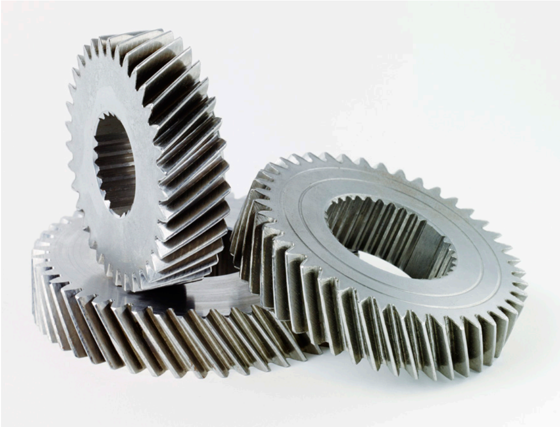
OVAKO

IQ-STEEL® – A CLOSER LOOK AT THE ISOTROPIC QUALITY PROCESS

Patrik Ölund

Executive overview

Highly loaded applications such as bearings, gears, diesel injection parts, rock drill components, cam- shafts, crankshafts and related components require material with high mechanical and fatigue strength. Low inclusion content is a prerequisite to achieve this. Which is why Ovako has made controlling non-metallic inclusions a priority.



A challenge for steel manufacturers is to improve steel quality for smaller components subjected to more power and torque demands. As designs become more complex, the requirements to withstand on multi-axial loading patterns increase. At the same time, steels with lower properties have strong anisotropic characteristics transverse to the rolling direction. To meet new demands, transverse properties must be improved. To this end, Ovako has developed a process based on advanced ladle metallurgy dedicated to inclusion engineering. This IQ process has resulted in the creation of IQ-Steel, an ultra clean steel with improved qualities in the rolling direction and dramatically improved properties in the direction transverse to rolling.

1 — Isotropic steel

One of the most intricate tasks is to correctly quantify clean steel. As the number of non-metallic inclusions of critical size are reduced there is a need to assess larger areas to obtain statistically significant numbers. Optical microscopy for micro inclusion assessment and blue fracture samples for macro inclusion assessment do not give sufficient information. Therefore Ovako has invested a great deal of effort in immersion ultrasonic testing methods (Figure 1). This allows volumetric assessment and may give statistically significant numbers of inclusions formed during deoxidation or reoxidation. Another technique that is applied is automatic scanning of large areas in a Scanning Electron Microscope (SEM) in order to detect non-metallic inclusions. The SEM is equipped with EDS analysis to determine the composition of all features, (Figure 2).

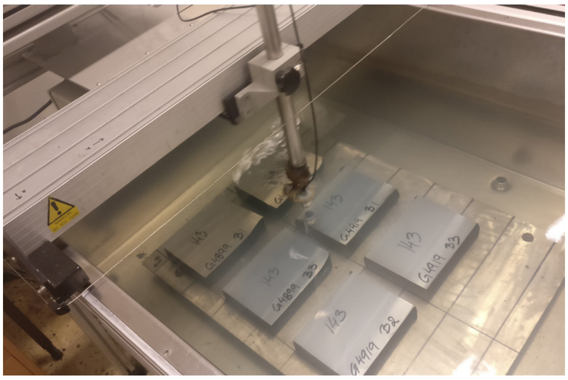


Figure 1 – Immersion ultrasonic test equipment.

Figure 2 – Scanning electron microscope.

Clean steel assessment techniques

For endogenous macro inclusion rating Ovako uses an internal 10 MHz immersion ultrasonic testing procedure. Compared to ASTM E588 and SEP1927 it is a more sensitive procedure allowing better discrimination between different quality classes and between different heats. Minimum detected feature size and tested area (or volume) are important testing parameters. Immersion ultrasonic testing will have both higher detectability and allow testing of significant volume instead of a moderate area. A comparison of traditional and ultrasonic techniques is shown in Tables 1 and 2.

	ISO 3763 Blue Fracture	**ASTM E45**
Feature detected	Macro inclusions Length > 1.0 mm	Micro inclusions Diameter > 2 µm
Amount of material investigated	≈ 3,000 mm^2	≈ 450 mm^2
Coverage	Area	Area

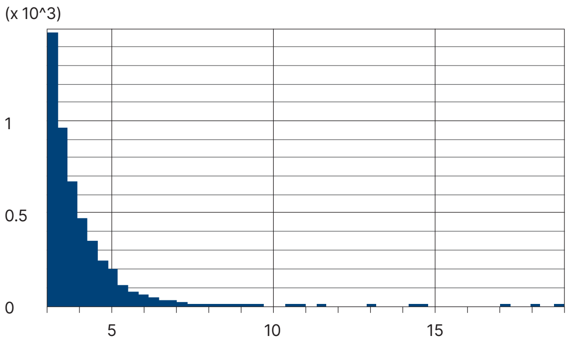
Table 1 – Detection limit and amount of tested material using ISO 3763 Blue fracture method and ASTM E45.

	Ovako 10 MHz UST
Minimum feature detected	Macro inclusions FBH > 0.120 mm
Amount of material investigated	≈ 1,500,000 mm^3 (≈ 50,000 blue fracture tests)
Coverage	Volume

Table 2 – Detection limit and amount of tested material using Ovako 10 MHz UST.

In Table 2 the corresponding numbers of blue fracture and ASTM E45 samples have been estimated. This is made by a translating volume into areas based on estimating that a 0.01 mm thick layer is assessed with the area methods. The results from 10 MHz UST testing are expressed as number of defects per volume unit exceeding a certain flat bottom hole (FBH) equivalent.

For inclusions smaller than 25 µm a Scanning Electron Microscopy (SEM) with automatic feature analysis is used. Figure 3 shows one way of presenting such data. Inclusions are entered into classes according to composition and the size distribution for all inclusions are plotted.



Class:	Features
Oxides:	162
Oxysulfide:	311
Sulfide:	3686
Ti (C, N):	560

Figure 3 – Example of output from the automatic feature analysis using the SEM

Process description

The IQ-process is based on the ingot cast process route used for the production of BQ-Steel® (bearing quality).

- Melting practice in the electric arc furnace EAF
  - Careful selection of scrap and raw materials
- Refining practice in the ladle furnace
  - Increased desulphurization to a sulphur content of a maximum of 20 ppm
  - Increased degassing time
  - Proprietary process added
- Ingot casting
  - Protected teeming using argon shrouding
- Soaking
  - Increased soaking time for improved homogenization
- Billet production
  - Increased crop-off mass to reduce segregation and to minimize number of macro inclusions

The improved isotropy is illustrated by the micrographs (Figure 4 and 5). Both show sections in the rolling (longitudinal) direction. The number of elongated inclusions are reduced drastically when the IQ-process is applied.

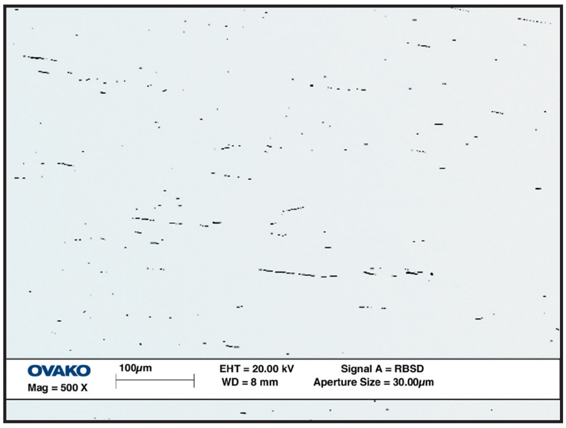


Figure 4 – Standard processed steel, longitudinal section.

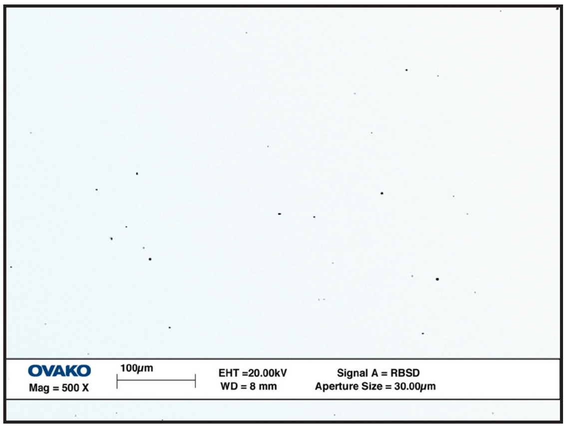


Figure 5 – IQ-Steel, longitudinal section.

2 – Cleanliness of IQ-Steel

For IQ-Steel Ovako has internal approval limits using 10 MHz UST testing. For bearing steel of the type SAE 52100 at maximum 10 defects/dm3 exceeding 0.2 mm FBH equivalent is accepted on a square 147 mm billet (Figure 6). Blue fracture tests will only generate zero ratings.

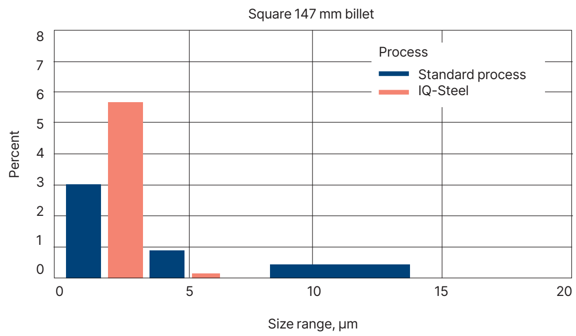


Figure 6 – Number of defects per 0.2 mm FBH per dm^3 evaluated using 10 MHz UST. The total number of evaluated samples are more than 1000.

The inclusion populations below 25 µm can be rated using automatic feature analysis in the SEM. Figures 7 and 8 show evaluations for 90 mm bar produced with Ovako standard process for low sulphur content and IQ-Steel. Generally the IQ-Steel has a lower number of inclusions larger than 4 µm.

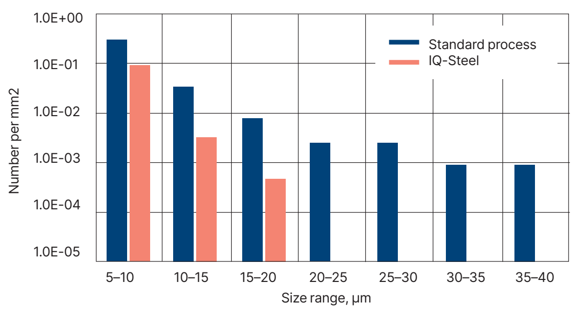


Figure 7 – Micro inclusion distribution in the range 5–40 µm.

However, for the very smallest inclusions there are higher numbers in the IQ-Steel (Figure 8). The intention is to shift the distribution towards smaller sizes since inclusions below 5 µm are considered to be harmless in most applications.

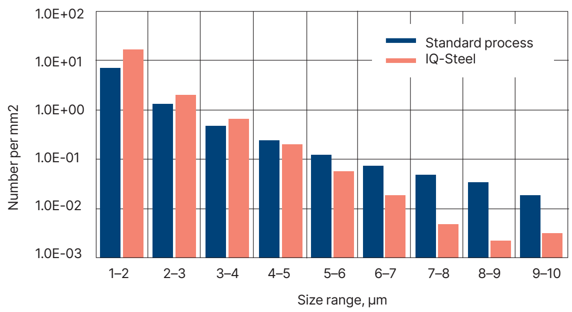


Figure 8 – Micro inclusion distribution in the range 1–10 µm.

The dramatic difference in inclusion content in transverse and longitudinal direction is illustrated in Figure 9. This figure show the accumulated length of all inclusions normalized per area. The standard steel show a dramatic difference in different directions whereas the IQ-Steel has a very small difference.

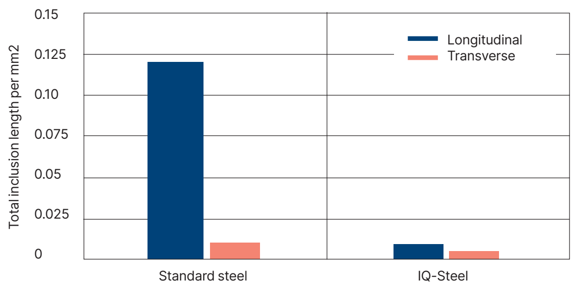


Figure 9 – Comparison of inclusions between standard steel and IQ-Steel in different directions.

Standard rating methods are also applied for quality control. For the IQ-Steel the DIN 50602 Method K has been chosen since it is normally used for rating on the semi-finished product dimension. Limits dependent on the degree of reduction for IQ-Steel are shown in Figure 10.

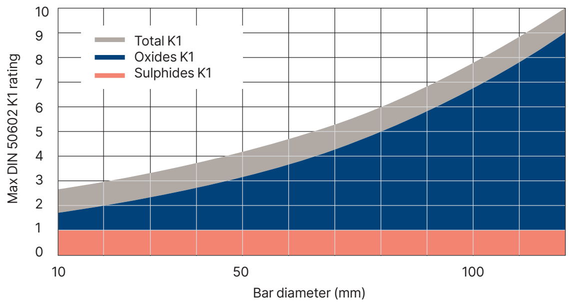


Figure 10 – K1 limits for IQ-Steel depending on bar dimension. Average value of six random selected samples.

Mechanical properties

The higher cleanliness and improved isotropy will improve the mechanical properties. Structural fatigue properties of an IQ-Steel and a standard variant of a hardened SAE 52100 type of steel grade is shown in Figure 11.

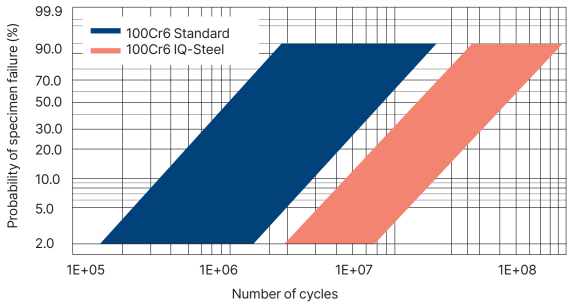


Figure 11 – Structural fatigue properties of an IQ-process and standard variant of SAE 52100 steel.

The test was performed at a single stress level of 950 MPa on an hour-glass shaped specimen with a diameter of 9.5 mm. The reduced inclusion size distribution will give a significant improvement of the fatigue properties. Impact toughness is a property that is significantly influenced by the inclusion content. Figures 12 and 13 show that the IQ-process will dramatically improve the impact toughness in the transverse direction.

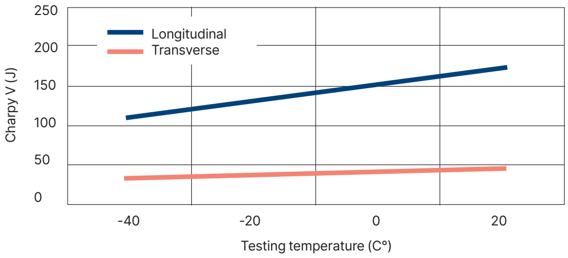


Figure 12 – Impact toughness in a standard variant of a 650 MPa engineering steel.

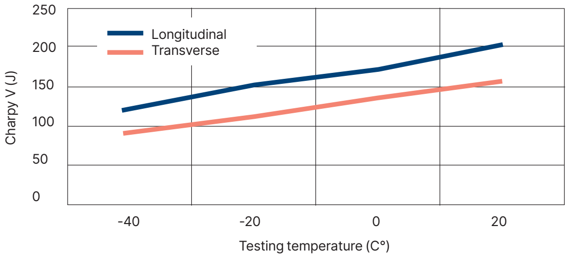


Figure 13 – Impact toughness in an IQ-process variant of a 650 MPa engineering steel.

3 — Summary & About the author

IQ-Steel when, compared to conventionally produced low sulphur grades, offers:

- More isotropic properties
- Higher oxidic cleanliness

This leads to benefits such as improved fatigue properties and increased impact toughness.

Patrik Ölund
Patrik Ölund is head of group research and development at Ovako. Educated at The Royal Institute of Technology (KTH, Stockholm, Sweden (1985-1990), he worked at the Swedish Institute for Metals Research (1990-1995) doing research relating to inclusions, fatigue and heat treatment.

In 1995 he joined Ovako in the research department, which he now heads. Ölund was the winner of the Kami Prize 2013, presented to a distinguished scientist whose research has become the basis of a technical development within the Swedish steel and metal industry.

Disclaimer
The information in this document is for illustrative purposes only. The data and examples are only general recommendations and not a warranty or a guarantee. The suitability of a product for a specific application can be confirmed only by Ovako once given the actual conditions. The purchaser of an Ovako product has the responsibility to ascertain and control the applicability of the products before using them.

Continuous development may necessitate changes in technical data without notice. This document is only valid for Ovako material. Other material, covering the same international specifications, does not necessarily comply with the properties presented in this document.

Ovako Head Office
Box 1721
SE-111 87 Stockholm, Sweden

+46 8 622 13 00
ovako.com