Admire its Purity

As gear manufacturing techniques become more precise and demanding, there is a growing demand for cleaner, higher quality steel.

Alex Cannella, Associate Editor

Steel cleanliness is becoming increasingly important. Luckily, we can already do better.

Accuracy is tight these days. Minute imperfections of only a few microns at any step of the process can be the difference between a gear that functions for years and one that fails critically in testing.

That includes the very first step: acquiring materials. According to Buddy Damm, scientist for advanced steel solutions at TimkenSteel, nonmetallic inclusions just 10 microns in diameter — thinner than a hair — can be enough to eventually trigger a gear's failure if you're unlucky enough to get one right near the gear's surface, where stresses are highest. In the past, when demands haven't been as stringent, such minute imperfections weren't as noticeable and a steel's purity wasn't scrutinized too strictly. But that's all starting to change, and many steel suppliers are developing methods for producing cleaner steel.

That all starts by taking a hard look at some of the current standards we use to rate a steel's cleanliness, many of which are aging and leave a little bit to be desired. ASTM E45, for example, is a standard that has been giving guidance on inclusions in steel for decades. It is worth noting that ASTM E45 does see revisions every few years, including in 2018, but according to Damm, the standard is being outpaced by evolving metrology machinery today.

"It doesn't give you a lot of information and detail about the statistical nature of the inclusion content in the steel," Damm said. "And not only does it not give you any statistical details, it's not a very discriminating measuring technique anymore."

TimkenSteel isn't the only company going above and beyond what standards decree. Lily Kamjou, senior specialist, power trains, industry solutions development at Ovako, has run into similar issues, pointing to ISO 6336 as vague and not having kept up with modern manufacturing techniques. As demands on steel quality continue to rise, Kamjou has found that many jobs just demand more than what baseline standards and guidelines suggest.

"If you just ask for it according to the ISO standard, it's very likely that you won't get that performance level that you're counting on," Kamjou said. "It doesn't really match the material demands. That's something we run into quite a lot."

And if you don't get the material quality you're looking for, it can exacerbate already excrutiating lead times by forcing you to redo prototypes. But that's where Ovako comes in. One of their major selling points is the personal relationship the company tries to build with customers early in the prototyping process. By trying to get involved early, Ovako's experts not only have an

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opportunity to share their expertise beyond the basics of what official standards demand, but also can get their steel in the manufacturer's hands quickly enough to give them a chance to perform multiple prototyping trials.

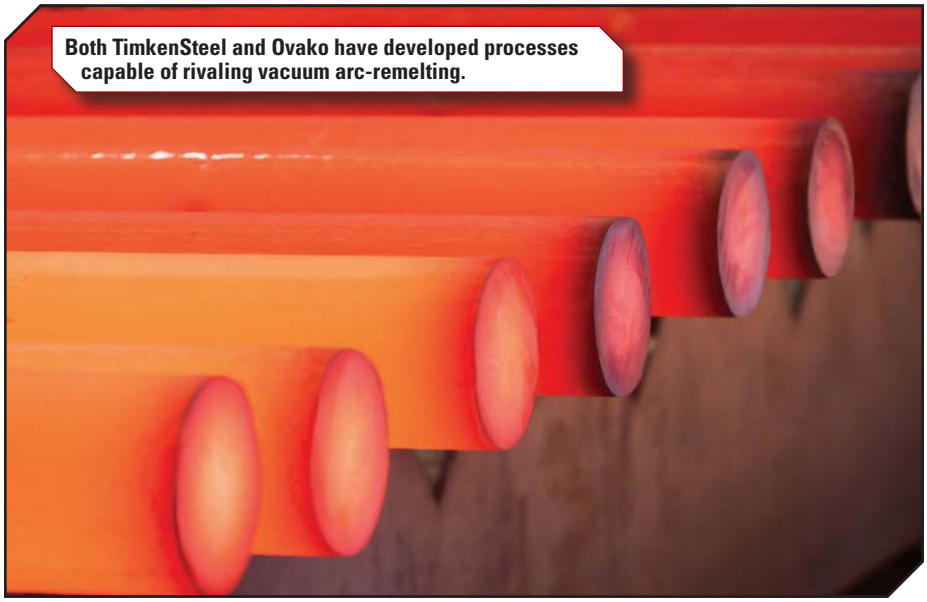
"If we can get involved at an early stage, we can make sure that we can supply the prototype material needed to do all the different testing," Kamjou said. "Which is from the end point of view, crucial because it can be such a waste of time waiting for prototypes for a year or longer than that. But also, making sure that the material performance level is what you're actually asking for. It's very easy to ask something in theory that looks good on paper, but the reality is very, very different from what we've learned over the years working with this industry."

Both TimkenSteel and Ovako have also been focused on improving the affordability of high-end, cutting edge steel. Ovako through the high-fatigue resistant IQ- and BQ-steel families and TimkenSteel through their new Ultrapremium advanced air-melted and vacuum-refined steel-making process that is the culmination of ten years of effort and study at the company.

"This is the steelmaking practice that we evolved over the past ten years," Damm said. "It's a combination of a lot of careful manufacturing processes when making the steel and then a lot of careful testing to verify the inclusion content and to provide our customers with a statistically relevant data set about the inclusion population in the steel. That's Ultrapremium. It's our top tier of clean steel practice."

Ultrapremium is impressive in that it already goes above and beyond even premium aircraft standards such as AMS 2300 and 2304, two of the most stringent standards around, for steel cleanness. But in addition, Ultrapremium can be done at a fraction of the cost and with better lead time than other methods of producing similarly clean steel such as vacuum arc re-melting (VAR).

Currently, vacuum arc-remelting is one primary way steel suppliers produce such clean steel. It's a lengthy and costly process that involves passing a high electric current through a solid steel electrode into a vacuum furnace. The steel electrode is slowly melted by the electric arc passing from the electrode tip to the newly forming liquid steel pool, which resolidifies in a water-cooled copper mold. This process continues slowly upwards incrementally, continuously melting the bottom until it's worked through the entire electrode. The whole process is time intensive and can only handle limited batch sizes, which means premium steels often get price tags to match their quality. According to Damm, you'll be paying three to five times more than average for vacuum melted steel.



Both TimkenSteel and Ovako have developed processes capable of rivaling vacuum arc-remelting.

The prime issue with these standards, and the primary reason TimkenSteel and Ovako compare themselves to vacuum arc-remelting, is that the current standards decree steel cleanness according to the process by which they were made, not the actual statistics of how pure they are. If you vacuum arc-remelt your steel, it gets a different rating than if you use a different process. This made a sort of roundabout sense during a time when vacuum arc-remelting was the only process capable of reaching a certain quality of cleanness, but now that companies like Ovako and TimkenSteel have developed competing processes that the standards don't account for, these processes are producing steel as clean or even cleaner than the strictest standards demand, but are still given a lower grade in the existing system.

But not only are processes like TimkenSteel's or Ovako's capable of competing with vacuum arc-remelting, they're also faster and can be produced in large-scale production quantities. Damm pointed out that TimkenSteel is capable of treating up to 240,000 pounds of steel in one heat using the Ultrapremium process. Faster and higher volume production gives TimkenSteel the ability to sell these high cleanness steels at a more affordable price.

So what do you get with all of this purified, high-grade steel? One primary advantage we've already touched on is improved endurance and reliability, but another major advantage is improved power density — sometimes even up to a 30% improvement. That means gears capable of handling 30% heavier loads or, conversely, being capable of handling the same load with a considerably smaller gearset.

In general, material suppliers are seeing power density as an increasingly important area to focus on. Numerous customers are looking to reduce the size of their products without compromising strength or durability. In particular, the aerospace and automotive racing fields are interested in improving power density for lightweighting purposes. Lighter planes and rockets require less fuel to propel themselves, and a lighter racing car obviously takes less effort to go faster. And starting with lightweight, premium materials that tout superior potential

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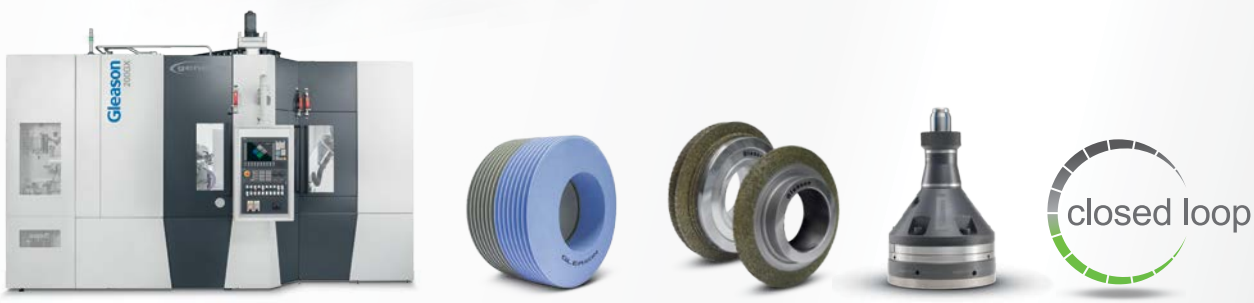

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power density is an easy, if perhaps more costly, way to improve that metric.

According to Elias Löthman, application engineer, industry solutions development at Ovako, that focus on lightweighting is one of the main reasons steel purity has come into the spotlight. Previously, the focus wasn't as important, as manufacturers could just upsize their gears to compensate for any deficiencies in the steel, but now that products are shrinking again, the easy option is less and less applicable, and now the pressure is shifting onto steel suppliers, as well.

"Before there hasn't really been issues because you've allowed yourself to make them big and bulky," Löthman said. "But now when the restrictions are getting more demanding and the space is getting smaller, then these things become issues."

"Steel hasn't really been important up until now because they can just make everything bigger or they could just throw after treatments at it," Kamjou added. "But now with increasing demands, it's putting pressure on steel, as well."

Steel purity isn't the only path to achieving improved power density. There's also the option of developing an alloy, as in the case of QuesTek Innovations' Ferrium line, a carburizable steel alloy which can deliver a 20% increase in power density. The Ferrium line is primarily designed to appeal to manufacturers looking to lightweight components.

"C64 is one of the highest-performance carburizable steels available today," Jeff Grabowski, manager of business development at QuesTek, said. "It's displacing some of these legacy alloys like X53 and 9310 that have been in use for many decades."

QuesTek's Ferrium lines provide high surface hardness, fatigue resistance, and perhaps most interestingly, high temperature resistance, one of the line's most unique and important selling points. Ferrium C61 and C64 are capable of maintaining their strength above 500 degrees Fahrenheit where legacy alloys would soften and fail.

"The high temperature stability of Ferrium C61 and C64 is due to the high tempering temperature and the stability of the main strenghtening phase, M2C carbides, at those temperatures," Grabowski said. "The strengthening carbides do not coarsen nor dissolve until about 50 degrees below the tempering temperature of 925-950 degrees Celsius."

And thanks to its high temperature resistance, Ferrium is also being tested for use in helicopter applications — specifically for oil-out performance.

Oil-out refers to conditions where a gear has to operate without any oil or other form of lubrication, most commonly because failure or damage has caused the oil to drain from the system. This rapidly becomes a problem for gears, as without lubrication, friction between the gears increases, and when friction increases, it produces a significant amount of heat. And when exposed to that heat, gears expand, causing the friction to worsen, and the situation continues to spiral until the gears tear themselves apart.

As we reported on almost two years ago, oil-out performance has become a renewed focus for some corners of the aerospace industry. The military, in particular, is interested in pushing a gear's endurance as far as possible, as in the event of damage in battle, aircraft may need to make it back to safety under these exact conditions, and with operational ranges extending as technology improves, they'll need as much time as possible to do so.

For some gears, the whole process can lead to a critical failure in as little as a minute. Previously, the upper limit of how long a gear could be expected to last had been 30 minutes. According to Grabowski, gears made with Ferrium have survived tests for 85. And considering heat is the primary driver of gear failure in an oil-out situation, it's no surprise that QuesTek's Ferrium line is appearing in these tests, or that it's performing so well.

QuesTek's Ferrium line is also being tested for use in additive manufacturing, which has the potential to finally provide a strong enough material to make 3D printed gears viable.

"We're taking one of our Ferrium steels — Ferrium C64 — and we've atomized it and we've done prints," Grabowski said. "And we're showing good static properties, strength and toughness and elongation, and we're just now in the next six months going to be looking at fatigue performance of additive gears."

One last innovation on this front comes from TimkenSteel's *Endurance* steels, which includes a trio of patent-pending steel grades that Damm claims can improve a gearset's power density by 20–30%. They were named American Metal Market's Best Product Innovation of the Year in 2018 and boast an excessively high degree of strength and toughness, with a yield strength ranging from 180 to 210 KSI and toughness going from 35 to over 60 ft.-lbs. And if that's not enough, it's also possible to apply TimkenSteel's Ultrapremium process to an *Endurance* steel for even further improvements to power density. These new steels offer a 25% to 40% increase in both strength and toughness over conventional gear steels like 8620, 4320 and similar.

"Both of these techniques, the Ultrapremium very clean steel or the *Endurance* high-strength, high-toughness steels offer real opportunities by themselves for improved power density," Damm said. "And by combining the two of them, you would get further incremental improvement."

No doubt, incremental improvement will continue to be the name of the game in the future, both for manufacturers looking for improved power density and for steel suppliers looking for newer and better products to offer. But right now, there isn't much incremental about a 30% jump — an entire step change — in power density. If you're looking for ways to shrink your own products down or have them handle heavier loads, consider looking at your materials. You might just find an opportunity for improvement.

For more information:

Ovako
+46 8-622-1300
www.ovako.com

QuesTek Innovations LLC
(847) 328-5800
www.questek.com

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(330) 471-6832
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