Ovatec 477™ – a new hardening steel for high quality components with air hardening capabilities

Technical Report Archive

OVATEC 477™ – A NEW HARDENING AND TEMPERING 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 2002 is about the properties of the at that time new grade, in the family of Air-hardening steel that Ovako developed, and specifically the grade 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 is a grade that is part of our current offer. In the Ovako Steel Navigator this material is described under the version name Ovako 477.

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.

Ovatec; This trade mark is owned but no longer used by Ovako Sweden AB.

OVAKO STEEL

Technical Report 2/2002

Ovatec 477™ – a new hardening and tempering steel for high quality components with air hardening capabilities

Thore Lund,
Patrik Ölund,
Maria Sjöstrand and
Henrik Sandqvist
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 targets is to offer our customers the best total economy in their production.

www.ovako.com

Background

Yesterday

Hardening and tempering, or quenching and tempering, is an imprecise term for the heat treatment used to provide medium carbon steels with adequate hardness and significant toughness. The German term ‘Vergütung’ or the Swedish ‘Seghärdning’ (tough hardening) covers the process better. Hardening and tempering is normally understood to through harden the components to full martensitic hardness (55 to 60 HRC) followed by tempering back to the hardness level desired, normally about 300 HB (30 HRC).

Today

Today, a large share of the steels used for component production is medium carbon steels which are hardened and tempered, and sometimes additionally surface induction hardened. Typical steels in this group, as SAE 4140, have won large volumes in the component and, for instance, the oil producing industries. Other significant application groups in this area are fasteners and springs.

Tomorrow

The Ovatec 477 has been designed to be a replacement for most steel grades used for components made out of medium carbon steels today. It 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. The production route can be simplified, is environmentally friendly and reduces cost. A simple cooling from the austenitising temperature can be used, avoiding quenching baths in a manner, which significantly can reduce hardening distortion.

And Ovatec 477 is a steel which has been engineered to provide maximum performance in stressed component applications with cost effective production routes.

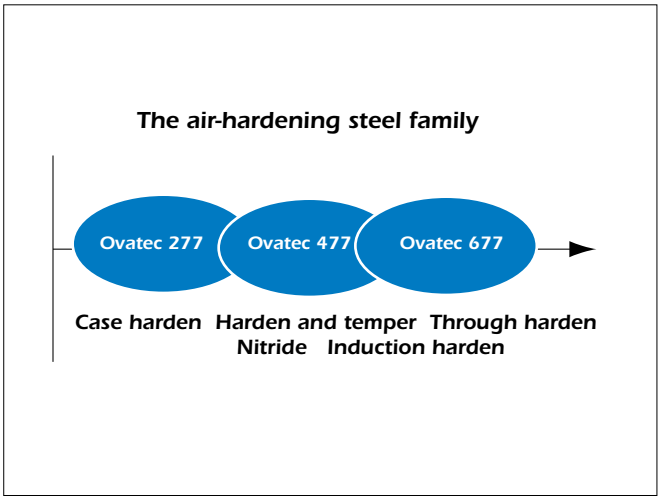
The Ovako Steel Ovatec™ Family

The alloying design concept in the Ovako Steel Ovatec family is the same: To provide steels for large scale component production which offer environmentally friendly 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, hardening and tempering or through hardening steels. Classifications of steel vary, and certain hardening and tempering 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, which 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 tempering 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 behavior
- Hardening results
- Heat treatment distortion
- Tempering influence on hardness and strength
- Dimensional stability
- Machinability in the hardened and tempered condition
- Processing directly from hot forming heat



Ovatec™ 477

Ovatec 477 is the hardening and tempering member of the Ovako Steel Ovatec family. It has been designed to enable environmentally friendly and safe heat treatment with significantly reduced risk of distortion for all components produced by hardening and tempering 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.

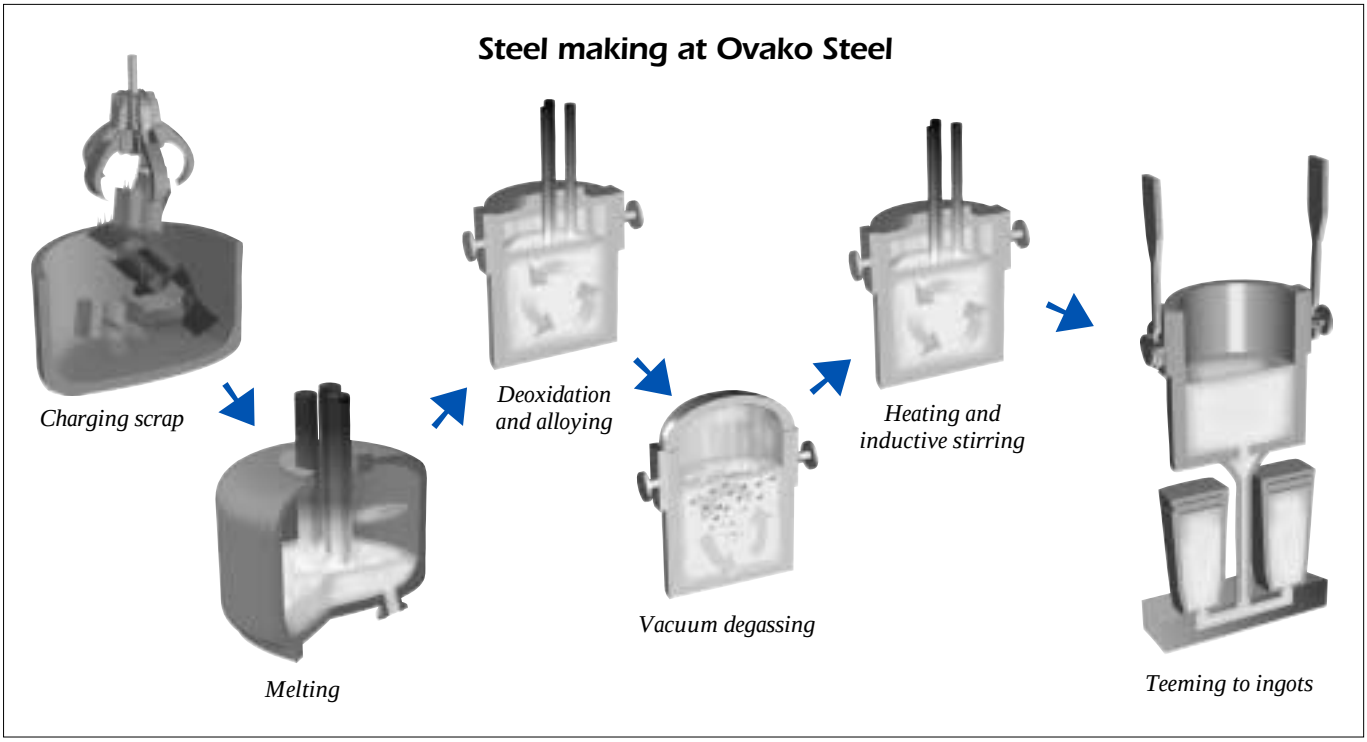


Figure 1 – Steel making at Ovako Steel.

Chemical composition

		C	Si	Mn	P	S	Cr	Ni	Mo	O (ppm)	Ti (ppm)
Ovatec 477L	Min	0.38	1.65	1.40		0.010	1.50		0.43		
	Max	0.42	1.80	1.55	0.020	0.020	1.60	0.30	0.47	11	30
Ovatec 477T	Min	0.38	1.65	1.40			1.50		0.43		
	Max	0.42	1.80	1.55	0.020	0.004	1.60	0.30	0.47	9	30

Table 1 – Chemical compositions of standard Bearing Quality (477L) and Premium Bearing Quality (477T).

Steel product production

Ovatec 477 is processed to tubes, bars, wire and rings in the same way as any other Ovako Steel product, and the same quality control procedures are applied. The only differences lies in the heat treatment condition in which the products can be supplied.

Delivery condition and properties in this condition

Standard hardening and tempering steels are today supplied and normally machined either in the as-rolled or normalized condition or in the hardened and tempered condition. The structure in as-rolled or normalized execution is a mixture of pearlite and ferrite, when hardened and tempered the structure is a highly tempered martensite / bainite. *(Figure 2 and 3)*

With Ovatec 477 the result of the cooling from hot forming temperature is a martensitic structure with high hardness instead of the pearlite structure generated in today's medium carbon steels.

This martensitic structure can be tempered back to a structure with fine, spheriodised carbides of any hardness selected between the as-rolled, fully martensitic hardness to a hardness of about 200 HB.

In the standard delivery condition, the steel is tempered back to a hardness of 280 - 310 HB. *(Figure 4)*

At this hardness level, the mechanical properties of Ovatec 477 are as follows:

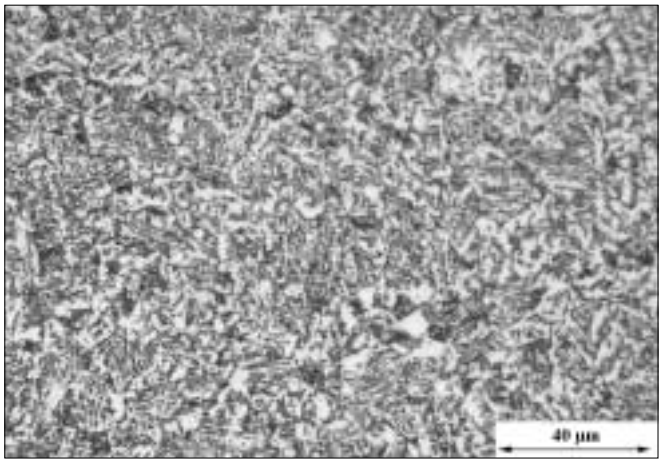


Figure 2 – Normalized structure of SAE 4140 (Ovako 327).

Tensile strength, R_m	1050 MPa
Yield strength, $R_{p\,0.2}$	900 MPa
Elongation, A_5	18 %
Area reduction, Z	53 %
Impact strength, KV	70 J
Hardness, HB	300 HB

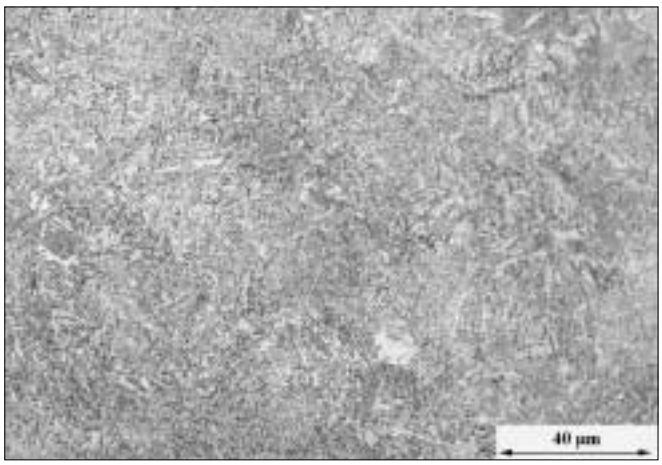


Figure 3 – Tough tempered structure of SAE 4140 (Ovako 327).

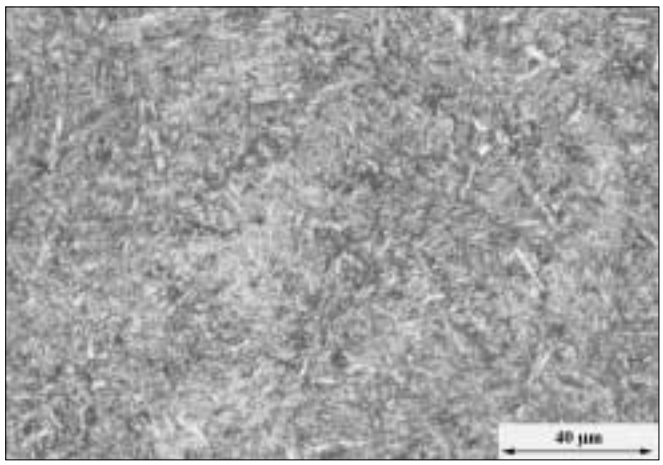


Figure 4 – Tough tempered structure of Ovatec 477.

By tempering back at higher temperatures for longer times, the hardness of Ovatec 477 can be reduced to lower levels, if this is required by the application.

Formability in the as delivered condition

Turning, has been tested for Ovatec 477 in comparison to standard harden and temper steels using the standardized ISO 3685 longitudinal turning test. Evidently, hardness largely controls the machinability. *(Figure 5)*

Welding

Ovatec 477 has a high carbon equivalent, and therefore welding must be made with caution. A tempering is recommended also after friction welding. *(Figure 6)*

Heat treatment procedure – standard heat treatment

In hardening of Ovatec 477, the austenitisation can be made within a wide temperature range, and can be followed by a slow cooling. Austenitisation can be made anywhere in the temperature range 900 to 1200° C, and no soaking time at temperature is required. The steel will transform to martensite even in slow, still air cooling for most industrial components through hardened today, but the steel naturally also can be conventionally quenched if so desired.

The advantage of air cooling is that such cooling can be made more homogeneous, 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 with a carbon potential which is slightly reduced compared to what often is used today, a carbon potential of about 0.4 % should be used. This in order to avoid carburisation of the surfaces.

Heat treatment procedure – special processes

Nitriding has been tested for Ovatec 477 in comparison to a standard harden and temper steel

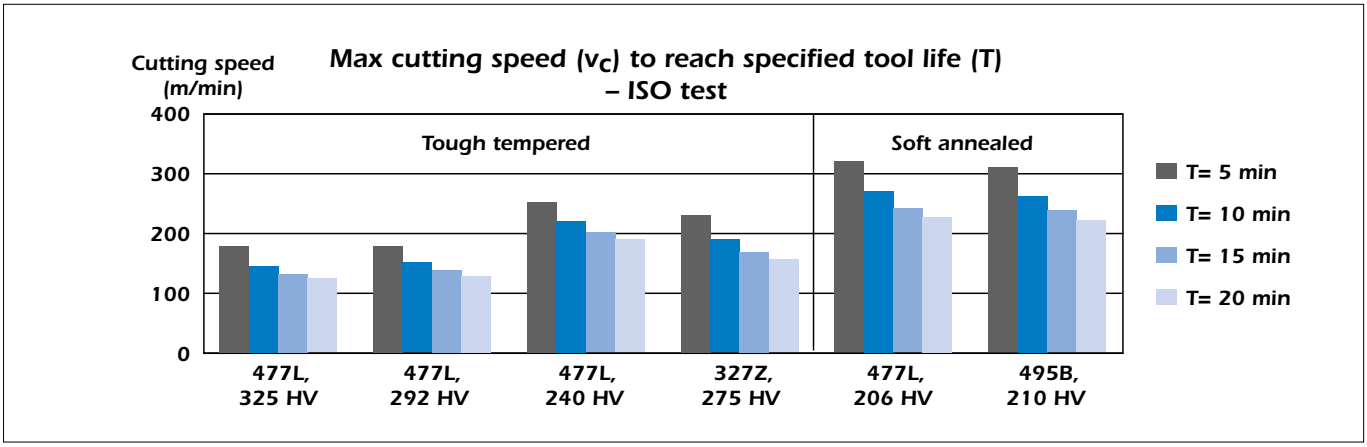


Figure 5 – vT curves for Ovatec 477, SAE 4140 (Ovako 327), and a high alloy tough temper steel (Ovako 495).

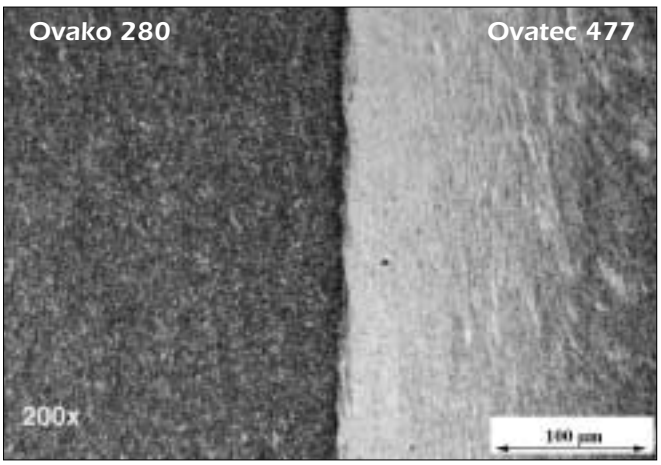


Figure 6 – Friction welding of Ovatec 477 against Ovako 280.

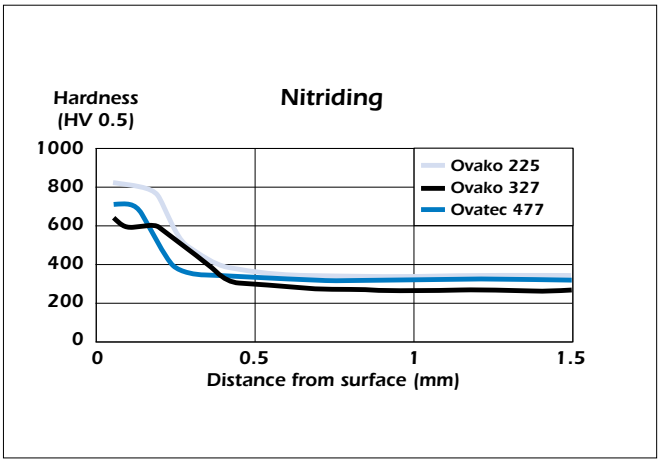


Figure 7 – Nitriding of Ovatec 477.

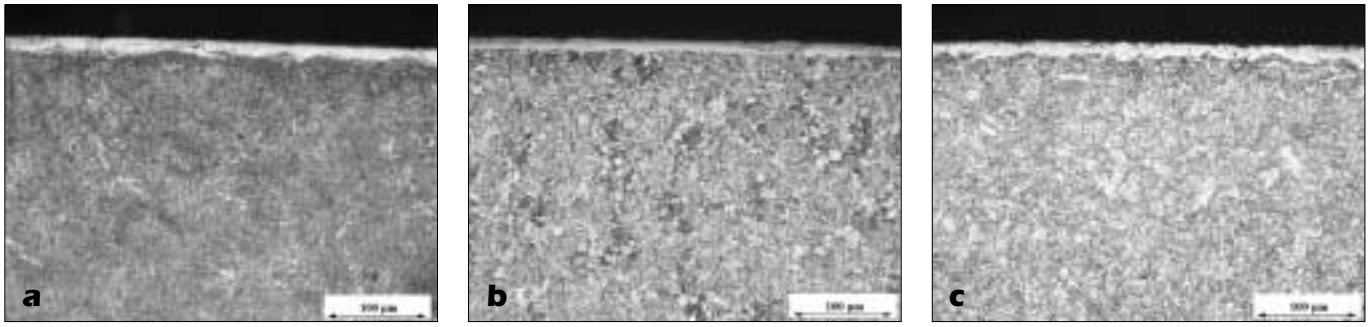


Figure 8 – White layer and microstructure of (a) Ovatec 477T, (b) Ovako 327A, and (c) Ovako 225A after nitriding.

(Ovako 327 – SAE 4140) and a nitriding steel (Ovako 225). The gas nitriding of Ovatec 477 resulted in high surface hardness, and as it retains its core hardness very well it lends itself well to nitriding. The hardness in the nitrided surface is also high for Ovatec 477. *(Figure 7 and 8)*

Carbonitrinding has also been tested for Ovatec 477 in comparison to a standard harden and temper steel and a nitriding steel and worked well.

As Ovatec 477 can be austenitised in a very wide temperature range, it is very suited for quick heating operations as induction-, magnetic- or laser heating. The hardening can then be made without any extra cooling media and after for example induction heating the components are simply allowed to air cool.

Heat treatment characteristics, transformation behavior

The austenitisation temperature 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.

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, even in fairly large size components, is much lower than for standard steels. *(Figure 9)*

Hardening results

With Ovatec 477 the properties will be equal regardless of the temperature used and hardened from, presuming temperatures have been high enough to austenitise the components.

The structure will be martensitic with some retained austenite. With increasing dimensions and slower cooling, bainite will form. *(Figure 10)*

Heat treatment distortion

The heat treatment distortion caused by the severe quenching required for the limited hardenability steels used today can largely be avoided, and this of course affects the amount of work required after heat treatment.

Tempering influence on hardness and strength

The Ovatec 477 steel retains its hardness better than standard steels. By selecting the proper tempering

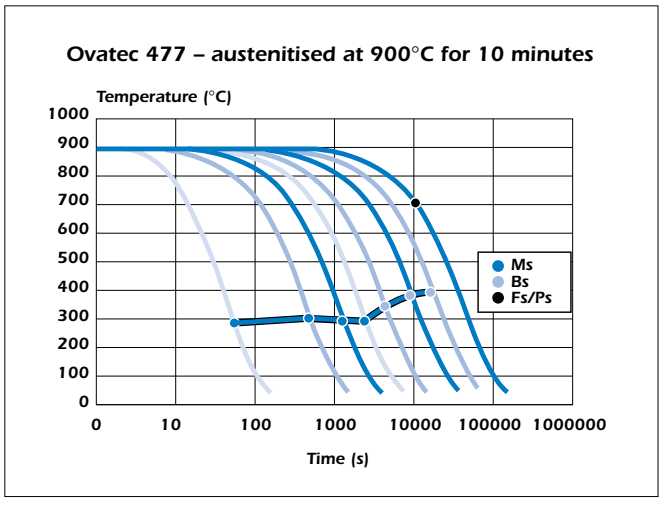


Figure 9 – CCT diagram for Ovatec 477.

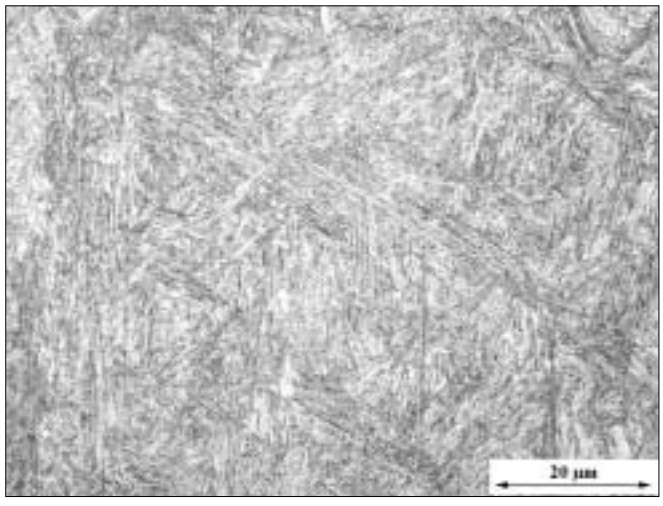


Figure 10 – Hardened structure of Ovatec 477.

temperature, the hardness and strength can be varied within wide limits. *(Figure 11)*

The high dimensional stability and the slow loss of hardness on tempering to some extent are due from the auto-tempering that occurs after the martensite formation, which occurs just above 400° C. *(Figure 12)*

The impact toughness of Ovatec 477 also varies with the hardness, of course. *(Figure 13)*

The impact toughness was tested at different impact temperatures to reveal the ductile-to-brittle transition for Ovatec 477. *(Figure 14)*

Dimensional stability

Ovatec 477 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. *(Figure 15)*

Processing directly from hot forming heat

Ovako 477 will, after a forging or rolling operation, air harden on the cooling. This opens some entirely new potential routes for component manufacturing. New manufacturing routes with reduced number of processing steps, and large positive impacts on energy and environment will be made available.

In particular, the combination of forging and air hardening gives attractive opportunities to reduce processing times and costs.

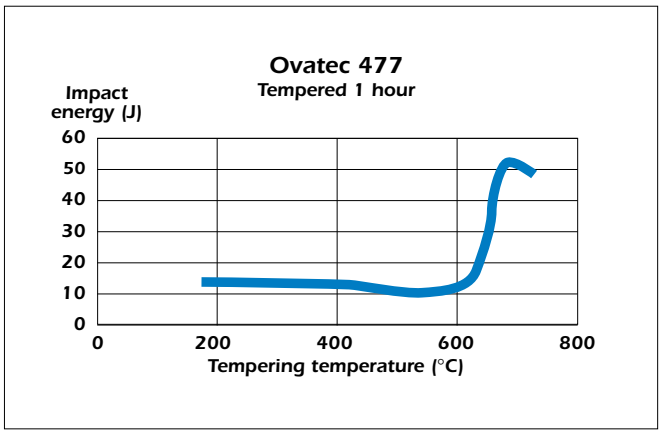


Figure 13 – Room temperature impact strength of Ovatec 477.

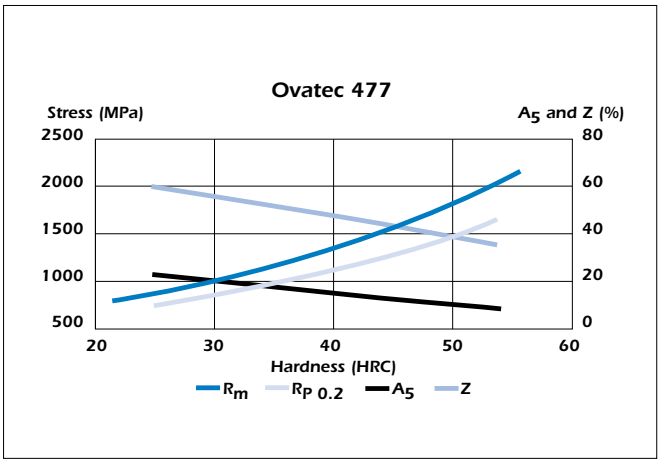


Figure 11 – Strength as function of hardness for Ovatec 477.

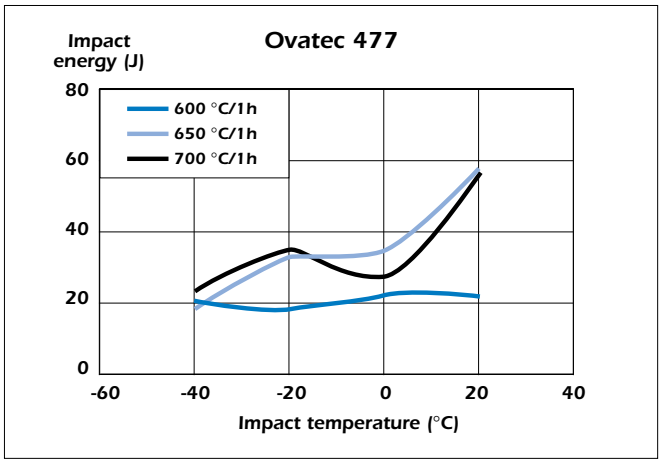


Figure 14 – Ductile-to-brittle transition in Ovatec 477.

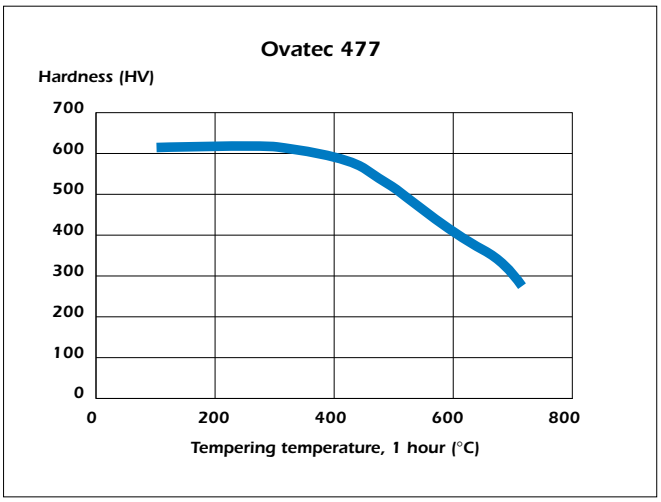


Figure 12 – Hardness as function of tempering temperature for Ovatec 477.

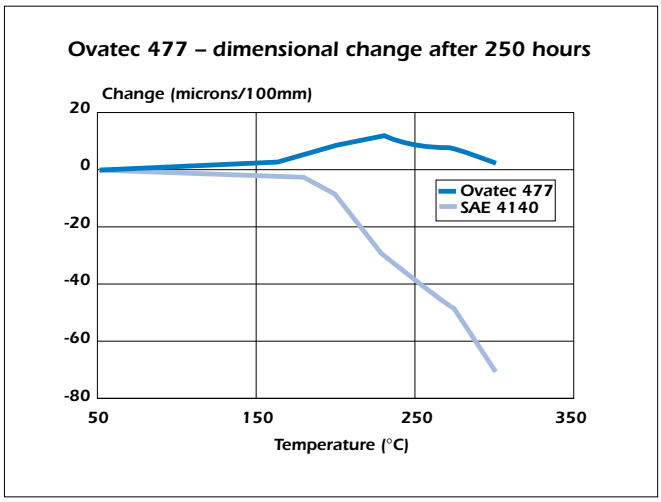


Figure 15 – Dimensional stability of Ovatec 477 and SAE 4140 (Ovako 327).

Conclusions

– The Ovako Steel air-hardening steel variants combine their air-hardenability with very high metallurgical cleanliness, good machinability and high product performance.
– The fundamental merits of the air-hardening steels are founded on the fact that today's quenching, which not only is a polluting health and safety risk but also expensive, can be avoided and replaced by cooling in air.
– Consequently, 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 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.

OVAKO STEEL
Technology & Quality
SE-813 82 Hofors, Sweden

www.ovako.com

RD-113US 05.02 2,000 Hällefors Tryckeri

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