REIMAGINE.
RETHINK. REDESIGN.
INTRODUCING HYBRID STEEL®
What is Hybrid Steel?

Hybrid Steel features beneficial properties normally found in other specialty steels, bridging performance gaps and creating a whole new category of steel.

“This steel combines two strengthening mechanisms... and the properties are very good. In particular, the material maintains these properties at elevated temperatures. The preliminary investigation shows that it has very good corrosion properties, and it contains fewer expensive alloying elements.”

John Ågren, Professor in Physical Metallurgy, KTH
Creating a new steel category
A few years ago, we set out on a mission to find and test alternative steel hardening mechanisms. Our aim? To meet the demands of high-stress, elevated-temperature applications where mechanical and fatigue strength are critical – without the need for expensive small-batch processes.

Hybrid Steel is here
Now, we are thrilled to announce that this new steel category is finally here. We named it Hybrid Steel® – a new range of steel grades that combines the properties of maraging steel, stainless steel, tool steel and lower alloy engineering steel. By bridging longstanding performance gaps in ways few thought possible, Hybrid Steel opens up completely new opportunities in performance gains, cost savings and the elimination of processing steps. It’s a remarkable breakthrough, enabled by the first successful combination of secondary carbide hardening and precipitation hardening.

Two groundbreaking steel grades
Hybrid Steel 55 and Hybrid Steel 60 are the first two commercially available grades in the growing Hybrid Steel range. The former is designed to 55 HRC hardness, which provides an array of engineering steel capabilities. The latter is designed to 60 HRC hardness and is an equally unique grade of bearing steel for applications where added strength is needed. Both are produced with the help of large-scale, automated ingot cast processes. And both are already in the hands of customers, testing teams and research institutes worldwide.

What can Hybrid Steel do for you?
True to its name, Hybrid Steel can mean many things to many people. By combining high strength at elevated temperatures with good weldability, high hardenability, low segregation and excellent surface treatment possibilities, it offers the best of many worlds. Which is why we’ve compiled this guide to Hybrid Steel to highlight eight key properties, as verified by the outcomes of our most recent validated tests.
1. High strength especially at elevated temperatures

2. High-volume, cost-efficient production

3. High hardenability enabling low distortion

4. High cleanness and fatigue strength at elevated temperatures

5. Uniform properties with low microstructural segregation

6. Ultra-high strength with good weldability

7. Excellent surface treatment possibilities

8. Good corrosion resistance
Discover an unprecedented combination of steel properties

Imagine a steel that develops its full hardness at tempering temperatures. One that can be machined in a soft condition and then hardened with very little distortion. A steel that enhances its strength following post-welding heat treatment. Hybrid Steel combines all these possibilities and more in a single innovative material.

The advantages of Hybrid Steel go far beyond its strength. Because the steel develops its hardness at tempering temperatures, it’s now possible to machine components in a softer condition closer to their finished form. Similarly, it is well suited for welding, since a post-welding heat treatment will actually enhance strength. It also offers a range of advantages for nitriding, polishing and much more.

Even at a glance, it’s clear that no material property is sufficient to define the expanded possibilities of Hybrid Steel. So we’ve broken them down into the eight key properties that our tests have proven to be the major performance breakthroughs so far. This research is ongoing, and we expect to identify many more material benefits and processing advantages.

Eight amazing properties of Hybrid Steel

1. High strength especially at elevated temperatures
2. High-volume, cost-efficient production
3. High hardenability enabling low distortion
4. High cleaness and fatigue strength at elevated temperatures
5. Uniform properties with low microstructural segregation
6. Ultra-high strength with good weldability
7. Excellent surface treatment possibilities
8. Good corrosion resistance
1. High strength especially at elevated temperatures

Of all the benefits of Hybrid Steel, its excellent strength at high temperatures is where it truly excels. This breakthrough creates new opportunities for manufacturers in need of a high-strength steel at elevated temperatures.

The original goal behind the development of Hybrid Steel was to create a steel grade that could successfully maintain its strength at high temperatures. For diesel injectors, this might mean conditions of around 250°C and 3,000 bar pressures. For turbocharger components, the temperatures can be even higher.

As seen in the first figure to the right, independent tests show that Hybrid Steel maintains remarkable levels of strength even when subjected to these high-temperature conditions.

In the second figure, the effect of adding nickel (Ni) and aluminum (Al) to allow for intermetallic precipitation is illustrated. No other steel on the market today offers comparable performance properties with the same cost-effective production methods.

2. High-volume production

The large-batch ingot casting process behind Hybrid Steel creates attractive economies of scale for steel component manufacturers who are accustomed to small-batch, expensive tool steels and maraging steels. This makes it an excellent alternative to electroslag remelting (ESR), vacuum induction melting (VIM) + vacuum arc remelting (VAR) and other high-cost, high-strength steel processing routes.

To achieve their beneficial properties, remelted steels must undergo a lengthy small-batch process. Each of these processing steps adds significantly to the final material cost.

By contrast, one ingot-cast melt produces one hundred tonnes of Hybrid Steel. This is a batch size ranging from ten to one hundred times larger than a typical batch of remelted tool steel, produced with just half the processing steps.

The result is a top-performance steel with low production costs, making it ideally suited to cost-effective manufacturing of advanced components in highly demanding applications.

Simplified Production Process

When compared with other high-performing steels, the steel making process for Hybrid Steel is radically simplified due to large-scale ingot casting. Hybrid Steel also makes it possible to limit costly downstream production processes such as heat treatment, forced cooling, machining and grinding, and enables welded high-strength components and repair-welding.
3. High hardenability enabling low distortion

Laboratory tests show that Hybrid Steel experiences minimal distortion during hardening, aging, nitriding and other processes at elevated temperatures. Depending on the components being manufactured, this means you can significantly reduce later processing steps and grinding allowances.

Hybrid Steel’s high hardenability and robust microstructure contribute to low distortion in various heat treatment processes. Low distortion after aging enables soft machining close to final product dimensions.

As a result, component manufacturers can significantly reduce or eliminate variables such as grinding allowances, leading to substantial reductions in overall manufacturing costs.

In the manufacturing chain, Hybrid Steel makes it possible to limit or eliminate a range of costly production processes.

In bearing production, grinding alone represents some 30% of total production costs. Thanks to Hybrid Steel’s low distortion after heat treatment, this cost can be vastly reduced.

4. High cleanness and fatigue strength at elevated temperatures

Because Hybrid Steel has low levels of unwanted inclusion elements, it is considered a clean steel with a fatigue strength similar to conventional bearing steels. At temperatures of 250°C or above, however, it has a higher fatigue strength than the other benchmarks tested.

At ambient temperatures, Hybrid Steel offers superior mechanical fatigue strength compared to conventional steels. However, it is at elevated temperatures that the steel truly excels. At temperatures of 250°C, the fatigue strength of Hybrid Steel decreases by just 8% vs room temperature, compared to 22% for conventional bearing steels.

The cleanness of Hybrid Steel can be seen in the low levels of inclusion elements such as oxygen (O), sulphur (S) and nitrogen (N). At just 19 ppm for Hybrid Steel 60, it is in fact the lowest value for these elements ever produced in a steel at our mill in Hofors.

Initial rotating bending fatigue tests show that one direct result is a high level of fatigue strength – up to 730 MPa – at temperatures of 250°C.

By further reducing inclusion sizes in future melts, we believe it is possible to enhance Hybrid Steel’s fatigue strength even at lower temperatures to achieve the same levels as the other bearing steels tested.

At 250°C, Hybrid Steel maintains its fatigue strength even at 250°C.

### CHEMICAL COMPOSITION OF HYBRID STEEL, % BY WEIGHT

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>Si</th>
<th>Mn</th>
<th>Cr</th>
<th>Ni</th>
<th>Mo</th>
<th>V</th>
<th>Al</th>
<th>O*</th>
<th>N*</th>
<th>(S+O+N)*</th>
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</thead>
<tbody>
<tr>
<td>Hybrid Steel 50</td>
<td>0.2</td>
<td>0.2</td>
<td>0.9</td>
<td>5.1</td>
<td>6.1</td>
<td>0.7</td>
<td>2.6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>40 ppm</td>
</tr>
<tr>
<td>Hybrid Steel 60</td>
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<td>0.3</td>
<td>0.3</td>
<td>5.6</td>
<td>5.6</td>
<td>0.7</td>
<td>2.6</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>13 ppm</td>
</tr>
</tbody>
</table>

= Lowest value ever produced in our steel plant in Hofors

* ppm
The low carbon content of Hybrid Steel provides yet another promising advantage for manufacturers: A truly weldable ultra-high-strength steel. With welding tests still in their early stages, Ovako has been able to confirm that welded joints maintain the same high-strength properties as raw, untreated Hybrid Steel.

In terms of performance, this means that Hybrid Steel provides all the same high-strength benefits as tool steel and maraging steel, but without the costly compromises. Hybrid steel requires no expensive remelt process to achieve low segregation. It also contains fewer expensive alloying elements, e.g. titanium (Ti) and cobalt (Co), compared to levels found commonly in maraging steels.

5. Uniform properties with low microstructural segregation

Our effort to create a strong high-temperature steel started with achieving the lowest possible segregation of elements. An extremely close look at the microstructure of Hybrid Steel reveals the secret behind its success.

The strength of Hybrid Steel depends on a uniform distribution of very small precipitated compounds. These intermetallic particles and secondary carbides are so small, in fact, that a volume of just 1 μm³ of Hybrid Steel contains more than 500,000 particles.

In terms of performance, this means that Hybrid Steel provides all the same high-strength benefits as tool steel and maraging steel, but without the costly compromises.

6. Ultra-high strength with good weldability

Until now, high-strength steels have been nearly impossible to weld due to their high carbon content, which makes them sensitive to cracking. Hybrid Steel makes it possible for the first time to weld together ultra-high-strength tubes and bars and explore new opportunities for additive manufacturing and other advanced applications. It also opens up new degrees of design freedom for component designers.

The low carbon content of Hybrid Steel provides yet another promising advantage for manufacturers: A truly weldable ultra-high-strength steel.

With welding tests still in their early stages, Ovako has been able to confirm that welded joints maintain the same high-strength properties as raw, untreated Hybrid Steel.

Ongoing tests are now being performed to expand on our initial findings, which suggest a wide range of breakthrough applications that were previously impossible with traditional high-strength steels.
7. Excellent surface treatment possibilities

Hybrid Steel makes it possible to eliminate today’s compromises between surface and core hardness. The material’s hybrid hardening and alloying composition allow for treatments at elevated temperatures with maintained core hardness. This makes the steel highly suitable for processes such as nitriding.

Thanks to its high content of aluminum (Al) and chromium (Cr), which are strong nitride-forming elements, Hybrid Steel is particularly well suited for nitriding. The ability to achieve high surface hardness and beneficial residual compressive stresses, with maintained or even strengthened core hardness, makes it possible to reduce both case depth and nitriding process time.

Additional coating treatments can also be applied with maintained strength. In collaboration with Applied Nano Surfaces, a company specializing in wear and friction reduction, testing is now underway on an innovative Tribonite coating, which is applied on a nitrided surface to reduce friction and wear. Hybrid Steel is ideally suited to such applications due to its ability to maintain or even increase strength at the elevated temperatures typically used in these processes.

8. Good corrosion resistance

Compared to common engineering steels, Hybrid Steel shows much higher levels of corrosion resistance. Preliminary rankings reveal a corrosion resistance far higher than bearing steel, and even slightly higher than AISI 440C stainless steel.

For demanding applications in corrosive environments, Hybrid Steel offers a hugely favorable alternative to common engineering steels. As seen to the right, it not only outperforms bearing steels, tool steels and martensitic stainless steels in corrosion tests—it also can be left outdoors for more than a year with little to no resulting surface corrosion.

Future developments of the Hybrid Steel family should allow for even better corrosion resistance. Thanks to a higher chromium (Cr) content than engineering steel, in combination with its aluminum content, Hybrid Steel’s excellent corrosion resistance challenges the commonly held notions behind today’s corrosion rating systems. The aluminum content also provides strong resistance to oxidation at elevated temperatures.

For more information, please visit our website at www.hybridsteel.com.
The chemistry behind the breakthrough

Our initial aim in developing Hybrid Steel was to create a steel with superior mechanical and fatigue strength at high temperatures, compared to conventional steels. This required a systematic study of small ingots to identify various segregation levels, and to ensure the most stable microstructure possible after tempering at 500-600°C.

The base composition chosen for Hybrid Steel was a low-carbon, low-vanadium, low-molybdenum alloy. In order to boost strength, nickel and aluminum were added in order to form an intermetallic precipitation strengthening mechanism.

Microstructural strength

An atomic probe reconstruction of Hybrid Steel 55, shown right, clearly demonstrates how successfully our initial objectives were achieved. The microstructure of Hybrid Steel consists of tempered martensite and fine carbides, with an intermetallic phase of NiAl. By removing the iron content in this atomic probe tomography, it is possible to see the extremely small, evenly dispersed strengthening particles of the tempered Hybrid Steel.

Unlocking new possibilities

Hybrid Steel’s unique chemical composition, in addition to ensuring high strength at temperatures up to 500°C, opens up a range of other possibilities. The aluminum and nickel content contributes to very good oxidation resistance, even after 500 hours at 700°C. The composition is uniquely suited to performing nitriding and tempering in a single process step. And low distortion during heat treatment enables substantial reductions in component manufacturing costs.

All of these properties and more stem from the breakthrough in chemical composition that is Hybrid Steel, thus introducing an entirely new family of cost-effective steels for the most demanding applications.

“The strength of dual hardening mechanisms

Hybrid Steel is relatively low in carbon and contains a number of carefully controlled alloying elements, most importantly chromium (Cr), molybdenum (Mb), vanadium (V), nickel (Ni) and aluminum (Al). This enables simultaneous hardening by secondary carbides and intermetallic precipitations at tempering temperatures, resulting in a steel with an ideal distribution of extremely small strengthening particles.

“As a scientist, the development of Hybrid Steel is truly fascinating. The nano-sized dual precipitation means we have to push the limits of the most advanced characterization tools. The material also has an interesting combination of intermetallic precipitates and carbides, which seem to contribute to unusual resistance towards overaging.”

Mattias Thuvander, Professor Chalmers University of Technology
ATOMIC PROBE TOMOGRAPHY SHOWS A FINE DISTRIBUTION OF SMALL PRECIPITATES

An atomic probe reconstruction of Hybrid Steel 55 aged at 520°C for 3 hours. Iron (Fe) atoms have been removed, and a homogenous fine distribution of very small NiAl intermetallic precipitates and secondary carbides can be seen.

Sample volume: 20*20*90 nm. 1μm³ steel contains 500,000 NiAl particles.

CHEMICAL COMPOSITION, % BY WEIGHT

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<th>V</th>
<th>Al</th>
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<tbody>
<tr>
<td>Hybrid steel® 55 Engineering Steel</td>
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<td>0.1</td>
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<td>6</td>
<td>0.7</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Hybrid steel® 60 Bearing Steel</td>
<td>0.28</td>
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<td></td>
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</table>

Two simultaneous strengthening mechanisms

- Secondary carbides
- NiAl intermetallic phase
**Bearings**

**High-performance bearings at lower cost**

High hardness and fatigue strength are fundamental for bearing performance. Hybrid Steel meets these requirements while also offering:

- High strength at elevated temperatures, with good resistance to corrosion and hydrogen embrittlement
- Significantly reduced grinding allowances in costly late-stage manufacturing steps, due to very low distortion
- Superior logistical advantages, since one steel grade can be used for both large and small bearing dimensions due to high hardenability
- Excellent nitriding characteristics for very demanding applications

**Fuel injection components**

**Reduce emissions by handling high pressure at elevated temperatures**

To improve fuel combustion, a steel that handles high pressure at elevated temperatures is essential. Hybrid Steel offers a wide range of benefits for fuel injection components including:

- High strength at elevated temperatures
- High fatigue strength
- Good corrosion resistance
- Low distortion after heat treatment

**Key Benefits**

<table>
<thead>
<tr>
<th>1. High-temperature strength</th>
<th>2. Cost-efficient</th>
<th>3. Low distortion</th>
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<tr>
<td>4. Fatigue strength</td>
<td>5. Low segregation</td>
<td></td>
</tr>
<tr>
<td>6. Good weldability</td>
<td>7. Surface treatment</td>
<td></td>
</tr>
<tr>
<td>8. Corrosion resistance</td>
<td></td>
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</tr>
</tbody>
</table>
Nitrided Hybrid Steel is ideal for strengthening and extending the lifetime of hydraulic and transmission components, in addition to eliminating process steps, thanks to features including:

- High residual compressive surface stresses
- Maintained or improved core strength during processing (no softening)
- High wear resistance
- Shorter processing times and low distortion

**KEY BENEFITS**

1. High-temperature strength
2. Cost-efficient
3. Low distortion
4. Fatigue strength
5. Low segregation
6. Good weldability
7. Surface treatment
8. Corrosion resistance
**Engine components**

**Stronger, lightweight engine components**

We aim to help system providers support OEMs in improving engine components. Our Hybrid Steel enables a lighter engine with lower material use. Thanks to its:

- High strength at elevated temperatures
- High fatigue resistance

**Production tools**

**High-performance, highly polishable production tools**

A steel with high strength and high polishability is vital for any producer of different types of production tools. Hybrid Steel can reduce total production costs and improve product lifetime in mining tools, machining tools and various forming tools by combining:

- High polishability
- High strength at elevated temperatures with good wear resistance

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**KEY BENEFITS**

**Engine components**

1. High-temperature strength
2. Cost-efficient
3. Low distortion
4. Fatigue strength
5. Low segregation
6. Good weldability
7. Surface treatment
8. Corrosion resistance

**Production tools**

1. High-temperature strength
2. Cost-efficient
3. Low distortion
4. Fatigue strength
5. Low segregation
6. Good weldability
7. Surface treatment
8. Corrosion resistance

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- Good corrosion/oxidation resistance
- Low distortion after heat treatment
- Good weldability

- Low distortion after heat treatment
- Possibilities for weld repair and additive manufacturing of tools
- Higher corrosion resistance than conventional tool steels
High hardness and fatigue strength is fundamental for gear performance. Hybrid Steel meets these requirements while also offering:

- Excellent nitriding characteristics for very demanding applications due to high core hardness
- Substantial reduction in process steps. No separate hardening step needed, and less machining required thanks to very low distortion.
- High strength at elevated temperatures for use in demanding applications such as helicopter transmission components

**Gears**

**Cost-efficient, high-performance gears**

**KEY BENEFITS**

1. Low segregation
2. Cost-efficient
3. High-temperature strength
4. Good weldability
5. Low distortion
6. Fatigue strength
7. Surface treatment
8. Corrosion resistance
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Ovako develops high-tech steel solutions for, and in cooperation with, its customers in the bearing, transport and manufacturing industries. Our steel makes our customers’ end products more resilient and extends their useful life, ultimately resulting in smarter, more energy-efficient and more environmentally friendly products.

Our production is based on recycled scrap and includes steel in the form of bar, tube, ring and pre-components. Ovako has around 3,000 employees in more than 30 countries and sales of approximately EUR 1 billion. In June 2018 Ovako became a subsidiary within the Japanese Nippon Steel Corporation group, one of the world’s largest steel producers. For more information, please visit us at www.ovako.com and www.nipponsteel.com