behave like metals, so it is always difficult to model plastics. You can't just pull data and trust it," he says. "Plastic tensile strength standards—such as ASTM D638-03 (ISO 527-1)—give an approximation only. ASTM test bars, which all suppliers use, fall far short of a gear in determining actual performance.

"Better is to get the wear and strength data from actual gear testing. Some, but not many, of the material suppliers are working on compiling that data."

According to some in the industry, plastic gear design and certifiable standards suffer from too much off-the-shelf thinking when attempting to nail down truly accurate tolerancing. As is often the case, it is a question of quality levels.

"The reason (tolerancing) is hampered," says Ticona's Sheridan, "is that the quality level that's assigned to a plastic gear is determined by its widest-toleranced feature, so recognizing that there needs to be something different is key. One of the proposed solutions is some kind of plastic gear accuracy system that allows specific tolerancing for specific features, instead of lumping it all together under one grouping and relying on the lowest common denominator."

Given plastic gearing's brief history, and the wider range of material choices plastic provides, the stakes are higher when attempting to qualify a certain plastic for a high-performance application. It is almost as if plastic is literally held to a higher standard than metal in that process.

"Plastic has been around for only 60 years, compared to metal where they've had a long time to figure out what's right and wrong, and even so they're still tweaking," says Smith. "So usually, when the metal guys are working on something they're looking at a relatively—especially in the high-performance stuff—few materials. So you can practically write a standard for a specific grade of metal.


Photo courtesy DuPont/Winzeler Gear.

"Whereas in plastics, we have all kinds of different polymer bases with all kinds of different additives we can put in to modify it. And then we can mix and match all kinds of different materials in the same gear set and a different housing. So you can have three or four different materials in the same application."

Beyond standards, plastic gears present other hurdles for material suppliers and gear makers. Lubricity, thermal expansion and contraction effects on mesh geometry, flexing and creep, parallelism of gear housings relative to stiffness, fatigue endurance and reliable calculation methodology are among the more important issues.

But one "hurdle," according to Grula, can in fact lead to a beneficial result in a number of ways. He points out that the teeth of plastic gears—by their very nature—flex back and forth repeatedly when in operation, which in fact results in significant load sharing between the teeth. This characteristic explains why plastic-molded gears often exceed their expected performance level.

"Other areas where gears made from polymer-based materials can significantly out-perform metal gears are in noise reduction, corrosion and chemical resistance, reduced weight, design freedom/combined functionality, and also cost."

Experience Counts.
And Saves Money.

The last, key ingredient in plastic gearing—as far as the customer/enduser is concerned—is where to go to have them manufactured. It depends in many ways upon the difficulty of the application. For commodity-type, simple gear sets, most injection molders are a reliable resource. But if gear quality—low noise and vibration, optimal repeatability of positioning tolerances and long product life—is paramount, an experienced gear injection molder is the best resource, says Mark Thompson, ABA-PGT's business development director for molding.

"Plastic gear quality is usually determined by measurements of concentricity, roundness, involute profile, tooth spacing errors, axial hourglass or taper, helix angle and size, i.e., arc tooth thickness, outside and root diameters."

Another distinct reason for not going on the cheap with a generic molder is that elephant in the room—the lack of reliable, universal inspection standards.

"Plastic gear quality is sometimes determined by analysis of material integrity, for which no common inspection methods have been developed," says Don Ellis, an ABT-PGT gear engineering team leader. "Some of the common areas that affect the quality of plastic gears are crystallinity (strength), voids (internal stress risers), cold welds, residual stresses and location (alignment of fibrous reinforcement along the tooth profile)."

He adds that to prevent part variation, it is vital that the injection molder have extensive experience and knowledge in gear making as they pertain to controlling: material conditioning; time and temperature (must be held to the recommended processing parameters to prevent the material from degrading, which would result in reduced material properties); time and pressure settings for injection; temperature/injection rate; and mold cycle time. And while non-gear molders may well be aware of all these concerns, it is typically their lack of a gear-specific information database that results in taking several bites of the apple before a gear is manufactured with the required precision.

So, if you are a gear designer or parts specifier, which will it be—plastic or metal? It is your decision, of course, but make sure you do your homework before you buy.

Another tale from Zan Smith explains why.

"I remember seeing a machine shop machining a bevel gear that was relatively low in volume. And when I asked why they were machining instead of injection molding it, the shop owner

Not your father's metal gear shop. (Photo courtesy ABA-PGT.)

said that his customer required the accuracy of machining. This was only a couple of years ago and he had been doing it that way for 20 years, and his customer is probably unaware that the accuracy of the plastic gear industry has changed so much in 20 years that he can probably get a more accurate (and cheaper) plastic part than from the guy machining it. But everyone was happy, although that was clearly an application that could have been replaced by injection molding."

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