Plastic Gear Design Remains a Work in Progress

Jack McGuinn, Senior Editor

Despite the development and availability of a number of newly engineered, rugged materials intended for plastic gear applications, some engineers/designers continue to believe metal is better. But there now exists a long list of simple poly materials (nylon and acetal, for example) that can now be mixed with other materials such as fiberglass and then reinforced with a carbon steel core.

However, designers may also be put off by the cost of certain plastic-in-place-of-metal gear applications. The cost occurs when the mentioned reinforcements are added to the mix — which can add hundreds of dollars to the cost of a simple spur gear, for example.

And while there are any number of websites available that present lists of plastic gears' positives and negatives, we include the following Good/Bad lists intended to provide some context for what follows.

Plastic gear attributes:

- Elimination of machining operations; capability of fabrication with inserts and integral designs
- Lightweight
- Reduction in shock, noise and vibration
- Parts uniformity
- In many applications, no or very little lubrication; self-lubricating in some cases (nylon)
- Corrosion-resistance.
- More forgiving tolerances than with metal gears
- Relatively simple production, with no pre- or post-production

A not-so-positive list of plastic gearing negatives includes:

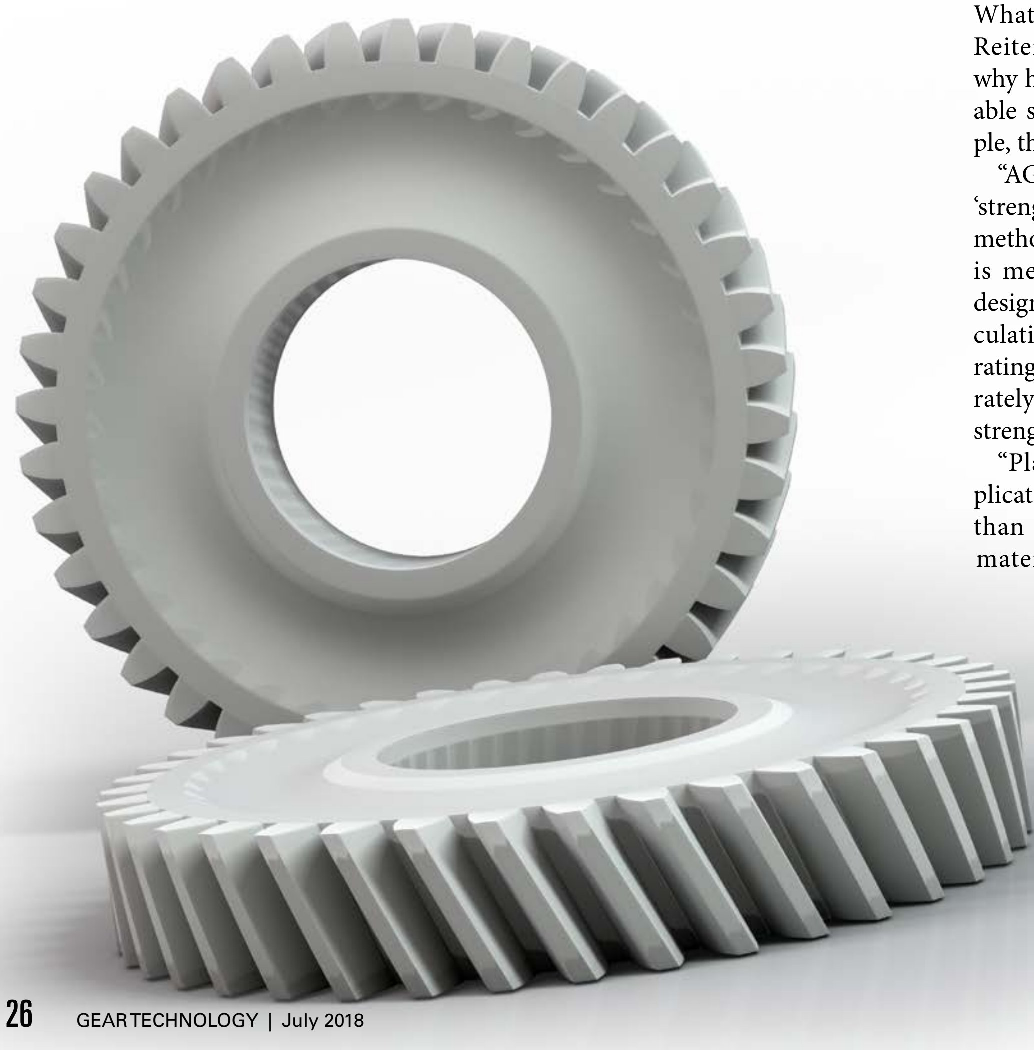
- Material cost can be markedly higher than basic metal gears, especially if custom poly materials are used
- Difficulty in wedding plastic gears with metal shafts
- Often less strength than similar metal gears
- Problems with high tolerances vs. metal gears
- Not as dimensionally stable as metal gears in that plastic gears are adversely affected by temperature and humidity conditions

Understand, however, that this is not an article on the specifics of plastic gear design. Rather, what follows presents some of the ongoing big-picture issues that affect plastic gear designers and end-users alike.

Take, for example, the continued lack of published standards for plastic gears (although some *rating* methods exist). What's up with that? We asked Ernie Reiter, who runs Web Gear Services, why he thinks that there is still no available standard for estimating, for example, the strength of plastic gears.

"AGMA and ISO do not estimate the 'strength of gears' but instead provide a method of rating gears. A rating method is merely a means of comparing one design to another using a common calculation method. The AGMA and ISO rating methods do not necessarily accurately predict a particular gear's actual strength.

"Plastic gears are much more complicated in developing a rating method than metal gears. This is because the material properties vary widely with temperature coming both from ambient conditions and frictional heat. The materials are also strain rate sensitive and, and depending on the grade may allow for larger elastic and plastic tooth deflections under load that may promote load sharing."



"ISO in its standards has not focused on plastic gears at all. AGMA's Plastic Gearing Committee has focused on writing documents related to specification, measurement, materials and testing of plastic gears. Creating a standard for rating plastic gears has been discussed as a work project, but the priorities have first been put onto other topics."

Brian Stringer, Manager KISSsoft Sales and Application Engineering, USA/Canada, says "There are currently some guidelines (not official standards) that can be used for calculation of the load carrying capacity for plastic gears. VDI 2736 part 2 (cylindrical gears) and VD2736 part 3 (crossed helical gears) are two examples. These calculation methods are available in gear software such as *KISSsoft*. AGMA also has a plastics gearing committee that is working towards some of their own new standards and guidelines for plastic gears."

For Glenn Ellis, Senior Gear Engineer, ABA-PGT Inc., "It does not seem that there is a standard system of testing plastic materials. Some gear software has estimating calculations but only for a limited amount of materials."

We asked if FEA (finite element analysis) — the long-established method for verifying the strength of metal gears — could work for plastic gears as well.

"I would disagree," Stringer says. "Plastics are viscoelastic materials, and therefore experience both viscous and elastic characteristics when undergoing deformation. With that being said, plastics are non-isotropic, and cannot be treated as such during FEA. This is complicated even further when you are looking at plastics with fillers such as glass fiber, where you have to take into account the stiffness and alignment of the fibers."

Meanwhile, today's designers of plastic gears have more material choices than ever before in developing new applications. But is there sufficient test data available for all of these materials?

Ellis declares that, "There is strength data for most materials. However there is limited data in regard to wear between different material types."

"Not even close," says Stringer. "This is the largest hurdle to currently overcome when designing plastic gears. It is very hard to design anything without sufficient material data. While there is plenty of data available for plastics that have been around for a long time (POM, PA66, etc.), there is limited data available for newer, high-temperature, engineering grade resins. Most of these materials have basic mechanical data available, like modulus and tensile strength, but most do not have fatigue data to help predict flank and root bending safety factors. This data is expensive and time-consuming to collect, as it requires expensive equipment, lots of time/money, and also the ability to control the temperature of the plastic gears during cycling in order to create S-N curves at many different temperatures. All this data must be collected at different temperatures since the mechanical properties of plastics degrade with

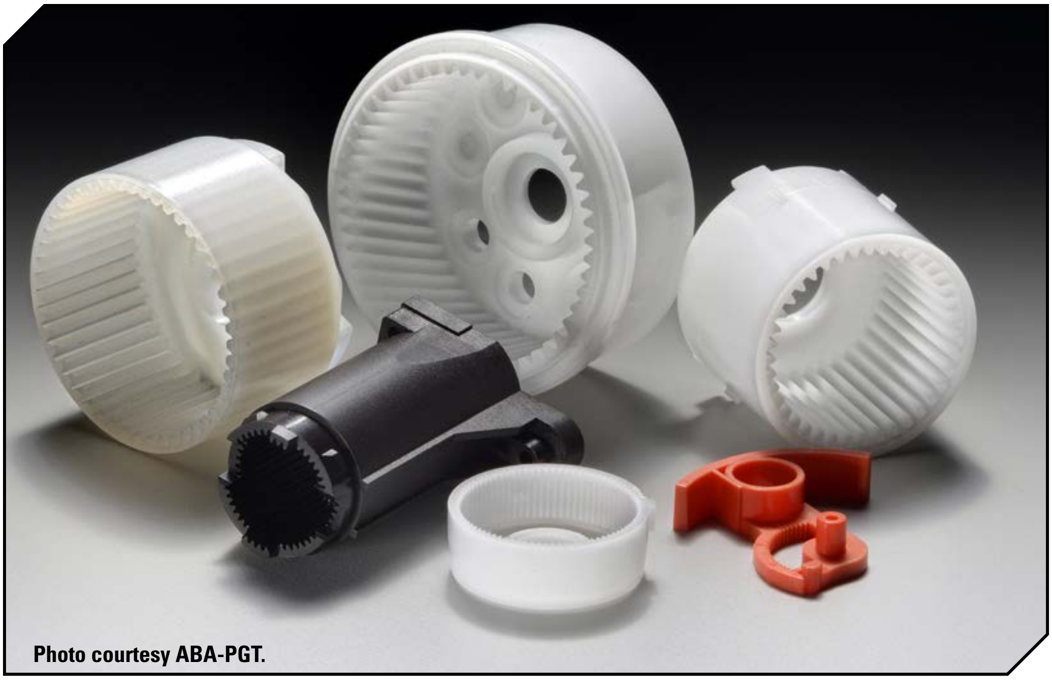


Photo courtesy ABA-PGT.

increase in temperature."

It has been reported that plastic gear designers are also hampered by a lack of available material characterization guidelines for plastic gear calculation.

"This is true on some of the newer materials, Says Ellis.

Also in agreement, Stringer says that, "As stated in the answer to the previous question, it is very difficult to design without having enough material data. Multiple calculation methods must be used if possible, and also experience and educated guessing. It is critical to get your material suppliers involved in the process, as they can speak on experience and past projects to compare stress values, and they may have additional internal data to share that they may have not released to the public."

Further researching plastic gear manufacture, we determine, not surprisingly, suppliers are tasked with designing and manufacturing plastic gears and gear components for applications in which there is no international standard available for gear predictive engineering.

Ellis offers the possibility that, "The end user may not be aware of this situation. They rely on the gear molder to produce an adequate gear."

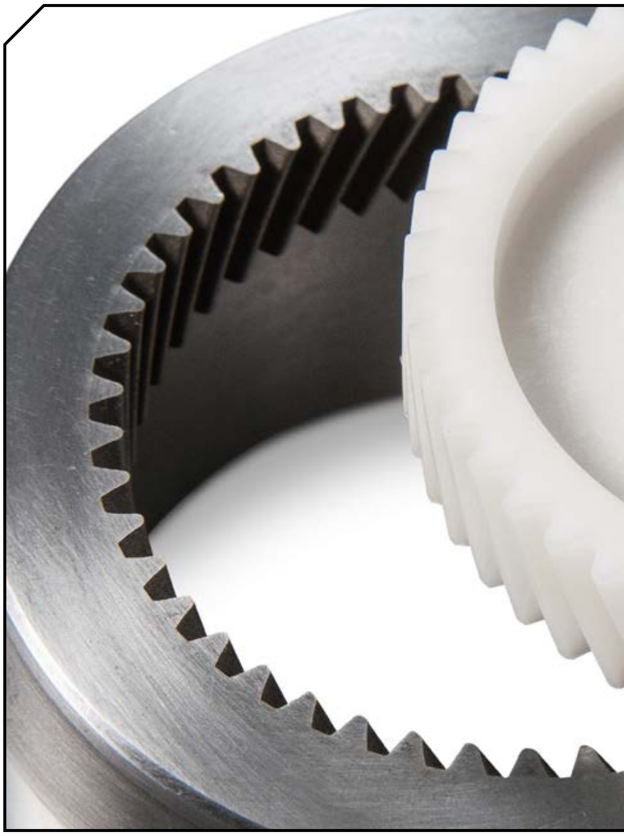
To that end Stringer explains that, "It is certainly tough to sell a plastic gear solution to companies whose applications are pushing the limits of the current materials. Most companies will not take the risk if they don't have the data and calculations to show confidence in the plastic. What is also challenging is that there are a lot of molding companies out there, and many of them mold gears like they would any other component. It is important to work with an actual gear molder who specializes in this. You cannot mold a gear correctly if you do not understand how to design gears, the gear materials themselves, or if you cannot inspect molded plastic gear using the appropriate methods. This includes at least double flank composite inspection using a master gear, to report Total Composite Error (TCE), Tooth-to-Tooth Composite Error (TTCE), and Test Radius (TR)."

Reiter states that, "Plastic gears are designed by benchmarking — so this is not an issue. They are necessary to use in order to achieve low cost designs. We evaluate an existing plastic gear design using some calculating method of our choosing. Most plastics people have their own methods for stress analysis that they have developed; none of these methods is exactly correct, but they get you a comparative result.

"We then evaluate a new design relative to the same calculating method as what was used in the benchmark to project ahead what is likely to happen. As long as the temperature of the application, materials, and loading is generally similar (even though magnitudes may be different) the benchmarking should lead to a good working solution."

In recent years simulation software development and increases in computing power have led to more reliable gear simulations, but often their full capacity cannot be exploited due, once again, to a dearth of gear material data. To what do you attribute the shortage in gear material data?

"The knowledge of what data is needed," Reiter says. "Also, plastic gears represent a fraction of the material volumes that granulate suppliers sell of the grades used in gears. Testing is expensive



and granulate suppliers may have a difficult time in justifying the expense to do the testing relative to the size of the granulate market they can achieve."

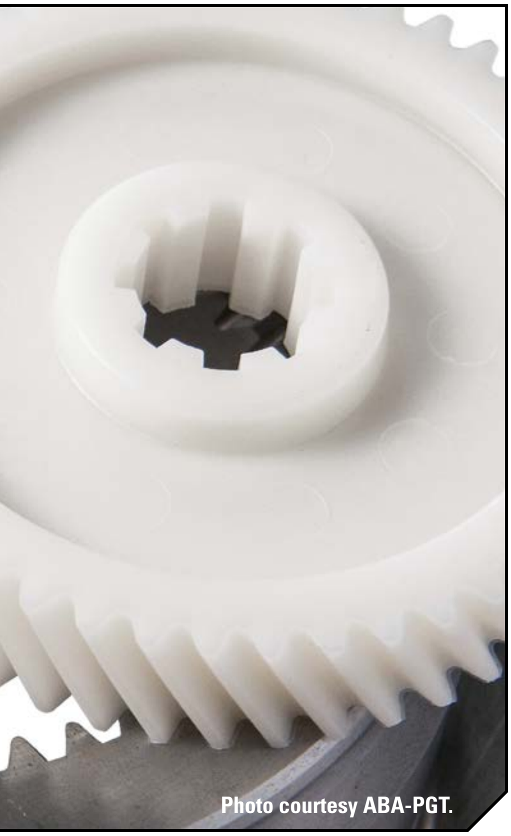
Gleason's Stringer says "Time/cost to actually collect this data. Also, material suppliers may be hesitant to release all their internal data due to liability and uncertainty in the data collection process. There is also the topic of how this data is collected, and if all material suppliers are using the same methods/standards (if available), to collect this data. Without a unified method to collect plastic gear data, we can never be certain that the data is accurate."

"This (lack of data) is true," says ABA's Ellis. "It appears that only a few material manufactures have gotten together with the software designers to fill the information data archives."

Research indicates that the most common plastic gear failure modes are wear, fatigue, and plastic flow due to material creep or elevated temperature exposure. We asked our contributors for comment.

"Yes," Stringer agrees. "Wear would be mostly seen on high RPM, unlubricated, continuously running applications (sometimes if the material has a filler such as glass fiber, this can increase the wear as well). Fatigue can occur from root bending stress over a number of cycles on higher loaded applications. Sometimes a gear pair will see a peak torque that simply breaks the teeth in a stall condition, which isn't due to fatigue at all, but more so due to the tensile strength of the material at a specific temperature. High temperature is the enemy of plastics, so it is important to not only understand what you're operating and ambient temperatures are, but what your actual temperature at the tooth flank and tooth root are during operation."

Reiter has a different take. "I disagree that wear is one of the most common plastic gear failure modes. It does happen but most plastic gears that I see are used intermittently and wear is not an issue. Fatigue fractures and plastic flow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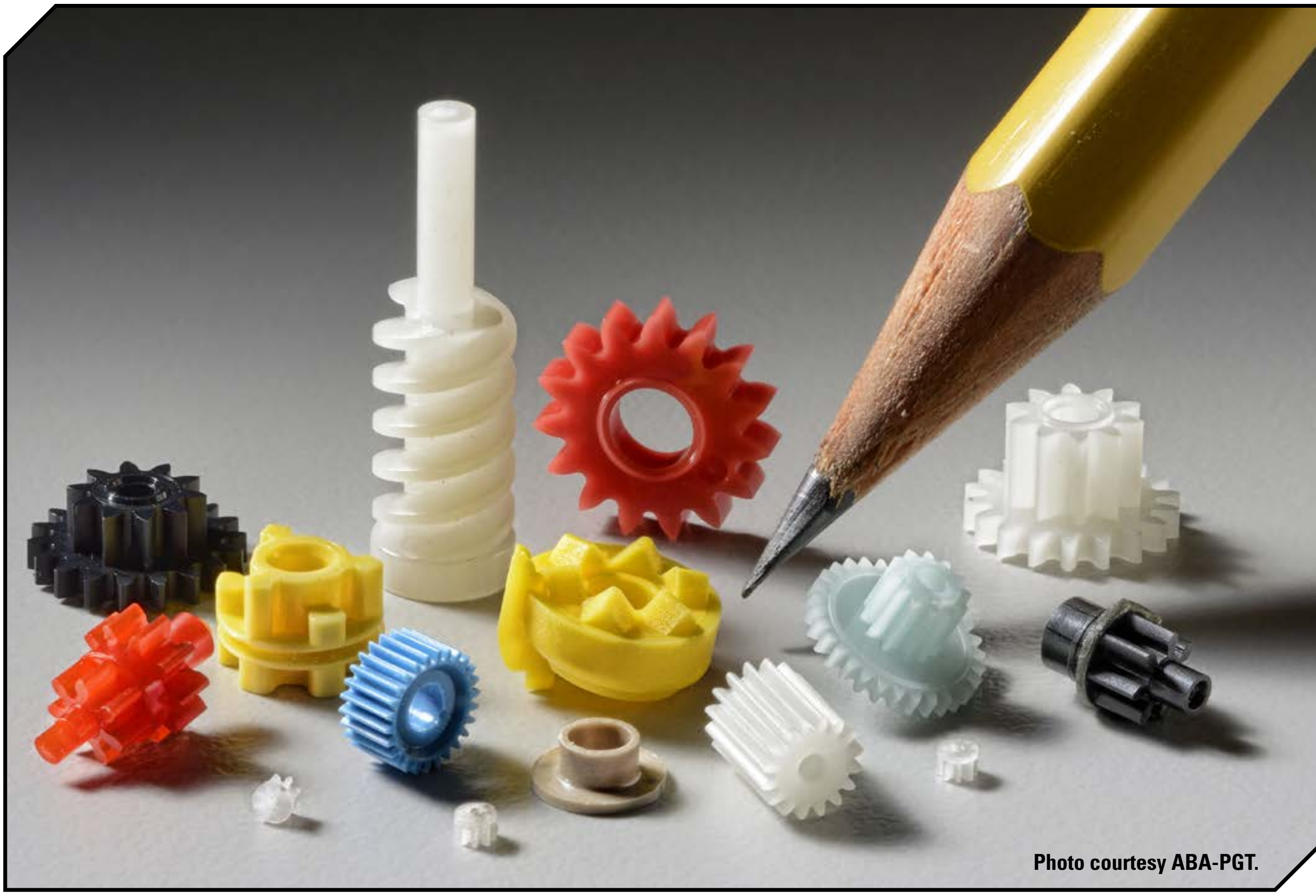

Photo courtesy ABA-PGT.

are significant failure modes. In crossed axis helical gear applications where hard stop exists in a gearbox, shear of the gear teeth is a significant failure mode at stall."

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