Ovatec™ 677 – a new through hardening steel for high quality components with air hardening capabilities

Technical Report Archive

OVATEC™ 677 – A NEW THROUGH HARDENING STEEL FOR HIGH QUALITY COMPONENTS WITH AIR HARDENING CAPABILITIES

Ovako has an extensive R&D since many years, an area that now is in an even higher intensity. Some of the R&D work is published in our technical reports.

Due to that Ovako of today has had a number of different company names and used various trade marks we have until now chosen to not have these reports publicly available. However, many of these technical reports contain valid data about material and steel grades that we still promote, but with other names etc.

The following Technical Report from 2001 is about the properties of the at that time new family of Air-hardening steel that Ovako developed, and specifically the two first grades Ovako 677 and Ovako 477.

Data and processes in this report represent state of art at time of publishing, that still in most cases are used and valid.

Ovako 477 and Ovako 677 are grades that is part of our current offer. In the Ovako Steel Navigator these materials are described under the version names Ovako 477L , Ovako 677L and Ovako 677Q.

In this Technical Report there is used the following Company names and trade marks that no longer is used by Ovako AB.

Ovako Steel; This company name is no longer used. The organization is now part of Ovako AB.

OVAKO STEEL

Technical Report 3/2002

Ovatec™ 677 – a new through hardening steel for high quality components with air hardening capabilities

Thore Lund,
Patrik Ölund,
Maria Sjöstrand,
Henrik Sandqvist and
Thord Johansson,
Ovako Steel AB

ISSN 0284-3366

OVAKO STEEL

Ovako Steel is the world's leading manufacturer of bearing steel and a major producer of other special engineering steels. We are a fully owned subsidiary in the SKF group.

Our main strengths are in the field of long special engineering steel products – seamless tube, bar, and surface removed wire. Rolled rings are also a specialty. Further processing of our products is available and illustrates our intentions to provide more specialized services.

The most important customer segments are the rolling bearing industry, the automotive industry together with their subcontractors as well as the rock drilling and general engineering industries.

We have manufacturing units in Sweden and France. Steel production is confined to Hofors, in Sweden. The production capacity is approx. 525,000 ton of special engineering steel per year.

Research & Development

Our R&D mission is to pursue an efficient product and process development, adapted to existing and new technology, and within our product areas be recognized as the world leader in metallurgy, materials technology, machinability and metal cutting technology as well as heat treatment. The ultimate target is to offer our customers the best total economy in their production.

www.ovako.com

Background

Yesterday

In the rapid progression of steel making and the production of hard components that followed the industrial introduction of the automobile in the late 19th century, the need for high quality steels as a base for rolling bearing production was acute.

The first published record stating the demands on bearing components dates back to Stribeck 1901, where he tries to summarise the requirements on bearing steel components. This type of steel was also used by SKF, and in 1910 the bearing steel composition of 1 % carbon and 1.5 % chromium had become the industrial standard.

Today

Today, about 40 ppm of the world steel production is rolling bearing steels. It still carries a lot of weight as rolling bearings are considered a frontrunner as regards demands on formability, quality and performance in the intermediate range between very large volume component steels and tool steels. This means that bearing steels catch a lot of attention, perhaps in the same way that Formula one racing car does for automotive developments.

While the chemical composition of steels used for rolling bearing components has seen small, or no, development over the years, one aspect of bearing steel production has received large attention and has given a leap in development - the metallurgical cleanliness level. Today, several bearing steel producers do manufacture bearing steel at cleanliness levels as regards macro- and micro-inclusions which would not be dreamed of only a decade ago. But the steel is the same, and due to the traditional alloying design the processing is cumbersome, environmentally damaging and several steps in the manufacturing process generate problems, which add to the cost of the finished component. And bearing steels are used for a large number of components outside the rolling bearing industry today when application requirements are similar: Demands on high fatigue- and wear resistance, good dimensional stability and high cleanliness.

Tomorrow

The Ovatec 677 has been designed to be a replacement for most steel grades used for bearing steel and other high performance components today, and offers the potential not only to reduce the number of variants in use, but also provides the opportunity to produce high performance products with consistent and repeatable enhanced performance by a production route which is environmentally friendly and reduces cost by simple cooling from the austenitising temperature, avoiding quenching baths, in a manner which significantly can reduce hardening distortion.

And, for the first time, a steel, which has been engineered to provide maximum performance in heavily loaded applications, based on modern scientific tools, to provide a cost effective production route has been developed.

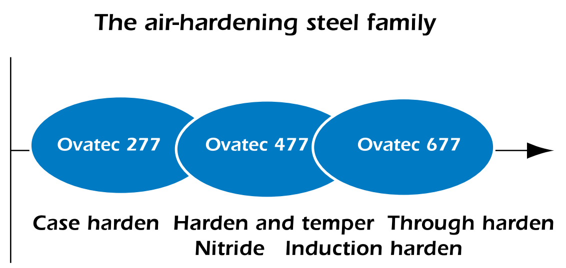
The Ovako Steel Ovatec™ Family

The alloying design concept in the Ovako Steel Ovatec family is to provide steels for large-scale component production that offer environmen-tal and economical production of products with minimum hardening distortion compared to standard steel grades.

Almost all components which are used in loaded applications today are heat treated, and the variants used are either case hardening, harden and temper or through hardening steels. Classifications of steel vary, and certain harden and temper steels are called spring steels when used for springs, or nitriding steels when used for nitriding. Some through hardening steels are designated rolling bearing steels when used for bearing applications, but this does not change the fact that the heat treatment operation employed to a large degree decides which specific variant that is used for a given application. And the heat treatment determines many of the most important properties deciding component performance.

In the three Ovako Steel Technical Reports 1/2002, 2/2002 and 3/2002 the three Ovatec steel variants intended for case hardening, hardening and tem-pering and through hardening are described, and details of the following are given as applicable:

- Steel manufacture
- Metallurgical cleanliness
- Chemical composition
- Steel product production
- Delivery condition and properties in this condition
- Formability in the as delivered condition
- Welding
- Heat treatment procedure – standard heat treatment
- Heat treatment procedure – special processes
- Heat treatment characteristics, transformation behaviour
- Hardening results
- Heat treatment distortion
- Tempering influence on hardness and strength
- Dimensional stability
- Machinability in the hardened and tempered condition
- Fatigue properties
- Processing directly from hot forming heat



Ovatec™ 677

Ovatec 677 is the through hardening member of the Ovako Steel Ovatec family. It has been designed to enable a more environmentally friendly and safe heat treatment with significantly reduced risk of distortion for all components produced by through hardening today, requiring high performance and enhanced properties.

Steel manufacture

At Ovako Steel the steel production is based on scrap, EAF melting of 100 tonnes in an oval bottom tap vessel. Deoxidation, alloying, and refining with inductive stirring and vacuum degassing with argon bubbling and inductive stirring is carried out in an ASEA-SKF ladle furnace. The steel is then uphill teemed to 4.2-ton ingots on three teeming plates. *(Figure 1)*

The same processing route is followed for the air-hardening steels, which means that these variants will meet the same cleanliness requirements as those used for all other Ovako Steel high-quality products.

Metallurgical cleanliness

As cleanliness is an important factor in many aspects of product applications, it has been decided to produce the air-hardening steels with at least Bearing Quality cleanliness. This means that the demands made as regards oxygen- and titanium contents and macro- and micro-inclusions in the Ovako Steel Cleanliness Specifications (Ovako Steel Technical Report 1/1998) are met.

The air-hardening steels can also be obtained at a cleanliness level normally used for replacing re-melted (ESR/VAR) steels.

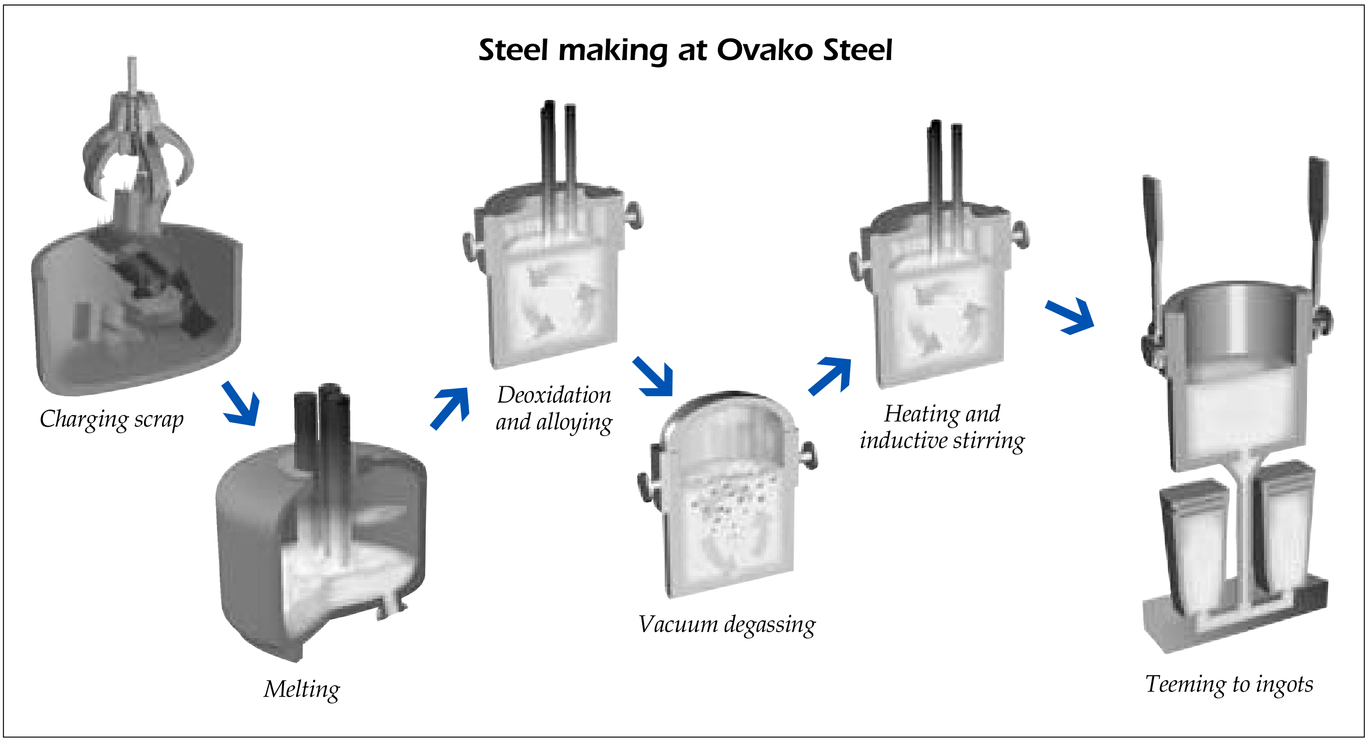


Figure 1 – Steel making at Ovako Steel.

Chemical composition

		C	Si	Mn	P	S	Cr	Ni	Mo	O (ppm)	Ti (ppm)
Ovatec 677L	Min	0.65	1.45	1.35			1.00		0.23		
	Max	0.70	1.60	1.55	0.025	0.015	1.20	0.25	0.27	9	30
Ovatec 677K	Min	0.65	1.45	1.35			1.00		0.23		
	Max	0.70	1.60	1.55	0.025	0.002	1.20	0.25	0.27	8	30

Table 1 – Chemical compositions of standard Bearing Quality (677L) and Premium Bearing Quality (677K).

Steel product production

Ovatec 677 is processed to tubes, bars, wire and rings much in the same way as any other Ovako Steel product, and the same quality control procedures are applied. One main differences lies in the heat treatment condition in which the products can be supplied.

Delivery condition and properties in this condition

Standard bearing steels are today always delivered and machined in the spheroidised annealed condition. The structure is spherical carbides in a ferritic matrix. *(Figure 2)*

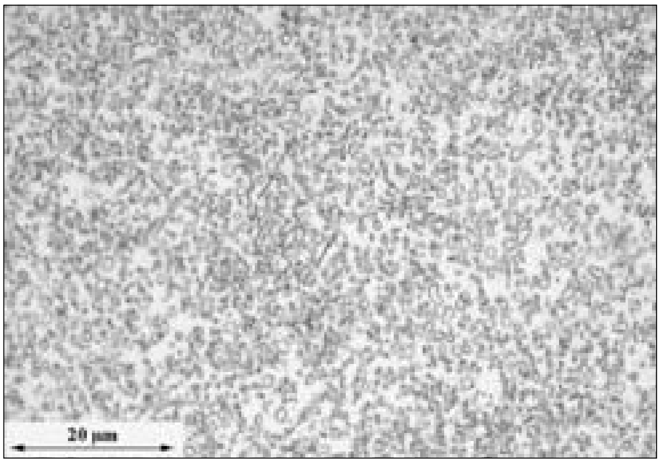


Figure 2 – Soft annealed 52100.

With the Ovatec 677, the situation is different, as the result of the cooling from hot forming temperatures is a martensitic structure with very high hardness instead of the pearlite/grain boundary carbide structure generated in today's standard bearing type steels.

This martensitic structure can be tempered back to a ferritic structure with fine, spheroidised carbides of any hardness selected between the as-rolled, fully martensitic, hardness to a hardness of about 240 HB. One possible delivery condition is a high temperature tempering with the hardness about 240 - 270 HB. *(Figure 3)*

At the high temperature tempered hardness, the mechanical properties of Ovatec 677 are as follows:

Tensile strength, R_m	750 MPa
Yield strength, $R_{p\,0.2}$	450 MPa
Elongation, A_5	30 %
Area reduction, Z	45 %
Impact strength, KV	20 J
Hardness, HB	240 –270 HB

If a lower hardness is desired, an annealing can be performed. When using soft annealing, the hardness of Ovatec 677 is reduced to lower levels, about 210 - 240 HB. *(Figure 4)*

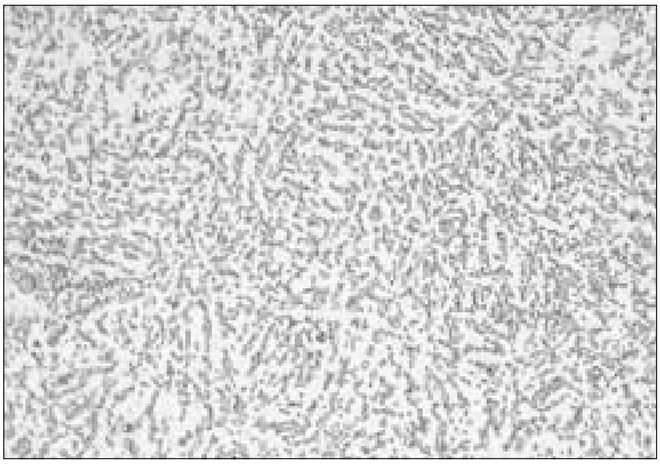


Figure 3 – High temperature tempered Ovatec 677.

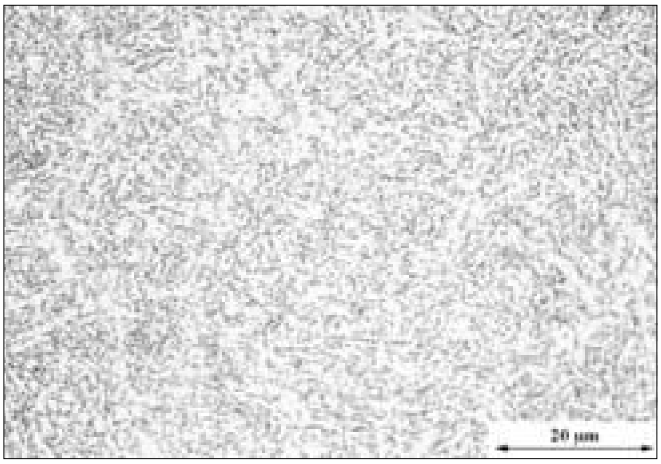


Figure 4 – Soft annealed Ovatec 677.

Formability in the as delivered condition

Forging can be carried out as today, but as the alloying content of Ovatec 677 is higher than in traditional bearing steels a slightly higher temperature should be used.

Turning has been tested for Ovatec 677 in comparison to standard bearing steel using the standardized ISO 3685 longitudinal turning test and in the Ovako Steel developed intermittent machining test (IMM), which relates more to a modern NC machining operation. *(Figures 5a, b, c)*

By different heat treatments, the hardness of Ovako 677 can be varied. Some variants of softening have been ISO tested and compared to soft annealed 52100. When the hardness of 677 approaches the same levels as for standard steels the tool life was better for Ovatec 677 than for 52100.

Welding

Ovatec 677 has a very high carbon equivalent, and therefore welding must be made with caution. A tempering is recommended after friction welding. *(Figure 6)*

Heat treatment procedure – standard heat treatment

In hardening of Ovatec 677, the austenitisation can be made within a wide temperature range, and can be followed by a slow cooling. The austenitisation can take place in the temperature range 880 to 1200°C, and the steel will transform to martensite even in slow, still air cooling for most industrial components through hardened today.

The advantage of the air-cooling is that such cooling can be made more homogeneously, and thus the undesired and unpredictable quenching distortion can be minimized. Additionally, the avoidance of hazardous and costly quenching media generates environmental and cost benefits.

The austenitisation should be made in a protective atmosphere and a carbon potential of about 0.7 % should be used. This in order to avoid carburisation of the surfaces.

Heat treatment procedure – special processes

Many different heat treatments of Ovatec 677 improve surface properties. Nitriding, carbonitriding, induction hardening and laser hardening have been investigated.

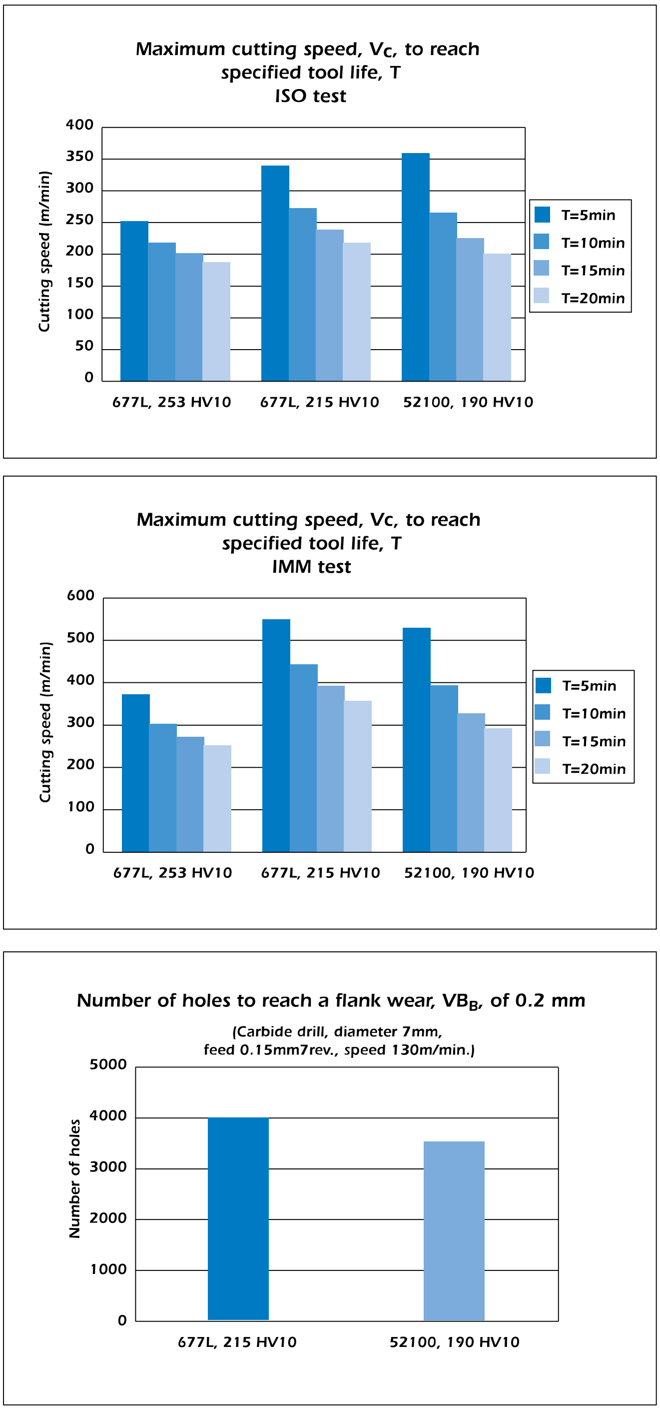


Figure 5 – vT curves for Ovatec 677 and 52100.

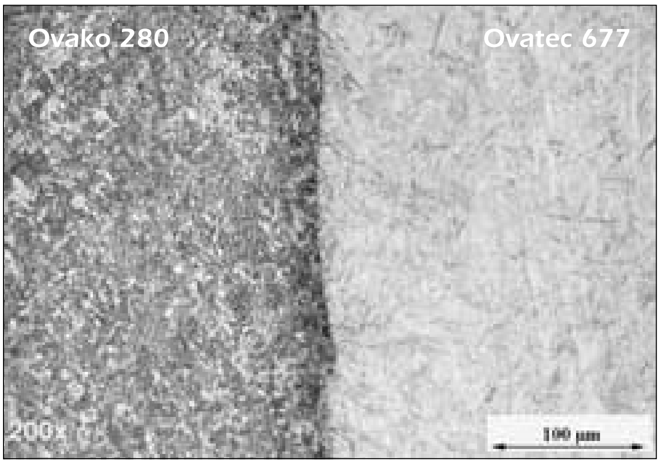


Figure 6 – Friction welded Ovatec 677against Ovako 280.

Gas nitriding was made with Ovatec 677 and 52100. The resulting surface hardness is enhanced in Ovatec 677 and it retains core hardness better. Nitriding of Ovatec 677 can be performed with the standard process used for today's steels. *(Figure 7 and 8)*

Carbonitriding has also been made on Ovatec 677 and with good results. *(Figures 9-11)*

Induction hardening was carried out with Ovatec 677, SAE 1045 (Ovako 047A) and SAE 4337 (Ovako 356D). The fact that high temperatures can be used at the surface in the austenitisation gives Ovatec 677 a major advantage in all surface heating processes over tradditional high carbon steels. *(Figure 12)*

Laser hardening has been extensively tested with Ovatec 677, and shows that significant hardening depths can be obtained without loss of surface properties. The transition between the high hardness in the surface to the core is smooth which is a consequence of the better tempering resistance of Ovatec 677. *(Figure 13)*

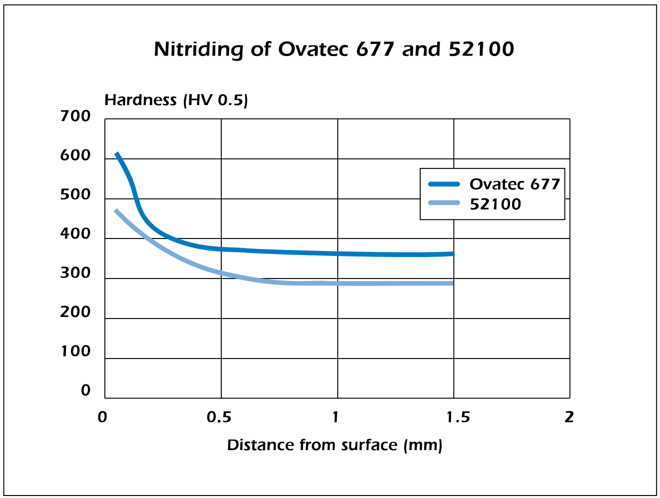


Figure 7 – Hardness after nitriding of Ovatec 677 and 52100.

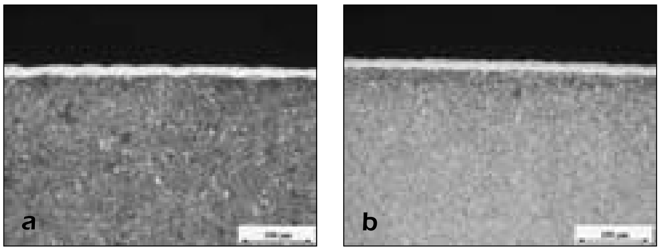


Figure 8 – Microstructure and nitrided layer of a) Ovatec 677 and b) 52100.

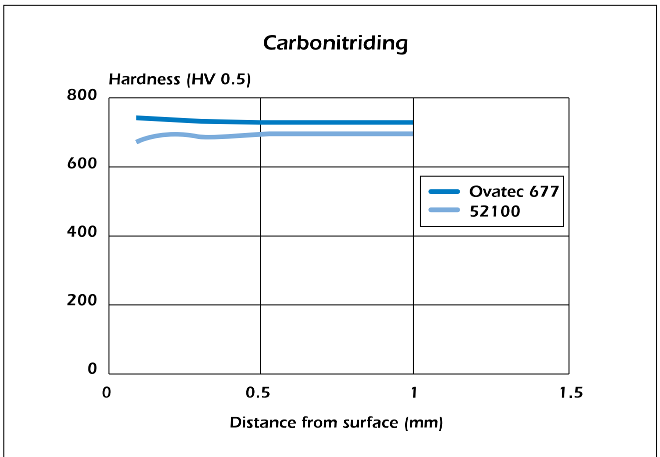


Figure 9 – Hardness after carbonitriding of Ovatec 677 and 52100.

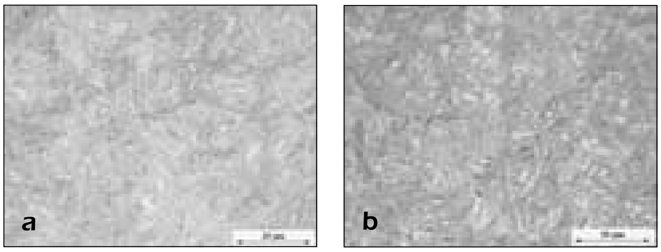


Figure 10 – Microstructure after carbonitriding Ovatec 677, at the a) center and b) surface.

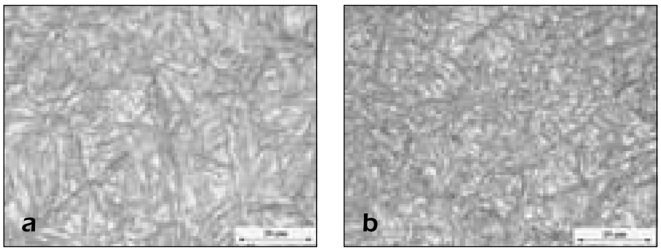


Figure 11 – Microstructure after carbonitriding 52100, at the a) center and b) surface.

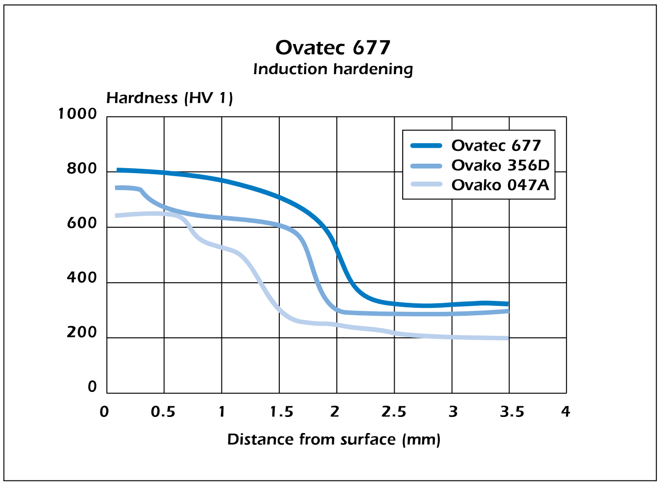


Figure 12 – Induction hardening of Ovatec 677, Ovako 356D (SAE 1045) and Ovako 047A (SAE 4337).

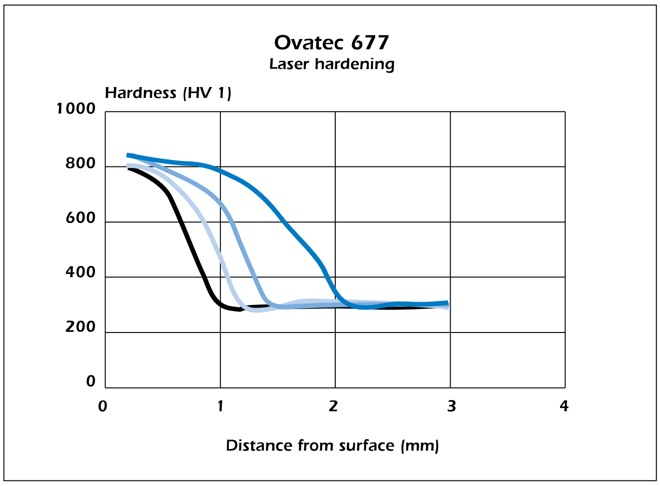


Figure 13 – Laser hardening of Ovatec 677 with varied energy impact.

Heat treatment characteristics, transformation behaviour

The austenitistion temperature used for Ovatec 677 affects the properties very little, and the same results will be achieved regardless of the austenitising temperature and component size, up to a certain size.

This is a major difference compared to standard bearing steels, and also gives the unique possibility to harden the steel on cooling from the hot forming temperature. Standard bearing steels have to be austenitised very precisely so that just 0.7 % carbon is dissolved in the austenite to achieve the desired hardness and structure of the martensite. *(Figure 14)*

The structure of Ovatec 677 will be martensitic with some retained austenite, the retained austenite content being about 10 - 15 % just as what is normal for standard bearing steels after oil quenching. *(Figure 15)*

The absence of residual carbides does not reduce the wear resistance of Ovatec 677, on the contrary, rolling bearing wear tests with oil contaminants show that Ovatec 677 gives significantly less wear than 52100.

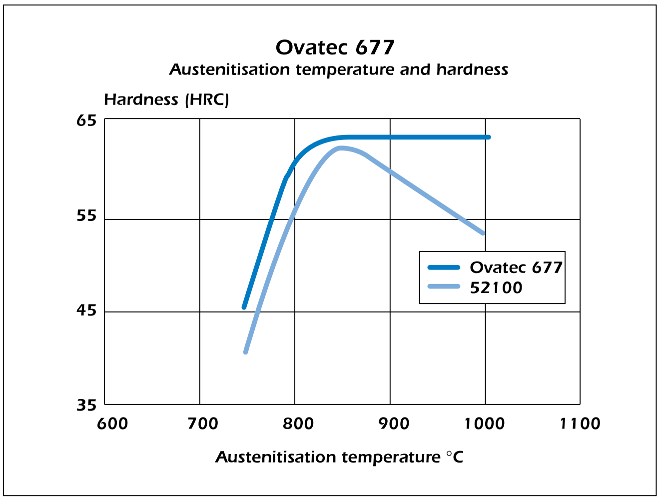


Fig 14 – Hardness at varied austenitisation temperatures for Ovatec 677 and 52100.

Hardening results

The alloying design has been made in such a way that long times are available on cooling before the onset of transformation to pearlite and/or bainite. This means that the cooling rate from the austenitic condition required to achieve a fully martensitic structure is much lower than for standard steels. *(Figure 16)*

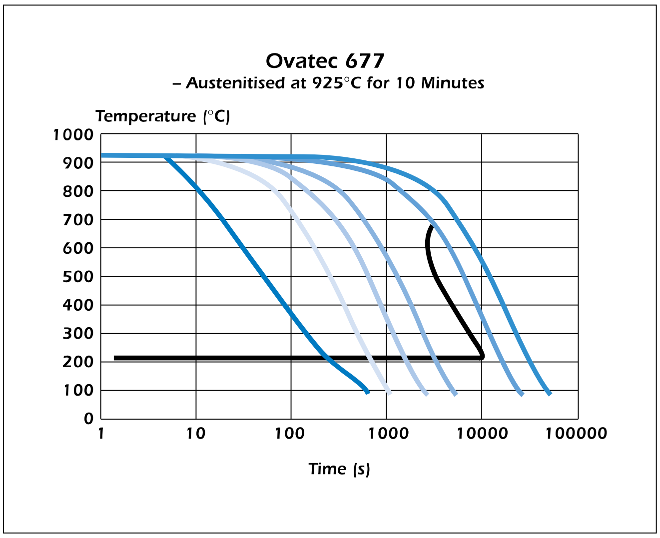


Figure 16 – CCT diagram for Ovatec 677.

After a hardening a low temperature (160°C) tempering normally is performed. The properties of Ovatec 677 in this condition are:

Tensile strength, R_m	1550 MPa
Yield strength, $R_{p\,0.2}$	1450 MPa
Impact strength, KV	6 J
Hardness, HRC	61–63 HRC
Retained austenite, %	10–15 %

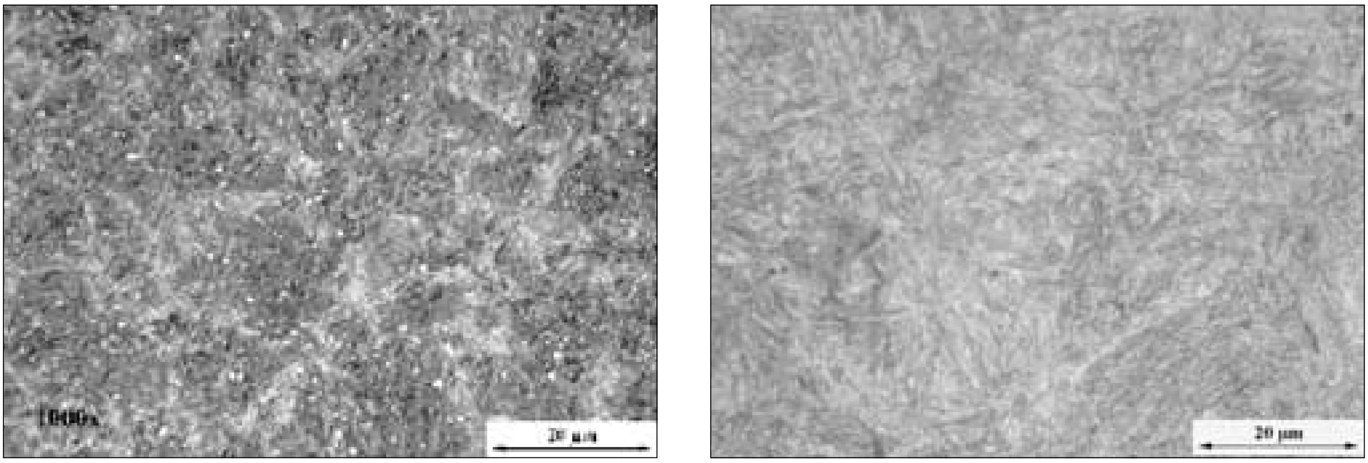


Figure 15 – Hardened structures of 52100 (left) and Ovatec 677.

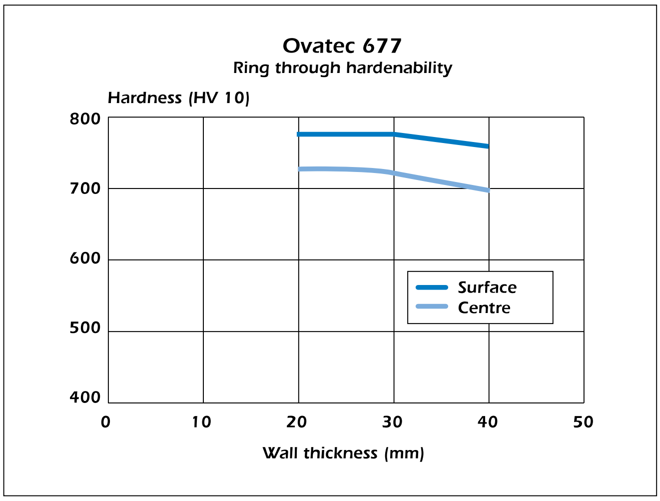


Figure 17 – Through hardenability of Ovatec 677 in still air-cooling.

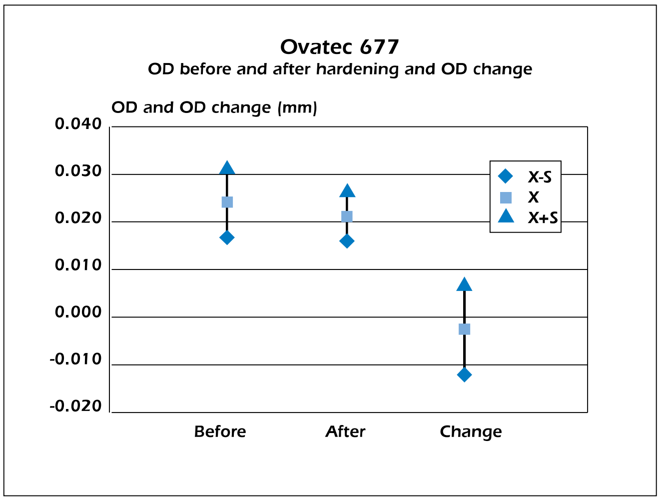


Figure 19 – Ring ovality before and after air hardening of Ovatec 677.

The hardenability of Ovatec 677 is high, and significant wall thicknesses can be through hardened even in still air-cooling. *(Figure 17)*

Heat treatment distortion

The heat treatment distortion caused by the severe quenching required for the steels with limited hardenability used today can largely be avoided, and this of course affects the amount of work required after heat treatment. In a first example, cylindrical rings were austenitised in a conventional furnace and then allowed to air cool on the transportation device normally taking the rings to the tempering operation. The rings were measured after turning and then again after the hardening. *(Figure 18)*

In another example, a small size roller bearing inner ring was heated by a magnetic field and airhardened by cooling in air. Again, the rings were measured before and after hardening. *(Figure 19)*

The ovality after hardening is exactly as the ovality after turning.

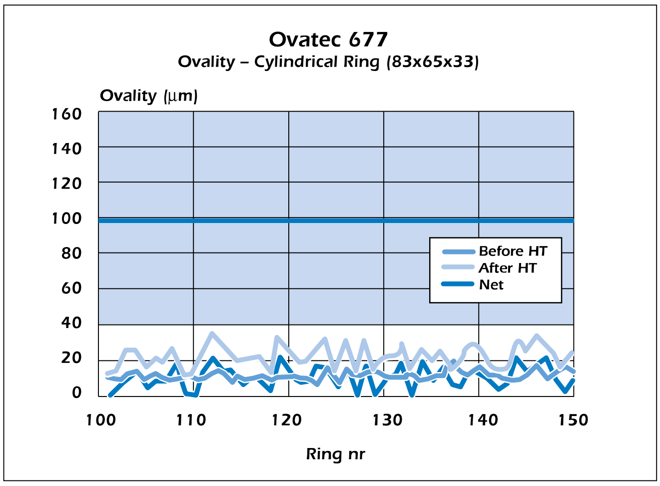


Figure 18 – Ovality of cylindrical rings before and after heat treatment.

Tempering influence on hardness and strength

The Ovatec 677 steel retains its hardness better than standard steels. By selecting the proper tempering temperature, the hardness and strength can be varied within wide limits. *(Figure 20)*

Dimensional stability

Ovatec 677 has high dimensional stability, and can be used for significant times at elevated temperatures without generating any significant dimensional changes. This offers the possibility to use low tempering temperature, retaining properties and performance but still having a good dimensional stability. This is not possible with standard bearing steels where initial hardness must be sacrificed to achieve dimensional stability. *(Figure 21)*

The stability of Ovatec 677 is largely due to the much higher stability of the retained austenite. *(Figure 22)*

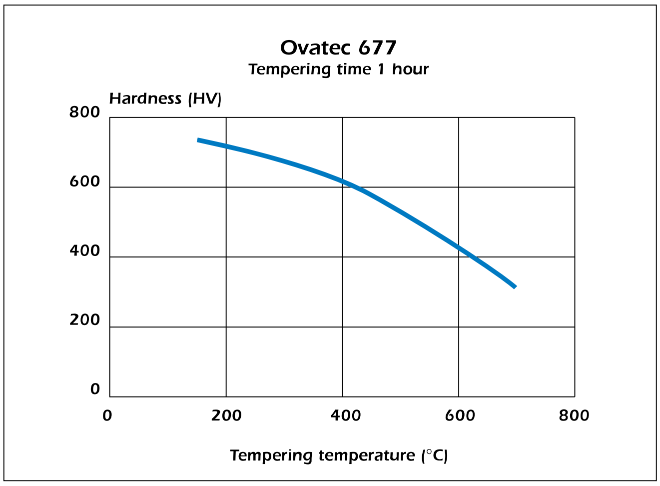


Figure 20 – Hardness versus tempering temperature of Ovatec 677.

Machinability in the hardened and tempered condition

Hard machining of Ovatec 677 has proved to be far easier than in comparative steels at similar hardness levels. Where the standard steels require boron nitride tools, this steel can be successfully machined with ceramic tools.

Using boron nitride tooling, significanly better performance is achieved with Ovatec 677. *(Figure 23)*

Fatigue properties

One fundamental property of steels used at high hardness levels for applications as rolling bearings is fatigue.

Ovatec 677 is produced to high metallurgical quality, providing a steel with low oxygen content and very low levels of non-metallic inclusions. *(Figure 24)*

Several different fatigue tests have been performed on Ovatec 677 as rotating bending and four point bending on bar samples, rolling contact point contact tests, rolling bearing tests for different types of bearings and single gear tooth bending fatigue and gear back-to-back tests.

Rotating beam tests

The fatigue lives of Ovatec 677 and standard produced, high quality 52100 steel were compared in

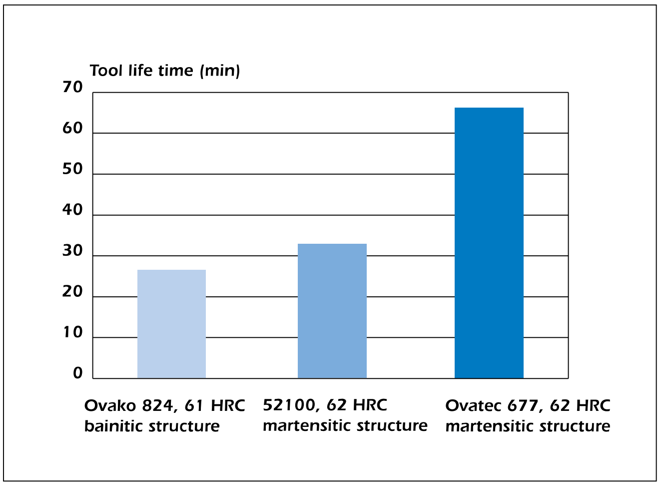


Fig 23 – Hard turning of 52100 (Ovako 803), a Mo alloyed bearing steel (Ovako 824) and Ovatec 677.
PCBN-inserts. Cutting data: Speed 160 m/min, Feed 0.1 mm/rev and depth of cut 0.1 mm.

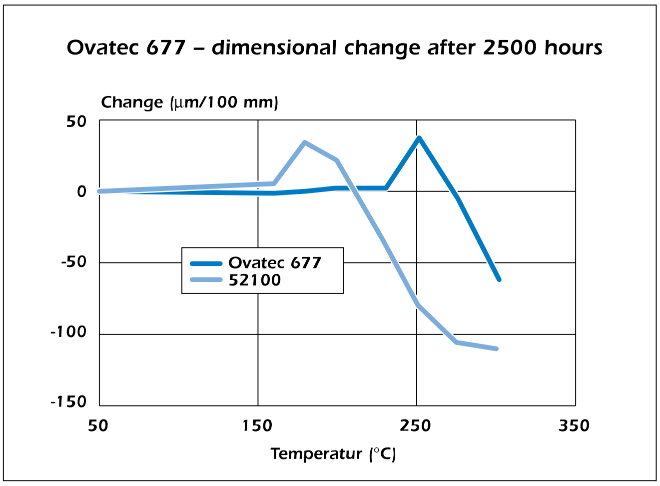


Figure 21 – Dimensional stability of Ovatec 677 and 52100

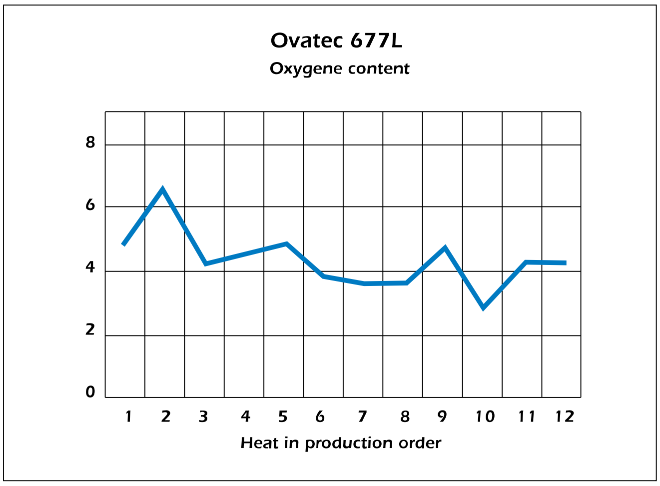


Fig 24 – Oxygen content in Ovatec 677L.

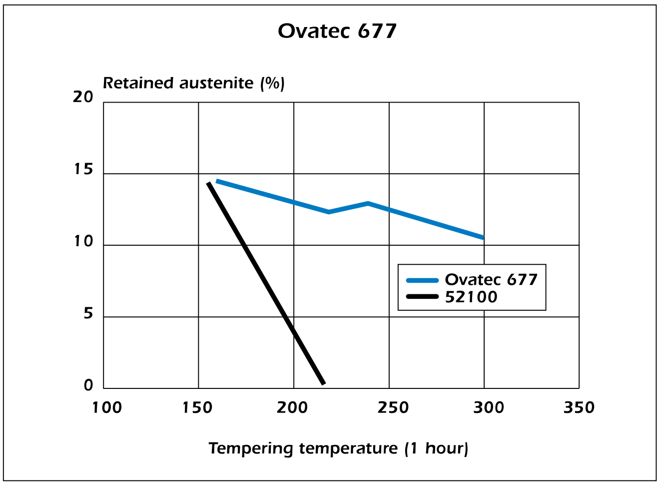


Figure 22 – Retained austenite transformation in Ovatec 677 and 52100.

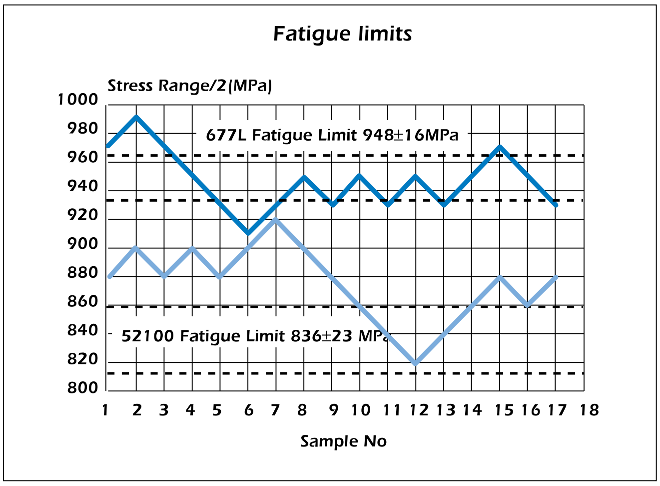


Figure 25 – Staircase test results for Ovatec 677and 52100.

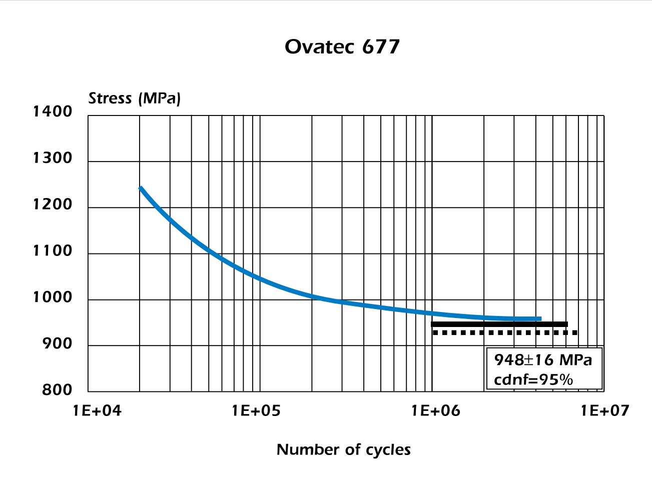


Figure 26 – Wöhler curve for Ovatec 677.

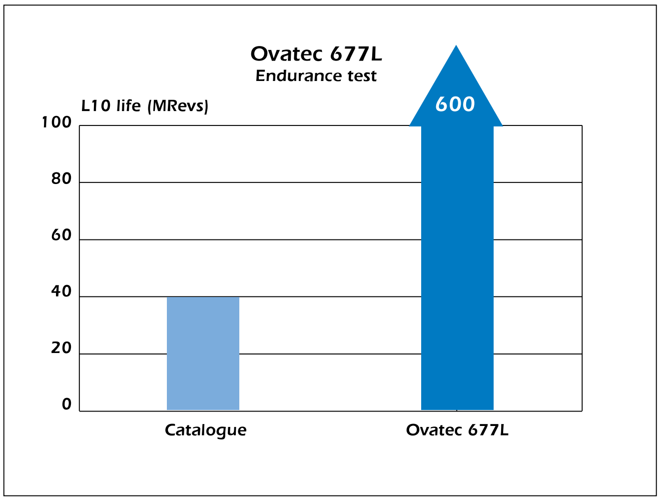


Figure 27 – Rolling bearing life tests on Ovatec 677L.

rotating beam tests where Wöhler curves were produced and where the fatigue limits were established using the staircase method. *(Figures 25 and 26)*

Rolling contact fatigue tests

Rolling contact fatigue tests have been conducted on Ovatec 677 in a flat washer-ball contact and in a tapered ring-ball contact with results which are at least as good as what is achieved with very high quality 52100 steel.

Rolling bearing tests

A number of rolling bearing tests have been performed on Ovatec 677 with different bearing geometries and under varying conditions. All of these data are not possible to publish at this stage, as the results are proprietary information to the companies conducting the tests.

In one test, the potential of heat-treating Ovatec 677 directly in connection with a hot forming operation was utilized.

The outer and inner rings of spherical roller bearing 222 20 bearings were hot rolled from bar stock and the rings were allowed to air harden directly on cooling from the hot ring rolling. The rings were then hard turned to final dimensions and the rolling contact surfaces were polished. The rings were assembled into bearings with standard 52100 rollers.

The bearing endurance tests were conducted under circulating, clean oil lubrication at loading conditions giving a C/P value of 3. The nominal bearing life under these conditions (the catalogue life) is about 40 million revolutions.

The tests were suspended at 400 million revolutions, and the two inner ring failures obtained were judged not to have been initiated by steel causes. (*Figure 27)*

Gear tests

As processing using Ovatec 677 opens up possibilities to produce components in ways very competitive to case hardenening components, Ovatec 677 has been used to produce gears for fatigue testing.

Single tooth fatigue tests have been carried out as well as back-to-back tests on gear wheels produced from Ovatec 677L, soft machined, air hardened, ground and shot peened. *(Figures 28-31)*

Processing directly from hot forming heat

Ovatec 677 will, after a forging or rolling operation, air harden on the cooling. This opens some entirely new potential routes for component manufacturing. With the advances in hard machining, and the fact that Ovatec 677 is much easier to hard machine than 52100, new processing routes with a reduced number of processing steps, and large positive impacts on energy and environment will be made available.

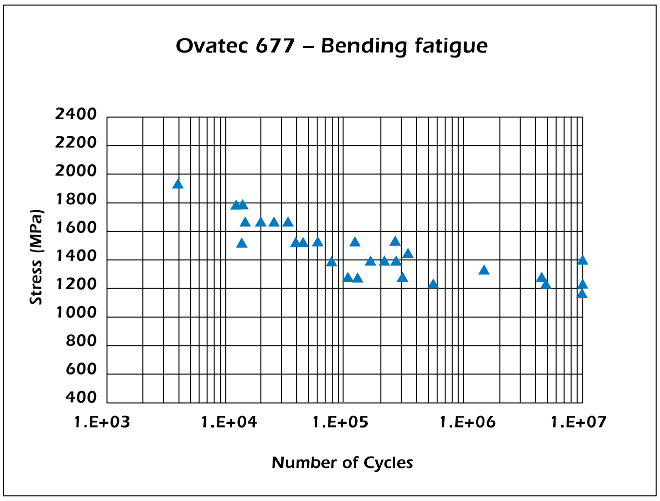


Figure 28 – SN curve for single tooth tests on Ovatec 677.

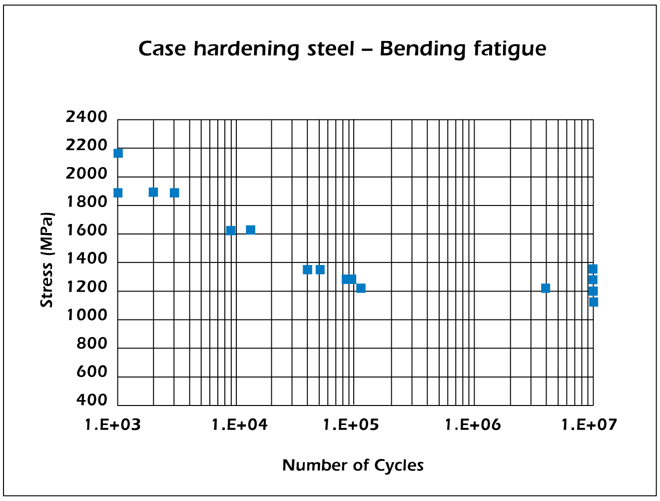


Figure 30 – SN curve for single tooth tests on a case hardening steel.

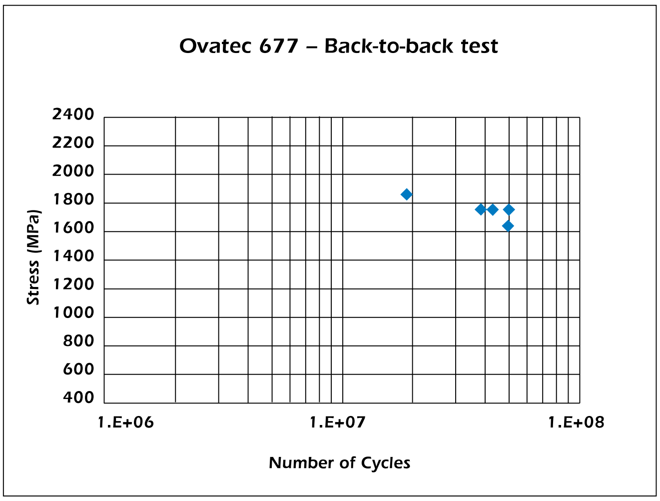


Figure 29 – Back-to-back test on Ovatec 677L gears.

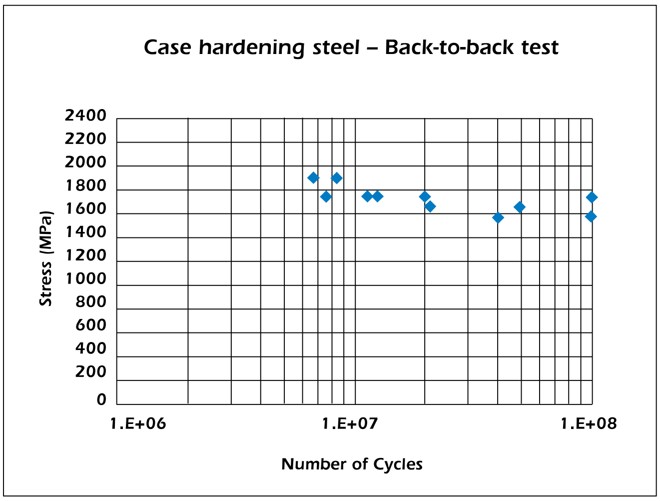


Figure 31 – Back-to-back test on a case hardening steel.

Conclusions

- The Ovako Steel air hardening steel variants combine their air-hardenability with very high metallurgical cleanliness, good machinability and high finished product performance.
- The fundamental merits of the air-hardening steels are founded on the fact that today's quenching baths, which not only are polluting health and safety risks but also are expensive to run and maintain, can be totally avoided and replaced by cooling in still air.
- This has as consequence that one of the main problems associated with modern heat treatment, unpredictable hardening distortion, can largely be avoided. This, in turn, provides large potentials to save time and cost in the process steps needed to rectify the hardening distortion.
- In addition to this, the fact that the air-hardening steels can be hardened even from very high austenitisation temperatures makes it potentially possible to reduce the number of processing steps required to produce a given component and thus significantly reduce total manufacturing cost.

Acknowledgements

Ovako Steel gratefully acknowledges the work performed on gear testing at the Design Unit at Newcastle University in England under the supervision of Dieter Hoffmann and Brian Shore.

OVAKO STEEL

Technology & Quality
S-813 82 Hofors, Sweden

www.ovako.com

RD-114US 09.02 2,000 Hällefors Tryckeri

CO-103 GB 21:05

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 AB
SE-111 87 Stockholm, Sweden
Phone: +46 (0)8 622 13 00

www.ovako.com