Talking Truth to Power: Plastic Gears Taking Back Seat to No One

Automotive industry embraces proven yet evolving technology

Jack McGuinn, Senior Editor

The $50 billion dollar 2008 bailout of the U.S. auto industry— initiated by President George W. Bush and completed by the Obama administration had— and continues to have—its detractors. Those in the business of supplying U.S. automakers with engineered-plastic gears and other critical car components are not among them.

Indeed, the U.S. automotive industry has been in rebound mode since 2010, according to the Society of the Plastics Industry (SPI) (*plasticsindustry.org*). And since 2011, according to Stout, Risius and Ross (SSR) (*srr.com*), an industrial-focused financial adviser and consultancy, "North American automotive production totaled 15.4 million units in 2012—up from 13.1 million units in 2011—and is expected to increase further to approximately 15.9 million units in 2013." Not all of that is in plastics, of course, but the industry's cut of the pie becomes increasingly significant with each new year. Backing that up in a recent radio broadcast, available online at the SPI site, is Bryan Osborne, vice presidentof sales and marketing for injection molder/manufacturer Venture Plastics, Inc. (Newton Falls, OH), stating that "About 50 percent of a car is plastics today," and that demand for more fuel-efficient vehicles is behind the increase.

"Under-the-hood" automotive gears from Kleiss Gears (all photos courtesy Kleiss Gears).

"That includes under the engine, manifolds, fuel rails, (etc.)."

And that claim is certainly supported by the fact that the automotive industry is the second-largest user—after packaging—of U.S. plastic products.

And finally, these 2011 post-recession numbers from the SPI business blog, *In the Hopper*, under the headline, "U.S. Automakers' Upbeat 2011 Is Sweet Music for Plastics Industry":

"2012 looks to be a good year for U.S. automakers, domestic and foreign brands, as well as for their creative partner suppliers in the plastics industry. For what they have each been through in the last few rough years, both automakers and plastics suppliers have more than earned some good times."

More (inclusive) "plastifacts" from SPI:

- The plastics industry is the third largest manufacturing industry in the United States
- The U.S. plastics industry employs more than 885 thousand
- The U.S. plastics industry creates more than $380 billion in annual shipments
- When suppliers to the plastics industry are considered, there are 1.4 million workers and total shipments grow to $465 billion
- There are more than 16,200 plastics facilities in the United States
- The U.S. plastics industry had a $16.3 billion trade surplus in 2011
- The plastics industry has a presence in every state
- From 1980 to 2011, U.S. plastics industry shipments have grown at a 0.1 percent annual rate

But enough numbers crunching; let's talk to some of the folks and companies behind the numbers— the engineered materials suppliers and the component manufacturers.

Rod Kleiss is the president of Kleiss Gears (*kleissgears.com*) in Grantsburg, WI. This story having an automotive focus, we cut right to the metal vs. plastic under-the-hood chase. (And let's face it: it's all about metal vs. plastic, is it not?) Plastic has already made great inroads regarding engine gears and parts for consumer-type vehicles; but we asked Kleiss just how far along are things in qualifying various gears and power components for industrial-size engines? (To be clear, industrial in this context means off-highway, heavy equipment.) The answer lies in both materials engineering and sophisticated design.

"(Partnering) with Victrex (a leading materials supplier to the engineered resins/plastics industry), we have been molding and testing plastic gears in engines for a few years now with some very good success. We have found some unique design approaches that work quite well in replacing their metal counterparts. This includes varying the pressure angle to fit the specific requirements and applying a minor helix to the gears just to limit the potential for tooth slap.

"We have just begun our first production order for a molded gear replacement of a ground gear in road building equipment. We are not at liberty right now to reveal the customer or application but I hope to get permission within the next few weeks."

And for John Winzeler (*winzelergear.com*), owner/operator of Chicago-based Winzeler Gear, and playing it a bit closer to the vest, "With all gearing applications, appropriate testing and development are critical. Today many small engines have molded plastic cam gears. Of course there are limits to temperature and load capacity."

By all accounts polymer is here to stay, but in what types of automotive applications? Where can plastic be counted upon to match or prevail in performance? In quite a few places, according to Kleiss. But he's willing to share (with metal).

"Plastic is better for vibrating loads, such as counterbalance shaft rotation or vibrating equipment applications," says Kleiss. "Also, in applications where normal loads are not excessive but occasional, short-term spikes must be anticipated. In general I think that plastic will find its place at the front end of transmissions where higher speeds and lower torques are occurring. They will reduce rotating mass and the corresponding noise and leave the high loads to the steel gears."

One claim of plastic gearing is beyond dispute — less noise and vibration.

And why is that?

"Sound levels are a function of speed and accuracy for all types of gearing," Winzeler explains. "Plastic materials generally are softer than metals and absorb energy better."

As Kleiss puts it, it's kind of a mystery. "One of the basic reasons is that they (plastic gears) just don't carry sound as well, and their natural frequency is much lower. I think you can hear the effect of that directly in (sound testing). (It may be that) under a vibrating load, the plastic teeth bend a little and this load-sharing may tend to dampen the physical oscillation of the gears, while the hard metal gears translate every small motion into rotation. That is just a speculation or theory though."

"About 50 percent of a car is plastics today; that includes under the engine, manifolds, fuel rails, (etc.)."

Bryan Osborne, *VP of sales & marketing, Venture Plastics, Inc. (Source: SPI).*

Among the most critical plastic components now — and for some time, in fact — being used in vehicles are plastic bearings. For the best source of updated information on that score we went to two major, international materials suppliers with diverse portfolios — DSM, headquartered in The Netherlands (*dsm.com*) and Ticona Engineering Polymers, a Celanese company based in Dallas, Texas *(celanese.com/ticona/ticona.aspx)*.

"Plastic bearings (bearing cages) are more mature (accepted) in the automotive market than gears and actuators," points out Pascal Feijts, DSM applications development manager/global research and technology. "For plastic gears the new trends in downsizing and turbocharging drive the need for more electrical actuators with geartrains. Also, metal replacement for in-engine gears to improve NVH or improve emission and fuel levels is more and more upcoming."

Ticona's David Sheridan, senior design engineer, agrees that "Yes, engineering thermoplastics are proven sliding materials in precision engineering applications such as thrust bearings, sleeve bearings and bushings. Although they don't have the high-load-bearing capacity of metal, plastic bearings offer lower cost; lower weight; ability to run 'dry'; inherent low friction and noise; maintenance-free operation; chemical resistance and broad design flexibility."

He also touts one of his company's patented products — Hostaform C 9021 AW — for its "low-wear, friction, and squeak system," as a "material of choice for high-quality molded engineering parts subject to high stress, including gears, bearings and other sliding elements used in precision engineering."

And what about gearboxes? It's a given that their engineering complexity is matched only by their need for robustly made components to operate in miserable conditions.

"It all comes down to loads on the gears (torque rating) in combination with the durability requirements to see how far plastics can go," Feijts allows. "Reinforced plastics are more likely (specified and used) here due to high strengths needed, but they suffer on wear rate compared to unreinforced plastics."

For his — and Ticona's — part, and on behalf of reinforced fiber products that Feijts alluded to, Sheridan points to "An innovative transmission from Hi-Lex America Inc. (that) reliably and quietly opens and closes automotive lift gates thanks to high-precision shafts and gears injection-molded with Celcon POM and Celstran long-fiber-reinforced thermoplastics (LFRT). The two-stage reduction transmission uses precision steel ball bearings mounted on plastic shafts and 2.5-inch-diameter plastic gears to achieve the desired reduction between the electric motor and a flexible torsional cable. The first-stage gear and shaft and second-stage output plastic gear are injection molded from Celcon POM M90 and Celcon GC25T, respectively. The second-stage output shaft is injection molded from Celstran PA 66-GF50-02. The

Hi-Lex transmission with plastic gears reduces cost, weight and especially, noise."

Yet regarding worm gears, common in gearbox designs, work remains to be done for the plastics industry.

"I understand that well-lubricated steel worm drives can be really efficient, much greater than 95 percent. We are not there with plastics," Kleiss admits. "One rule-of-thumb is to estimate efficiency as .95 for a reduction ratio of 3.5:1; therefore, a 40:1 worm drive might be expected to achieve 85 percent efficiency in the gear mesh. You really have to look at the sliding friction of the teeth on each other in a plastic worm to get a good idea of efficiency."

On the other hand, Winzeler believes that "Plastic worms may provide lower friction — thus higher efficiency — due to the lubricity of the plastic material compared to metals. We recommend all applications be, at a minimum, initially lubricated with grease."

Staying with our components suppliers, we queried Kleiss on microgears, a nascent-yet-promising technology with great promise for plastic.

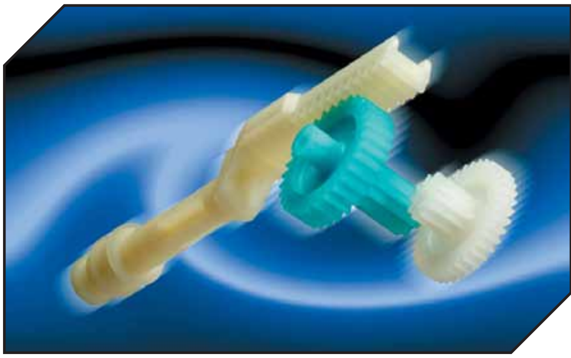
"Micro gears (> 200 DP) are still an infant science in my book," Kleiss concedes. "In larger gears, grinding accuracy can produce more exact geometry than molding, but as the gears keep getting smaller, that advantage begins to disappear. But along with that disappearing advantage comes more difficulty in inspecting the gear itself. For instance, we are using .2 mm probes now, but are still unable to reach totally into the root of a small microgear. Vision inspection is problematic because it requires a sharp edge, which molded plastics do not have. X-ray scanning or CT tomography looks to be the most promising, but its accuracy is still not truly precise enough. The very best way to measure them right now is by testing the finished product in an instrumented transmission. We've done this; it works."

And when it "works," does that mean polymer microgears will be more "features-laden," than their steel counterparts, as has been reported in some quarters?

"Because we can add features easily to a molded gear that would be virtually impossible to add to a cut steel gear — yes," says Kleiss. "Even a simple compound gear becomes a task for the gear hobber, but it is simply adding another cavity for the molded-gear manufacturer. We can put a spur gear onto the end of a worm with no problem and add features on to that spur, if desired. That would be quite difficult for the metal gear manufacturer."

Current uses and applications-in-waiting for plastic microgears include, says Kleiss, "small medical pumps with throw-away gears that could never be considered as a cost-effective option in steel," adding that "All the new microgear applications will be served better by plastics. The challenge will be to actually build the little transmissions. Molding the gears might be the easiest part of the project."

Jumping back to the materials end of things, one wonders is the glass half-full or half-empty regarding the heights to which plastic gears and related components (bearings, actuators, etc.) might ascend in the automotive arena.



"The state-of-the-art has advanced to where plastic gears are now in drives of up to three-quarters horsepower; future applications may take them higher."
David Sheridan, *Ticona*

"Depending on the system or application, I have seen durability requirements for motor management actuators going up to 30, 40 million load cycles, with quite challenging torque ratings," says DSM's Feijts. "Other in-engine applications are fit-and-forget, so durability levels can go up to 1, 1.3 billion load cycles! We at DSM are continuously looking into possible ways to improve our materials. Both strength and durability (which can be differently defined depending on which application we are talking about) are important subjects that we are looking at both on the polymer matrix and/or reinforcement/filling side."

For Ticona's Sheridan, it is a matter of "The higher the performance requirements for a drive, the more complicated the up-front design effort is required to make plastic gears work. The state-of-the-art has advanced to where plastic gears are now in drives of up to three-quarters horsepower; future applications may take them higher. Horsepower limits for plastic gears vary with the polymer, depending upon the mechanical properties that change with temperature. Temperature control, therefore, is critical for plastic gear load capacity. Lubricants — both internal and external — that reduce frictional heating or dissipate heat will increase plastic gear load capacity. Furthermore, long-glass-fiber-reinforced plastics will allow for larger tooth and wall thicknesses of a larger-size plastic gear that will withstand higher loading."

To some analogous degree, plastic gearing is as reliant on the art of injection molding and its continued research and development as is its more mature

All photos courtesy Winzeler

metal counterparts — forging and casting. Is there a tilting point?

"Injection-molded plastic gears have come a long way," says Sheridan. "Historically, they were limited to very low-power transmissions such as clocks, printers and lawn sprinklers. Today's stronger, more consistent engineering polymers, and better control of the molding process, now make it possible to produce larger, more precise gears that are compatible with higher horsepower."

In addition, "Gear analysis software can now optimize plastic gear designs based on temperature, moisture pick-up and other environmental factors. The unrealized potential of plastic gearing is becoming more apparent to the industry. Testing of plastic gears specifically to characterize gear resins in different service environments has begun. The new data will allow design engineers to more accurately predict gear performance. Better predictions mean faster, shorter design cycles, since the development phase may be approached with greater confidence."

Perhaps; DSM's Feijts believes plastic continues to suffer "second-cousin" status vs. metal in the perception of some. And it has nothing to do with process.

"No, current limitations are more depending on the market's perception of using plastic gears instead of metal ones. The market is opening up due to more stringent national and international emission and fuel consumption legislation, so for the time being the injection molding technologies available (which are also evolving continuously) are sufficient enough."

Proper lubrication and lube maintenance can be as critical to the working order of a plastic-fashioned gearset as with metal. Difference being, however, and it's a big one, there are *reams* more literature on metal gear and bearing/lubrication issues than exists for plastic. For the relative "new kid" on the block, it can be more trial-and-error as the application opportunities — and their challenges — continue to multiply.

"We work very closely with oil and grease manufacturers, but are also working on improving the dry lubricants (types and composition) that we use for our engineering plastics," says Feijts. "New, emerging applications also introduce new insights in lubrication requirements, so this needs constant develop-

ment and research into the fundamentals of wear and friction between plastic — with itself — or other materials."

The way Sheridan explains it, it's even trickier — details, details, details. And — less is more.

"A fundamental misconception in plastic gear design is that — whatever the resin — 'It's just plastic.' The choice of a gear resin demands careful study. Inexpensive, commodity resins generally lack the fatigue life, temperature resistance, lubricant resistance and dimensional stability required for quality plastic gears in all but the most primitive applications. However, many of today's engineering resins provide the necessary performance for working gear trains. They also have the consistent melt viscosity, additive concentrations and other qualities essential to consistent, accurate molding.

"Generally, it is easier to mold high-quality gears with resin containing minimal additives than with highly filled blends. The specifier should call for only as much glass or mineral filler or lubricant additives as are actually needed. If external lubrication is required, the drive designer, resin supplier and lubricant supplier should work together to select an appropriate lubrication system."

A discussion of plastic and automotive cannot ignore the — perhaps not yet of elephant stature, so let's go with creature — in the room: the powder metal (PM) industry. How does its performance match up with plastic? A fair question, or an apples-and-oranges thing? Judging from the following replies, sounds like PM and plastics have a peaceful coexistence, with limited overlap. Think of PM as the plastic family's brawny-not-brainy counterpart.

"Powder metal serves an important function as a low-cost, high-strength mate to plastics at the input or output end," says Kleiss, (but) "PM gears are limited in their architecture. Helix angles must remain low and it is much more difficult to add features to the parts. They also have rougher surfaces. In general, we are finding that if we can't use plastic, we will go to a cut metal gear for better function."

Adds Winzeler, "Powder metal gears can withstand higher loads and temperatures, (but) plastic gears will be lighter, quieter, and may withstand more impact. Plastic gears can be configured with more complex configurations."

And what of plastic-based gear and other standards — international or otherwise? The lack of an internationally blessed set of commercial, industry/application standards continues to frustrate and challenge most every aspect of the plastics industry.

As for the material suppliers appearing here, "Apart (from the fact) that this is mainly driven by gear manufacturers, DSM as a material supplier is also involved in developing national or international standards, (whether with) AGMA or VDI/DIN," says Feijts.

"Ticona is an active member of the (AGMA) Plastics Gearing Committee," Sheridan adds. "We work with members to evaluate materials, designs, rating, manufacturing, inspection and the application of molded or cut plastic gears. This committee is responsible for drafting plastic gearing industry documents and guidelines."

Meanwhile, have a heart for Mr. Kleiss.

"I despair of any chance for meaningful standards in the plastics industry. I spent years attending Plastic Gearing Committee meetings at AGMA to no real effect. I finally just left to preserve my sanity. It is nice sometimes to stop beating your head against a wall."

Ouch!

> "I despair of any chance for meaningful standards in the plastics industry."
> Rod Kleiss, *Kleiss Gears*

As one considers the issues just touched upon here, one last question beckons. Just how will all this shake out? "This" being the whole dynamic of metal replacement and the continuing advance of highly engineered materials with seemingly no ceiling in sight. Will the eventual and ever-shifting playing field always have a place for metal? Will we see companies buying up one another, whether it being metal-based vs. plastic or the opposite?

"What I see is that metal companies are forced by OEMs or Tier1s to investigate the possibilities for plastic gears, but most of them will unlikely acquire a plastic gear manufacturer," Feijts conjectures. "Most of the bigger plastic gear manufacturers do have metal gear production in place already (to a certain level). As they are (now) more and more system suppliers, they try to keep the 'gearing' business in-house."

As for Kleiss, if we read him correctly, both industries (within one larger industry, keep in mind) should be able to co-exist peacefully — and in one piece.

"I don't know who should acquire who in this crazy world," he laments. "I do know that we are working with more traditional gear houses now than ever before. Customers want a source for their transmissions. They don't want to be the controller of a process that they really don't understand.

"I do not think that metal and plastic are competitors. The two materials and their manufacture each solve unique problems in the generation of rotary motion. I know that my engineers find it very easy to talk with traditional gear engineers. We are all working on the same problems. I would love to have gear cutting as available to us as molded gears. I'd love to go to a potential client with both types of gears on the table. I think it would open us up to a whole new level of work."