Hybrid Steel Enhances Component Performance at Reduced Weight

Ovako is presenting a hybrid steel with more than twice the yield and tensile strength of conventional steel when operating at temperatures up to 500 °C. The steel opens up new design possibilities for high-performance components with reduced weight and lower production costs.

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Bridging Steel Categories

Highly stressed components, such as those used in engines, bearings and machine tools demand materials that offer high levels of mechanical and fatigue strength, especially when operating at elevated temperatures. The traditional approach to producing steels for these components is an expensive small-batch process. But now there is an alternative in the form of hybrid steel, Figure 1, that

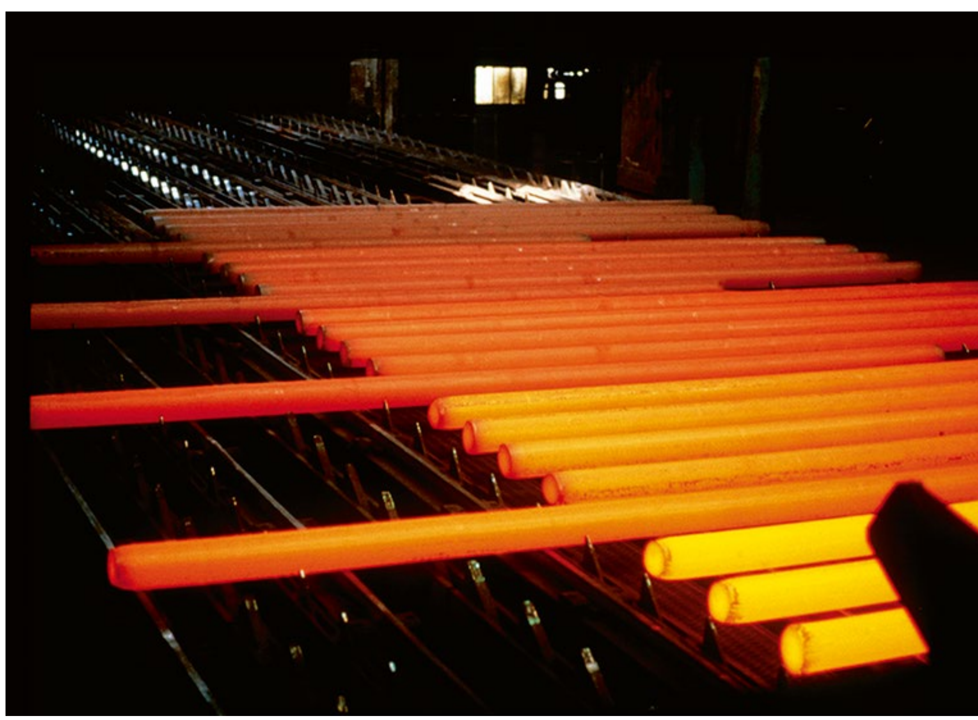

FIGURE 1 Hybrid steel on the cooling bed (© Ovako)

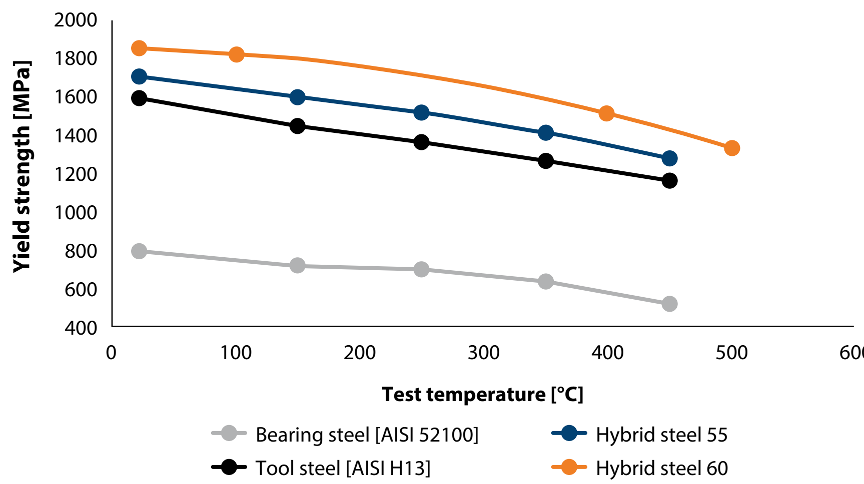

FIGURE 2 Hybrid steel offers high strength at high temperatures (© Ovako)

offers the same performance while being suitable for more cost-effective high volume steel-making processes.

Hybrid steel has been developed to bridge the gaps between the previously well separated categories of tool steel, maraging steel, stainless steel and lower alloy engineering steels. It offers attractive properties from all four categories with superior mechanical and fatigue strength to conventional steels, especially at high temperatures. Most importantly, hybrid steel has more than twice the yield and tensile strength of conventional steel when used at temperatures up to 500 °C, Figure 2.

In addition to this behavior at elevated temperatures, hybrid steel also offers properties that enable new lightweight, high-performance products across many applications.

Combination of Hardening Mechanisms

It is the hybrid combination of secondary carbide hardening and intermetallic precipitation hardening mechanisms that has resulted in the development of hybrid steel. Secondary carbide hardening results from the formation of small carbide particles which make the steel more resistant to deformation, and is usually associated with tool steel production. Precipitation hardening involves different intermetallic precipitation phases which increase the steel's strength, and is normally used for maraging steel production. Hybrid steel is the most successful attempt to date to bring these two mechanisms together. It can be produced by normal air-melt processes, which enables large volume capabilities and cost-efficiency.

In addition to its exceptional properties in end-use applications, there is the potential for the new steel to offer a reduction in the number of processing stages to take the steel from blank to finished component.

The main benefit during production is the way that the steel develops its full hardness only after aging. That means a component can be hardened without any significant distortion. Ultimately, this could enable a simplification of the manufacturing process with a reduced number of stages required, resulting in reduced production costs.

Creating welded steel components is often a challenge for designers as the welding process can result in a significant loss in the steel's mechanical properties. With hybrid steel it is now possible to manufacture welded components that can then be aged at moderate temperatures to achieve their full strength, far beyond what most steels can achieve, with homogenous properties across the welded joint.

Segregation

In elevated temperature applications, conventional engineering steel lacks the necessary mechanical and fatigue strength and oxidation resistance. In which case a designer would normally specify a highly alloyed secondary hardening steel – these types of steel are strengthened during the aging process, which causes the precipitation of fine alloy carbides. There is however a potential problem created by the so-called segregation. This is where some alloying elements migrate to areas where they cause weakness. Preventing segregation requires very precise control of the steel-making process. That is why secondary hardening steels are generally more expensive than conventional steels. Figure 3 illustrates why segregation is a challenge for secondary hardening steels.

Secondary and Intermetallic Precipitation Hardening

The aim in developing hybrid steel was to find a steel that could deliver the required performance as well as being capable of cost-effective high volume production. Following a long development program it was determined that the optimum route was to utilize a hybrid approach that combines two different, but complementary hardening mechanisms – secondary hardening and intermetallic precipitation hardening.

The development process involved the evaluation of segregation in 20 different test

> Different hardening mechanisms were combined for the development.

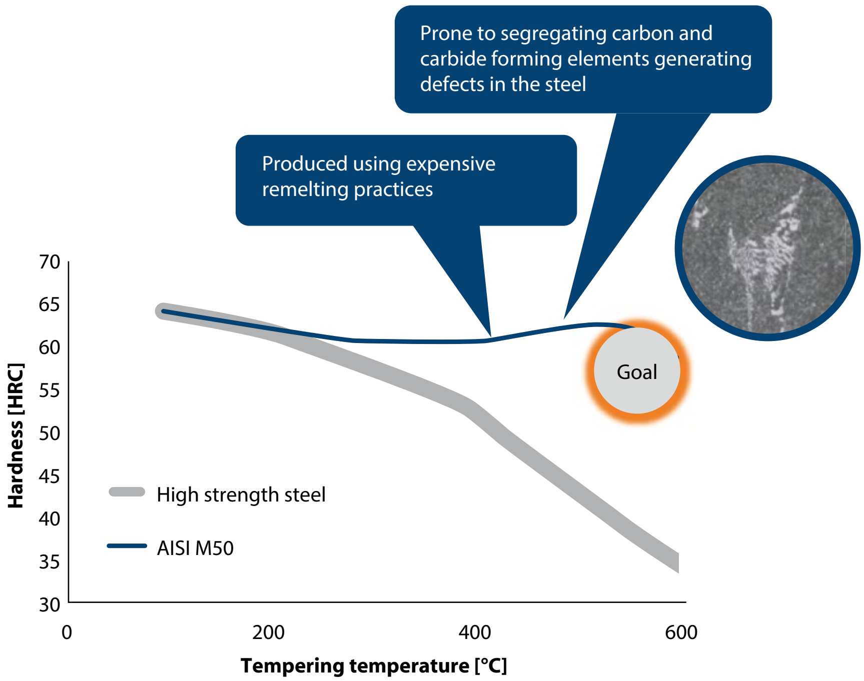

FIGURE 3 Segregation is a risk for highly alloyed secondary hardening steels, such as AISI M50 (© Ovako)

melts. Analysis by a Scanning Electron Microscope (SEM) was then carried out to measure the variations in chemical composition that are markers for segregation.

For minimized segregation of a secondary hardening steel, the test results showed that it was vital to limit the levels of carbon, molybdenum and vanadium. Consequently, secondary hardening did not provide the required strength if the alloying content was limited by the maximum segregation criteria. The aim was to achieve a Rockwell hardness of 55 HRC after aging at 550 °C, however the actual value was 42 to 43 HRC. Success was achieved by introducing nickel and aluminum into the new steel to boost its strength – as shown in Figure 4.

The test program resulted in the creation of the new hybrid steel. It contains carefully controlled alloying elements such as chromium, molybdenum, vanadium, nickel and aluminum while being low in carbon, Table 1.

A combination of carbon in solution together with secondary carbides and nickel-aluminum (NiAl) precipitates result in the hybrid steel reaching its full properties after tempering at a temperature between 500 to 600 °C, Figure 5.

Atom probe tomography carried out by the Chalmers University of Technology showed that the average size of the NiAl particles was 5 nm. Therefore just 1 mm³ of hybrid steel contains around 500,000 of these particles. The hybrid steel program was successful in achieving its two key objectives:

- Production is made possible by a normal high-volume steel production route with a low segregation of elements.
- The steel exhibits an enhanced strength at elevated temperatures that is comparable to secondary hardening tool steels.

Nitriding Capability

In addition to its material properties, hybrid steel is particularly suitable for nitriding, which can be carried out at the same temperature as aging. This process creates a thin nitrided surface layer with the strong, hard-wearing properties required by critical components, while maintaining a high core hardness. This maintained core hardness in hybrid steel is important, as a nitriding process performed on conventional steels at elevated temperatures often reduces the underlying strength of the steel. That is why nitriding is not currently applied in a number of load bearing applications where it could potentially be of great benefit.

Hybrid steel enables nitriding for use across many applications by achieving a high surface hardness together with an attractive level of residual compressive stress. Figure 6 shows the result of plasma nitriding hybrid steel 55 at 520 °C for 20 h. A high surface hardness of 1200 HV1 (Vickers) is achieved while the core remains at 600 HV1.

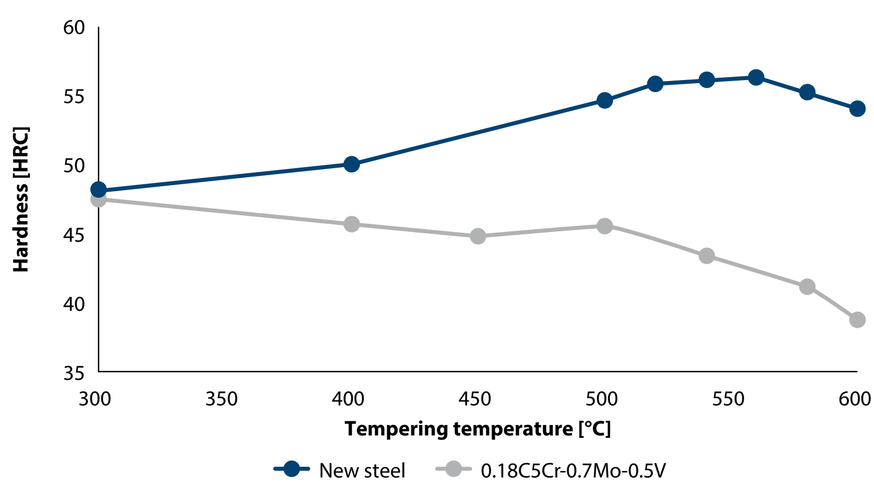

FIGURE 4 The strength of hybrid steel is boosted by the addition of nickel and aluminum (© Ovako)

TABLE 1 Alloying elements used in the formulation of hybrid steel (© Ovako)

Chemical composition [%]									
–	–	C	Si	Mn	Cr	Ni	Mo	V	Al
Hybrid steel 55	Engineering steel	0.18	0.1	0.3	5	6	0.7	0.5	2
Hybrid steel 65	Bearing steel	0.28							

Stainless Steel-like Corrosion Performance

The presence of chromium and aluminum, along with the other alloying elements, provides an added advantage for hybrid steel in terms of its enhanced corrosion resistance. The preliminary corrosion testing, as shown in Figure 7, indicates that hybrid steel can perform at around the same level as high carbon martensitic stainless steels.

It should be noted however, that the chromium content of hybrid steel could also be increased to achieve even higher levels of "stainless performance." This remains to be explored, but would enable welded stainless ultra-high strength steels, which should in theory enable many new weight-saving applications across a larger range of applications.

> Hybrid steel yields a high surface hardness together with an attractive level of residual compressive stress.

Advantages for Component Manufacturing

Hybrid steel was introduced in September 2017. However, its potential applications had already been under discussion with component manufacturers for some time before then. These preliminary discussions have indicated that hybrid steel might be applied across a wide variety of potential highly stressed applications such as engine components, bearings, gears, fuel injection components, mining tools and machine tools.

Diesel Injectors

Hybrid steel looks set to help the automotive industry meet its ambition to further improve diesel combustion. This requires a steel that can withstand even higher pressures at more elevated temperatures. Compared to conventional steels, hybrid steel demonstrates more than twice the strength at high temperatures. The steel is currently being tested against such requirements.

Lighter Engines

Hybrid steel could enable the development of lighter engines with lower material usage due to more compact designs and smaller pistons. This approach will enable both lower emissions and lower total costs. It is made possible by hybrid steel's high strength at elevated temperatures and high corrosion resistance. Tests are currently ongoing to evaluate how hybrid steel can improve engine performance.

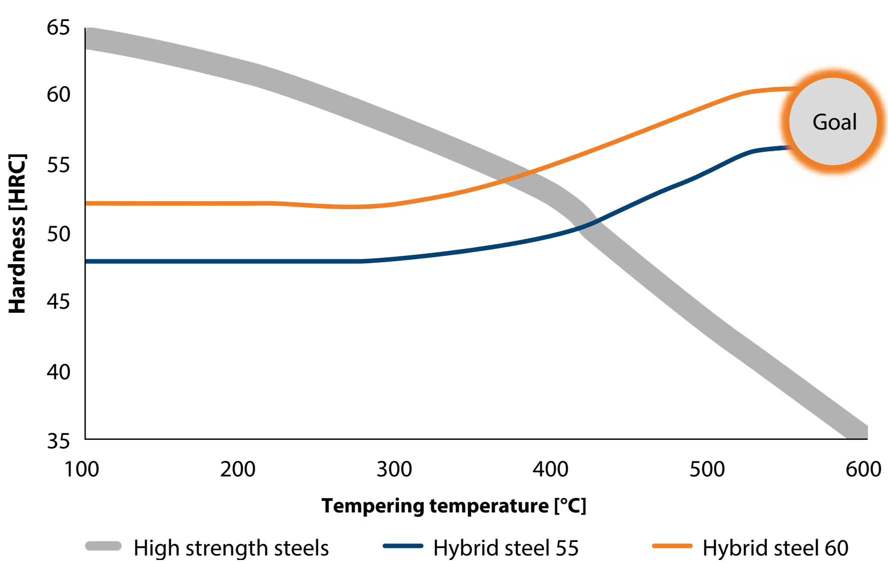

FIGURE 5 Hybrid steel increases in strength during tempering (© Ovako)

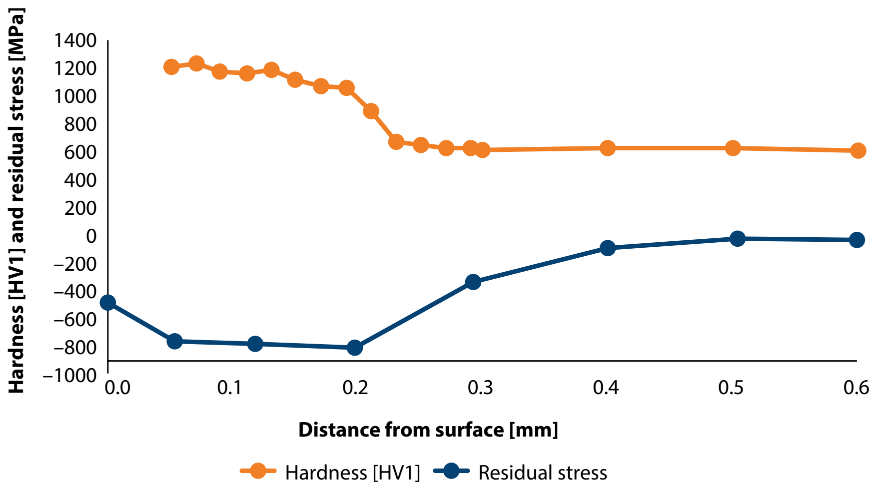

FIGURE 6 Plasma nitriding of hybrid steel shows that it maintains its core hardness (© Ovako)

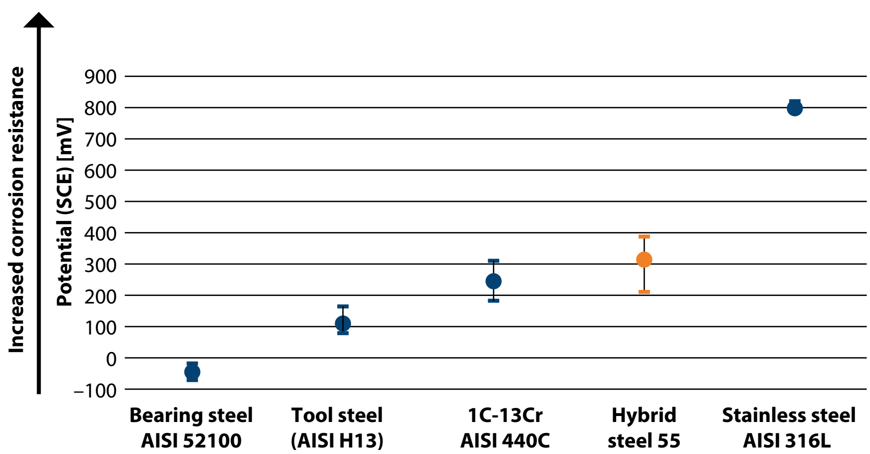

FIGURE 7 ISO 15158 corrosion of metals and alloys at 10 mV/min and 0.01 NaCl: Hybrid steel can approach lower end stainless steels for corrosion resistance (© Ovako)

Cost-effective Engine Pistons

The production advantages of hybrid steel are shown clearly in the manufacture of steel engine pistons, with the aim of achieving increased strength at high temperatures to meet the performance goals of modern engines. A traditional production route in five steps can look like this:

1. Forging
2. Soft annealing
3. Rough machining
4. Quenching and tempering
5. Hard machining.

Using hybrid steel offers the potential for a three-step route:

1. Forging
2. Hard (45 HRC) machining
3. Aging.

This approach will reduce manufacturing cost and complexity as well as producing a component with superior performance. In addition, the hybrid steel can be welded to create a final product that maintains its full strength.

> The steel is suitable, for example, for engine components or transmissions.

Why Has Hybrid Steel Only Been Developed Now?

The individual hardening mechanisms that have come together in hybrid steel have been well understood for many years. The question arose why this type of steel has not been introduced before. The reason is that the successful execution of hybrid steel requires a high level of expertise in steel metallurgy. Ovako has a particular advantage in this area with a business focused on volume manufacturing of steel to very closely controlled production parameters, such as bearing quality steels. In fact, in addition to its special hardening properties, hybrid steel is one of the cleanest steels ever produced by Ovako with a combined level of oxygen, sulphur and nitrogen of less than 20 parts per million (ppm).

Summary

Adopting hybrid steel can enable designers of critical components to achieve enhanced performance in terms of mechanical and fatigue strength, especially at elevated temperatures. This translates directly to a new capability to downsize components to reduce their weight, which could offer significant possibilities in terms of improved energy efficiency for vehicles. Furthermore, hybrid steel can also enable manufacturing processes to be optimized with a reduced number of processing stages.

Hybrid steel is not just one steel grade. Rather, it is a family of steels from which new grades will emerge over time to suit specific customer applications. The introduction of hybrid steel promises to drive the development of lightweight steel components for years to come.