Plastic Gearing Continues Converting the Unconverted

Metal-to-plastic gear conversion glass only half-full

Jack McGuinn, Senior Editor

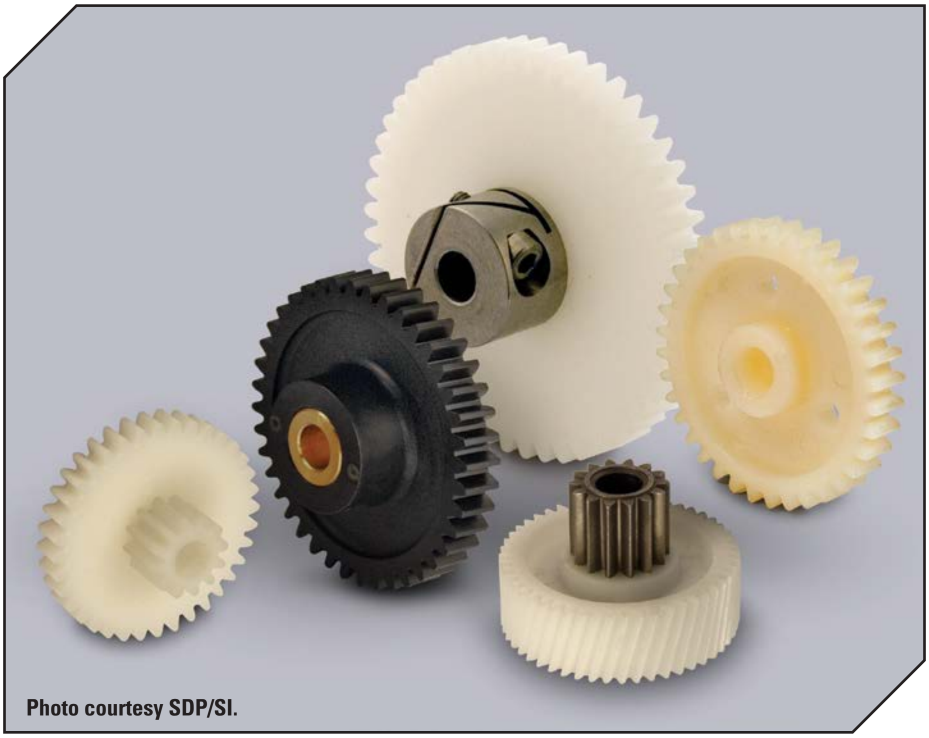

Photo courtesy SDP/SI.

Plastic gears are everywhere today—throughout your car, at the oceans' lowest depths, in deep space. The question, when is a metal gear a candidate for plastic conversion, can be addressed in three words, i.e.—what's the application? One can argue whether conversion to plastic gears remains application-limited. Not a problem—there exist many current and potential applications for polymer, waiting to be tapped, according to George Zollos, Celanese Corp.'s tribology segment market manager, engineered materials. This applies, for example, to applications like medical. "High-precision gears for medical applications are the next frontier for plastic gears," he says. "Medical applications require high-precision, tight tolerances, outstanding reliability and durability, and they need to be small, light and quiet. They must also be approvable for medical use. These are demanding requirements, but they lend themselves well to the capabilities of high-performance, engineered plastics."

Fact is—plastic gear technology is all about the less-is-more dynamic—as Zollos cites. What plastic in some applications cedes to metal in load limits is offset by the benefits of those applications where, say, lighter parts, lower cost and lower noise reset the bottom line.

In other words, you'll see plastic gears not only in all the old familiar places, but also—as the ability to convert progresses—in "any application where precise motion transfer is required," according to Glenn Ellis, senior engineer for ABA-PGT, Inc.

Some 50, 60 years since the first plastic gears started popping up in watches, office equipment, toys, household appliances and sundry gadgets of varying usefulness, they are now literally all around us—used in craft and equipment from the lower depths to the heavens. But are you going to see plastic gears in your car's drivetrain anytime soon? No. As Cris Ioanitescu, SDP/SI Engineering manager succinctly nails it, "If two gears of identical size and configuration are made from plastic and metal respectively, the metal gear will be stronger. Metal gears can be heat-treated to improve strength, but for plastic gears it is entirely material-dependent." Plastic gears do indeed dislike heat, being, according to George Diaz, general manager, The Gleason Works—Gleason Plastic Gears, the "No. 1 reason for (plastic) gear failure in high-torque applications."

But Ioanitescu then offers up a Top-10 list of solid reasons why plastic (and PM) gears continue in the conversion from their metal mates with each new design and material improvement:

1. Cost-effectiveness of the injection-molding process
2. Elimination of machining operations; capability of fabrication with inserts and integral designs
3. Low density: lightweight, low inertia
4. Uniformity of parts
5. Capability to absorb shock and vibration
6. Ability to operate with minimum or no lubrication
7. Relatively low coefficient of friction
8. Corrosion resistance
9. Quietness of operation
10. Tolerances often less critical than for metal gears, due in part to their greater resilience
11. Consistency with trend to greater use of plastic housings and other components
12. One-step production; no preliminary or secondary operations

And you can bet there are many new conversions, the "as yet unconverted" you might say, being earmarked for plastic gears as they continue usurping their metal-made progenitors. Indeed, metal-to-plastic gear conversion is keeping material suppliers in full-time R&D mode.

Adds Zollos, "The development of Celanese's Hostaform SlideX POM represents a significant breakthrough for plastic gears and bearings because it has extremely low wear and friction properties, but unlike other polymers, it also slides easily on itself. This is significant because it enables engineers to utilize the mechanical and physical properties of POM in both sliding components (surface and counter-surface) without negatively affecting wear, friction and noise performance. Hostaform SlideX even provides outstanding tribological performance, when paired against glass-filled POM."

Scott Paulot, sales and engineering manager, VictrexUSA/Kleiss Gears, says his company "has many material design and manufacturing innovations in development and in production, while Diaz offers that, "Gleason Plastics is actively involved in (gear) material testing efforts. Our 'no-weld-line' technology continues to deliver superior plastic gear quality levels."

Material aside — there is nothing without a plan — more to the point regarding plastic gears — a *design*. Without that, regardless of the material quality, the result will be garbage in, garbage out.

So what goes into making a good — or bad — metal-to-plastic gear conversion? (*Also see sidebar page 38 — Metal-to-Plastic Conversion Precautions: Three Traps to Avoid.*)

"The gear design is the first step to develop a stronger gear," says Ellis. "If the design for strength is not adequate, then a review of the material is required. If the selected material is molded improperly, then the properties will suffer and strength will be reduced.

"(But) the design of the gear is only one part of many influences that can cause noise in an assembly; a properly designed gear mesh will help reduce mesh noise. This design is only as good as the final molded gear. A good, molded gear is the result of a quality mold and a quality injection-molder."

Zollos adds that "Stronger material strengths can possibly result in better gear performance. But with plastics, significant improvement in gear performance can be achieved from the plastic's greater flexibility and elongation resulting in greater load sharing. So, an unreinforced plastic can have better gear performance versus a glass-reinforced plastic than a comparison of their tensile strengths would indicate.

Photos this page courtesy ABA-PGT.

"Design can also affect gear performance. For example, the gear designer should take advantage of the fact that a custom gear mold must be cut to account for shrinkage variations by modifying gear teeth beyond standard proportions to increase contact ratios and load sharing. Additionally, full-round gear tooth roots should always be used to minimize stress concentrations and molded-in stresses that can compromise gear performance. Molding can likewise affect plastic gear performance. Poor crystallinity as the result of low mold temperatures and hastened cycle times can compromise plastic gear strength. Poor molding conditions can also create residual molded-in stresses than can cause dimensional changes after gears are put into service."

Says John Winzeler, owner-operator of Winzeler Gear, "Gear strength starts with optimum gear geometry for the application. The design of gating systems that determine flow paths can impact the durability of plastic gears. The strength of plastic gear materials is influenced by process variations. Optimization of the process for the material is essential for best performance."

"The gear design phase is critical in the development of an optimal gear," Diaz stresses. "In this stage critical design conditions are developed to address the gearbox requirements (material selection, increase contact ratio, decrease sliding ratios, etc). During the tool design and fabrication phase, one must ensure that the gear cavity geometry is sized properly to accommodate for plastic shrinkage. Finally, during the injection molding process development phase, one must also develop a robust process (following decouple molding practices) to ensure consistency in the manufacturing process."

Regarding noise, that's a definite deal breaker, given that less of it is supposed to be a leading attribute of plastic gears.

Zollos explains. "Most plastic gear noise is the result of bad geometry; either from bad initial design, poor manufacturing (including mold making and molding), and resulting dimensions, or both. Tribological material performance also contributes to overall gear noise. One of the biggest oversights in plastic gear design is the failure to account for thermal expansion differences between the gears and their mounting geometry. Plastics have an order of magnitude greater thermal expansion than metals. These differences can result in significant variations in the effective center distance, contact ratio, and load sharing that, when gets too bad, will create tooth impacts, noise and premature failure."

ABA-PGT's Ellis raises another caveat — uniform material testing procedures — or the industry's lack of them, more precisely. "Material manufacturers do not have a common procedure for testing their products," he says. "This makes it difficult to compare some materials to find the best fit for the application. Some gear programs have material properties to compare when designing a gear mesh. However, this list is very limited, so in many applications the material you would like to review is not available."

Regarding the rich veins yet to be mined in the automotive industry, we've already addressed the drivetrain gear conversion possibility—which is nil. But of course that's only a small part of the number of car parts in play. But to actually produce those parts, says SDP's Ioanitescu, "Future developments in material science could create hybrid materials which will combine the best properties from plastics and metals. The fact that plastics are self-lubricating materials eliminates the need of using grease and oil for two gears in mesh."

Ask Gleason's Diaz about the further potential for metal-to-plastic conversion in automobiles—you'd have to say he's all-in.

"The day will come when we will drive an all plastic *automobile*! Gleason's 2011 plastic gear acquisition is a long-term commitment in support of this trend. Over the next 10–20 years, new polymer resins will be developed to withstand increased loads / temperatures. We do not see steel gears in drivetrain going away, (but) there are an increasing number of plastic gears used for a variety of applications outside of drivetrain applications."

Offering a more restrained, yet positive view is Celanese's Zollos. "In the near future, there are just too many parts requiring materials with widely different performance properties to expect that one type of material could be used for (every auto part). However, as the move toward electric vehicles continues, the demand for lighter, stronger materials will result in an ever-increasing percentage of plastics being used in cars."

Victrex/Kleiss Gears' Scott: "This is a very wide scope question. Clearly significant performance improvements and cost savings are available if plastic is utilized in more under-the-hood applications. CAFE standards will drive this forward." And Diaz further adds that "In general, metal-to-plastic transformations typically yield a weight reduction that directly impacts energy efficiency performance. Plastic gear transformations also can offer dampening gearbox responses as well as noise reduction advantages."

And, finally, what of lubrication? True, in most cases it is not needed for plastic gearing. But when it is…

"One of the most important drivers for converting from metal to plastic gears and bearings in many applications is the ability to eliminate the need for lubrication," says Zollos. "The lack of lubrication is a key factor in premature gear and bearing failure, whether it's due to inadequate maintenance, breakdown of the lubricant due to temperature, dirt or other contaminants, or simple depletion of the lubricant over time. The development of new and better performing tribological polymers will allow more and more metal gears and bearings to be converted to plastic and potentially eliminate the need for lubrication in those applications. That is why Celanese is continually developing new grades and compounds to improve tribological performance of gears and bearings in all applications and across a wide range of industries."

"It is very important. Plastic gears offer more flexibility for lower viscosity lubrication or no lubrication than metal," Scott agrees, with Diaz pointing out that "In general, lubricated applications may offer a cooling benefit to the gearbox system. One must also ensure proper compatibility between the lubricant and the plastic resin. We see nanoparticle technology as a major technology breakthrough in both resins and lubricants."

"Lubrication—internal or external—is a science in itself," Winzeler points out. "The appropriate lubrication system is critical for optimum performance of a plastic gear system, which is no different for metal gearing. Many plastic gear systems can meet life requirements with only initial application of grease. We engage lubrication engineers in our design process."

Metal-to-Plastic Conversion Precautions:
Three Traps to Avoid

Courtesy Victrex/Kleiss Gears

With a constant demand for performance improvements and cost reductions, the conversion of metal gears to plastic in high-performance applications is a growing sector in the marketplace. Following are some common pitfalls to be avoided when you are asked to make the conversion:

Trap No. 1—Direct replacement. The earliest and easiest trap is the convenience of a direct replacement: i.e.—the metal gear works, so why not quote making the "same part" from plastic? There are times where this direct replacement would be acceptable and a plastic gear designer will perform that analysis for you; however, many times the gear needs some redesign work. The good news is this trap is easily avoided by sharing the current design along with requested improvements with your plastic gear designer to see what solutions—including direct replacement—may be available.

Trap No. 2—Failure to optimize for plastic. This leads to the next pitfall, which is not giving the plastic gear design enough flexibility at the onset of the redesign. The original design was optimized for a *metal* gear, so changing the gear material warrants a redesign for the *plastic* gears—which may extend beyond the design of the gears alone. Plastic gear optimization is the key to removing unwanted weight, cost, NVH and other undesirable elements, so specific concerns should be discussed with plastic gear designers early in the conversion process. Plastic gear designers can work with project engineers to develop a solution tailored for the unique operating conditions of any system; this is necessary to select the correct material and optimize the gears to meet the functional requirements throughout the entire operating environment. Because the part is converting to plastic, other design elements may be present that were not before, such as designing an insert for over-molding, combining multiple parts into a single component, and removing secondary operations.

Photo courtesy VICTREX USA/Kleiss Gears

Trap No. 3—Prototype testing setbacks. Once a plastic gear design is agreed upon, the design must be built and tested. The prototype testing phase of the conversion process is usually seen as a pass/fail test of the plastic design, but therein lays the trap. The reality is the prototype testing phase should be an iterative process during which improvements can be made that take full advantage of the plastic redesign opportunity. Plastic material properties have been generated through repeated lab tests which follow precise standards, but the prototype plastic components are not operating in a lab environment. Because this is a new technology, gear reference tables at different temperatures and loads do not exist for each resin. This can lead to setbacks in prototype testing during alpha/beta testing. Though undesirable, unexpected results in prototype testing are not uncommon: often these results lead to a refinement of actual environmental conditions that expand the specified ranges. If a gear does fail during testing, find the root cause and properly account for it in subsequent designs and tests.


Photo courtesy VICTREX USA/Kleiss Gears

Countless opportunities for metal to plastic conversion are present in the automotive and aerospace industries. The medical industry also offers abundant applications ideal for plastic gears. Whether you are looking for durable replacements for large metal gears or small disposable gears, plastic gears can provide a valuable solution to bring your product successfully to market. Any plastic gear solution can offer advantages that, when realized in new applications, may revolutionize the standards in that industry. Great innovations are close at hand with plastic gears in the toolbox, so start researching if you have gears suitable for plastic conversion.

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