Cleaner Steels Provide Gear Design Opportunities

Randy Stott, Managing Editor

Gear designers face constant pressure to increase power density in their drivetrains. In the automotive industry, for example, typical engine torque has increased significantly over the last several decades. Meanwhile, the demands for greater fuel efficiency mean designers must accommodate these increased loads in a smaller, more lightweight package than ever before. In addition, electric and hybrid vehicles will feature fewer gears, with fewer transmission speeds, running at higher rpms, meaning the gears in those systems will have to endure life cycles far beyond what is typical with internal combustion engines.

All of this puts a lot of stress on the materials used to make the gears, and conventional gear steels will not be able to accommodate these increased demands.

Fortunately, there is a readily available solution, according to Erik Claesson, Director, Head of Industry Solutions Development for Ovako AB. That solution is cleaner gear steel, which has smaller inclusions, and which may also be produced to yield isotropic properties so that the material provides equal strength in all directions.

What Is Clean Gear Steel?

At its heart, cleaner gear steel means smaller inclusions. Inclusions are hard, nonmetallic flaws in the material that result from oxidation during the manufacturing process. They are the primary cause of fatigue failure in steels. Traditionally, reducing the inclusions in steel to low amounts and sizes required very expensive secondary operations at the mill, such as vacuum arc remelting, electroslag remelting, vacuum induction melting or some combination of those techniques, and many aerospace, medical, military and nuclear applications specify that their steels must be made using these processes. But because of those extra steps, along with the vacuum process required, those steels come with an extremely high price tag.

However, the air melting techniques, along with the secondary metallurgy, casting and reduction processes used by Ovako are all tightly controlled, says Patrik Ölund, Head of Group R&D at Ovako. This allows Ovako's BQ (bearing quality) and IQ (isotropic quality) steels to offer fatigue performance much higher than conventional steels made via air melting processes, and even offering performance comparable to some of those made with more complicated or expensive processes.

Step one is controlling the starting material, Ölund says. Ovako steel is made from recycled material, so selection of the scrap used for melting is extremely important. The scrap is carefully selected towards batches with minimized amounts of residuals.

Also, careful control of the melting process is extremely

Steel melt at the Ovako facility in Hofors, Sweden.

important, as are the secondary metallurgy processes, where de-sulphurization and de-oxidation are controlled. Ovako casts the steel into large ingots, and the tops and bottoms of those ingots are cropped off, because that's where the greatest risk of inclusions is found. Finally, a carefully controlled rolling process helps to reduce any inclusions down to smaller and less harmful features, Ölund says.

In fact, Ovako's ability to control the inclusions has made the company's BQ and IQ steels a viable, economical alternative for those wanting more performance out of their gear steels.

Unfortunately, standards such as ISO 6336-5, which covers the strength and durability of gear materials, don't include definitions for steels such as Ovako's BQ and IQ steels. So, Ovako has done extensive testing to determine the bending fatigue limits and contact/surface fatigue limits of its steels in comparison with standard grades. The tests included extensive rotating bending fatigue tests, as well as pitting failure tests using the FZG method. Also, Claesson says, the values in Figures 3–4 are "at least" values, meaning that the bending and contact fatigue values are the minimum provided by the BQ and IQ steels.

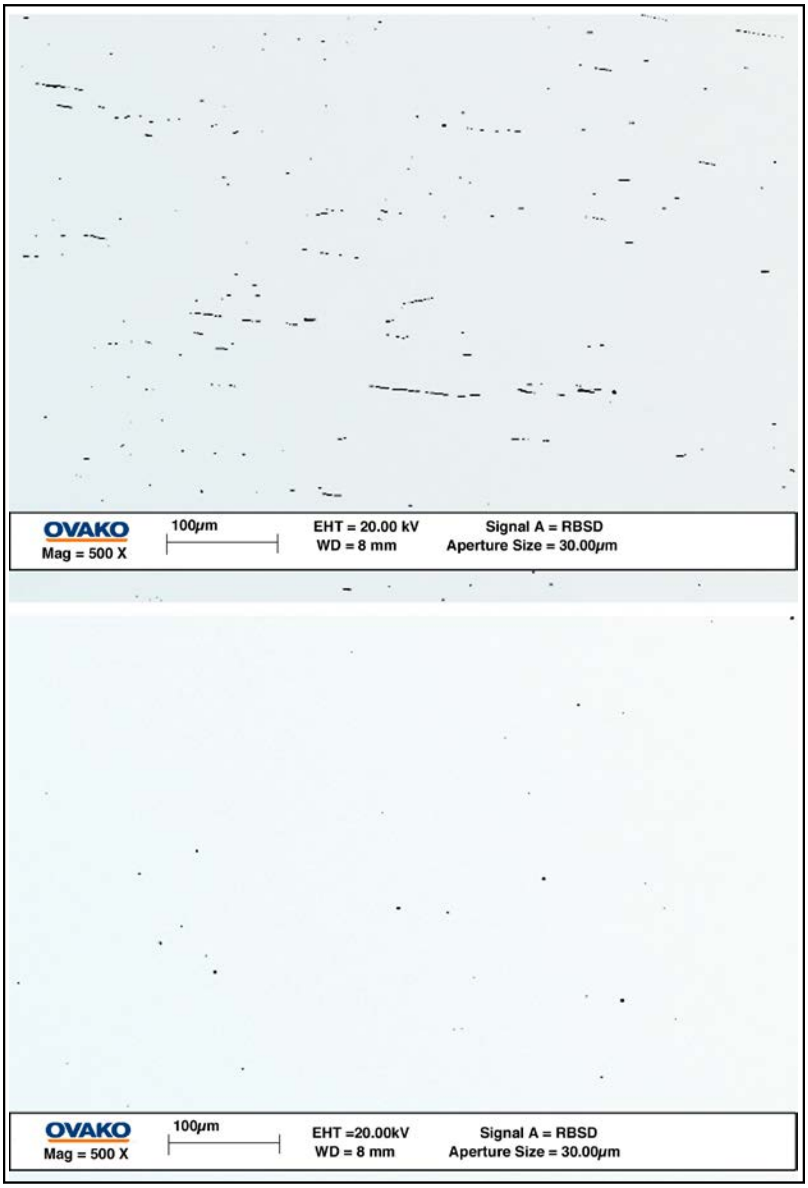

Figure 1 **Comparison of the inclusions found in standard steel (top) and Ovako's BQ steel (bottom).**

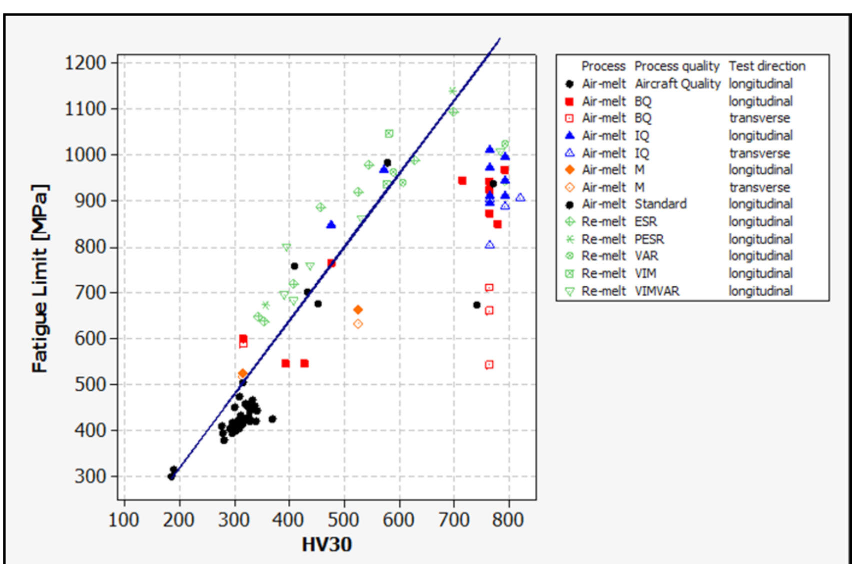

Figure 2 **Fatigue limits for Ovako's BQ and IQ steels, in comparison with steels made by other methods.**

According to Claesson, most gear designers use the MQ values. However, the much higher values of σ_{Flim} (bending fatigue limit) and σ_{Hlim} (contact fatigue limit) offered by the BQ and IQ steels give gear designers a lot more flexibility with their designs.

Increased Design Opportunities

Gear designers looking to increase power density in their designs have a number of options, Claesson says. Ovako proposes three different levels of change that cleaner steels offer. They call it their "20-50-100" concept:

20 level — upgrading the material while maintaining an existing design or making only minor design changes, such as modifying gear tooth geometry to take advantage of enhanced bending fatigue strength of the new material while reducing contact pressure on the gear flank.

50 level — combining the use of cleaner gear steel with significant internal design changes, allowing designers to reduce component size, add components or otherwise modify the system without changing the overall size.

100 level — designing the complete system from the ground up to take maximum advantage of all the benefits cleaner gear steel can offer. "Basically, you get a smaller, stronger gearbox," Claesson says.

In the most basic example, changing the material for an existing component to a cleaner steel of the same grade allows the designer to provide increased life or greater torque in the same package, without undergoing extensive modifications to the manufacturing process.

For example, a manufacturer of an automotive final drive unit might consider just upgrading the material in the pinion. This is often a very cost-effective modification, Claesson says, because it can significantly increase the performance of the transmission without the costs of redesigning the whole system or any of its components. In other words, it's an economical way to extend the lifetime of the transmission, or to expand the options available to include a higher performance model.

The need for increased fatigue resistance will definitely come into play for engineers working on transmissions for hybrid electric or straight electric vehicle drivetrains, Claesson says. The higher rpms and fewer gears mean that each individual gear will have to endure significantly higher load cycles than the gears in a transmission coupled to an internal combustion engine.

What Does it Cost?

BQ and IQ steels definitely cost more than standard quality steels, Claesson says. But it's important to consider that the increased performance they provide might allow manufacturers to eliminate some secondary machining operations such as shot peening. Shot peening is typically done to improve the fatigue resistance of gears. But if the base material has significantly better fatigue resistance because of the cleanliness of the steel, then shot peening might be reduced or even eliminated. In fact, Claesson says, some manufacturers have even seen a decrease in overall costs while still significantly improving the performance of their transmissions.

For more information:
Ovako North America Inc.
1096 Assembly Drive
Fort Mill, SC 29708
www.ovako.com

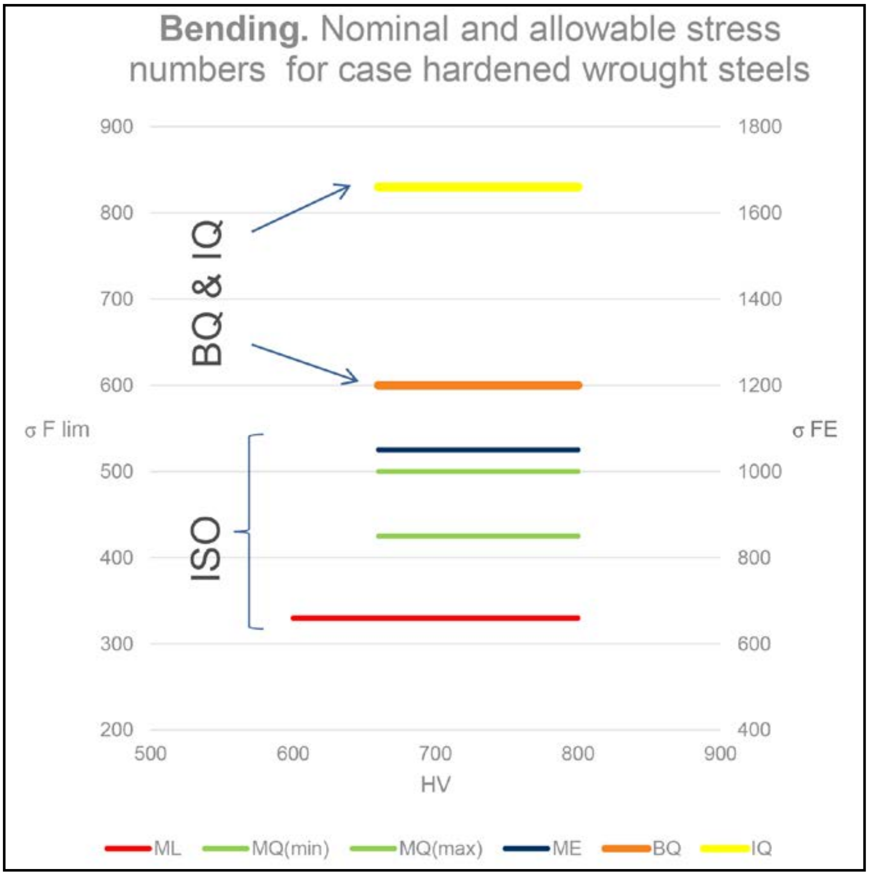

Figure 3 Bending fatigue limits for BQ and IQ steels are not represented in standards such as ISO 6336-5.

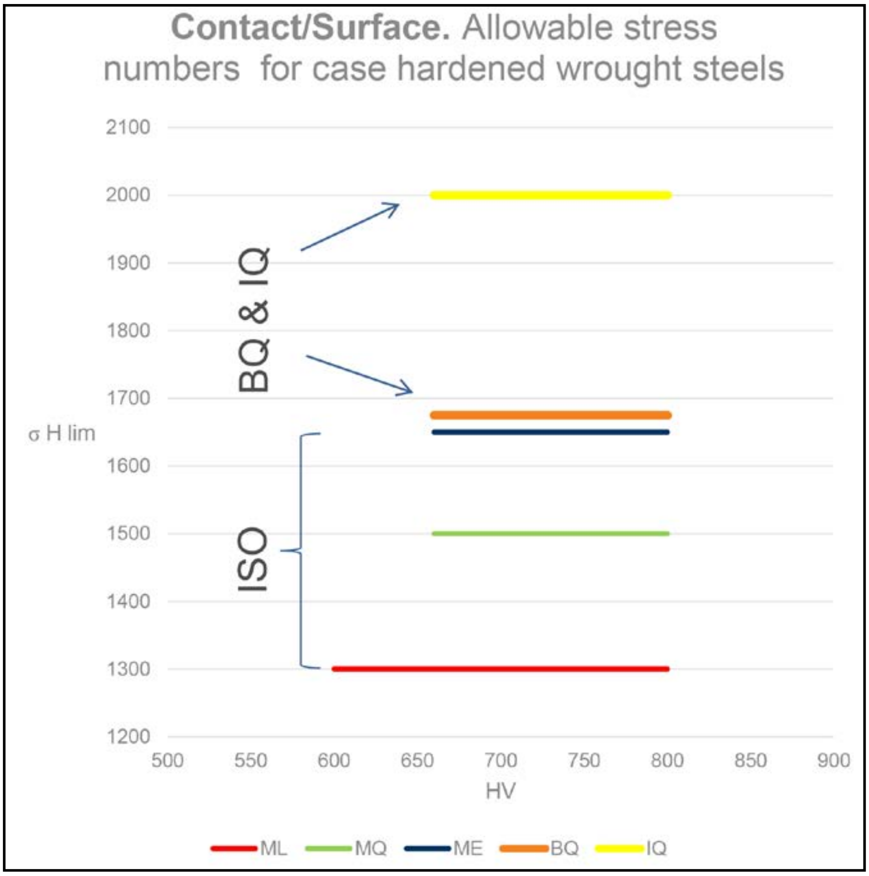

Figure 4 Contact fatigue limits for BQ and IQ steels exceed those of the standard grades represented in standards such as ISO 6336-5.