Ovahyd™ 650 – a high performance steel for the hydraulic industry

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OVAHYD™ 650 – A HIGH PERFORMANCE STEEL FOR THE HYDRAULIC INDUSTRY

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 2004 is about properties and benefits using an Ovako grade named Ovako 277Q in high performance Hydraulic Cylinders. At that time this product was named Ovahyd 650.

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

Ovako 277 is a grade that is part of our current offer. In the Ovako Steel Navigator this material is described under the version names Ovako 277L and Ovako 277Q.

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.

Ovahyd® ; This trade mark is owned but no longer in use by Ovako Sweden AB.

Ovahyd 650; This was the product brand name for grade Ovako 277Q used in Hydraulic cylinders.

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Ovahyd™ 650
– a high performance steel for the hydraulic industry

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OVAKO STEEL
Excellence in engineering steels

OVAKO STEEL

Ovako Steel is the world's leading manufacturer of steels for rolling bearings and a major producer of other special engineering steels. The company is a fully owned subsidiary of AB SKF.

The production programme includes hot and cold worked products in the forms of bars, surface removed wire and seamless tubes. In addition the programme also includes rolled and forged rings. A large part of the production is further processed into precomponents for direct applications in the customers' production.

The most important customer groups are rolling bearing manufacturers, the automotive industry together with their subcontractors, suppliers of rock drilling equipment and the general engineering industry.

Ovako Steel has own production units in Sweden and France. The marketing is carried out by own sales companies or independent distributors on the most important markets in Europe and North America.

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.

Abstract

The Ovahyd family of steels will encompass a range of strength levels. One steel grade in the Ovahyd family is the Ovahyd 650. This steel has a guaranteed yield strength of 650 MPa, along with a transverse Charpy toughness in excess of 27 Joules at a test temperature of –40°C.

The manufacture of Ovahyd material requires a precisely controlled steelmaking practice so as to ensure a high degree of cleanliness and reproducibility. In order to achieve this, the production of Ovahyd material utilises knowledge from the Ovako Steel clean steel programme. This programme is one of continuous improvement in the reduction of harmful non-metallic inclusions in premium steels.

Background

The hydraulic industry is setting higher and higher demands on steel quality. Whilst the primary reasons are downsizing and cost reduction, there is also the fact that there have recently been several serious accidents at low temperature. These catastrophic failures have resulted in a demand for increased toughness.

The high internal pressures in hydraulic tubes leads to high stresses in both the longitudinal and the transverse direction. The tubes and bars for this industry must therefore have adequate strength and toughness in all directions.

Objectives for the new steel grade

The Ovahyd family of steels will encompass a range of strength levels. The steels have to be weldable and their machinability comparable to other high strength steels.

One steel grade in the Ovahyd family is Ovahyd 650. This steel has a guaranteed yield strength of 650 MPa, along with a transverse Charpy impact toughness in excess of 27 Joules at a test temperature of –40° C.

The Ovahyd™ 650 Steel

The manufacture of Ovahyd material requires a precisely controlled steel making practice so as to ensure a high degree of cleanliness and reproducibility.

In order to achieve this, the production of Ovahyd material utilises knowledge from the Ovako Steel clean steel programme.

This programme is one of continuous improvement in the reduction of harmful non-metallic inclusions in premium quality steels.

The nominal chemical composition of the steel can be seen in *Table 1*.

C	SI	Mn	Cr	Ni	Mo	V
0.15	0.10	1.3	2.2	0.5	0.5	0.2

Table 1 – Nominal composition of Ovahyd 650.

The strength of this steel arises from the precipitation of small carbides in the bainite/martensite microstructure; along with the presence of extremely small vanadium carbides, precipitated during tempering. The microstructure of Ovahyd 650 can be seen in *Figure 1*.

It is recognised that any steel grade with a bainitic/martensitic microstructure, with relatively small carbide particles, exhibit an optimum strength-toughness relationship. It is generally the case that the carbon precipitates as larger particles or plates, as in a ferrite/pearlite microstructure and this will always be detrimental to this relationship. This is because the larger features in these microstructures

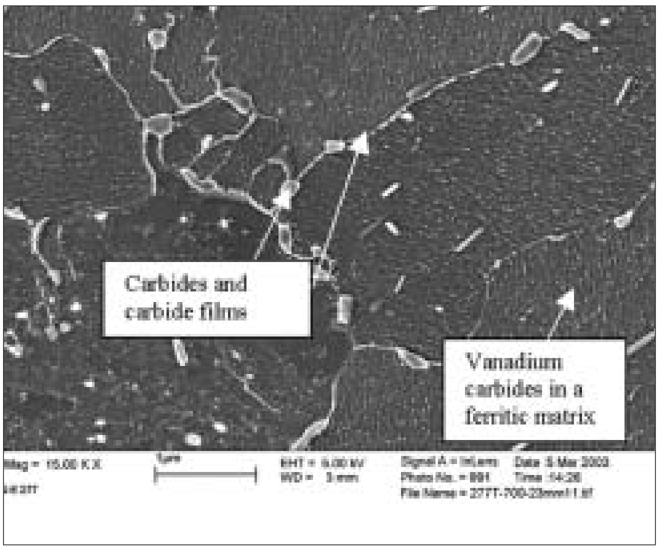

Figure 1 – Microstructure of Ovahyd 650 steel. Small carbides and carbide films in a ferritic matrix. Precipitated nano-meter sized vanadium carbides.

act as crack nuclei during deformation. The microstructure in *Figure 1*, shows the very small carbide particles, as well as extremely thin carbide films. Even smaller are the vanadium rich temper carbides.

Hardness and Hardenability

The alloying elements, chromium nickel manganese and molybdenum, makes the steel air-hardenable. Thin tubes as well as large diameter bars hardens into a martensitic bainitic microstructure with a hardness of 340-370 HB. This microstructure of martensite/bainite is much more homogenous than a conventional ferrite/pearlite microstructure and, as indicated above, has superior toughness for a given strength level. Large bars, in the as-rolled condition, have only a slightly lower hardness in the core compared to thin tubes, which can be seen in *Table 2*.

Product	Tube Wall thickness 12 mm	Tube Wall thickness 23 mm	Bar Ø 90 mm	Bar Ø 130 mm	Bar Ø 160 mm
As-rolled surface hardness	370 HB	370 HB	360 HB	360 HB	360 HB
As-rolled core hardness	370 HB	370 HB	350 HB	340 HB	340 HB

Table 2 – Hardness in as-rolled condition for various Ovahyd 650 products.

The low carbon content means that during welding, an acceptable hardness increase will be achieved in the Heat Affected Zone (HAZ). The HAZ will in most cases consist of a low-carbon lath martensite/bainitic microstructure due to the steels high hardenability. Vanadium is added to increase the strength of the steel due to precipitation hardening by vanadium carbides. These precipitates are in the nano-meter size range.

As part of the production process of Ovahyd material, a tempering treatment is applied to achieve the desired strength-toughness relation. The Ovahyd 650 variant is tempered at 700° C for three hours. Higher strengths can be achieved using a lower tempering temperature. See *Figure 2*.

Since the tempering for Ovahyd 650 is performed at 700° C, any thermal treatment under 650° C i.e. nitriding or nitrocarburising can be successfully

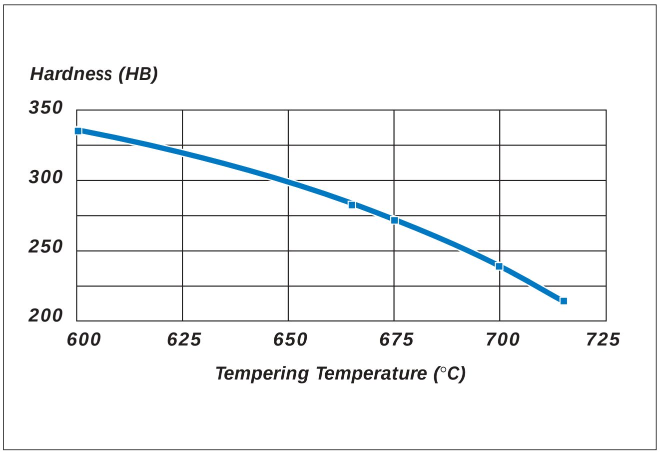

Figure 2 – Tempering response for the Ovahyd materials.

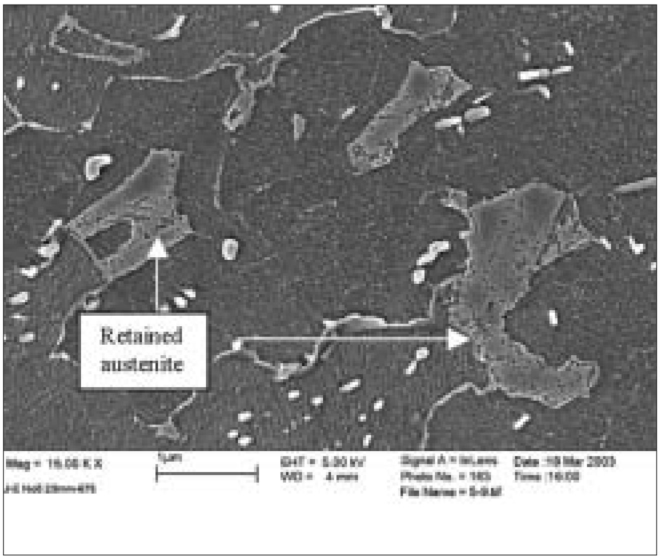

Figure 4 – Microstructure of low tempered Ovahyd 650 steel. Retained austenite is present in the microstructure.

carried out on this steel, with no detrimental effect on the mechanical properties.

Mechanical Properties

The yield strengths and the tensile strengths for various hardnesses can be seen in *Figure 3*. These are results taken from production as well as from laboratory tests with various tempering treatments in order to generate a range of different hardnesses. Results are from tubes of various wall thickness and from bars up to a diameter of 160 mm.

The tensile strength has a linear relationship with hardness but the yield strength drops off at higher hardnesses. This is due to the relatively low tempering temperature for these hardnesses, which does not fully precipitate the carbon or transform all of the retained austenite during tempering. Both these effects result in a lowering of the yield strength. *Figure 4.*

The Ovahyd 650 is tempered to a hardness of 230-240 HB, which ensures a yield strength in excess of 650 MPa. The tensile strength for that hardness is above 750 MPa.

The elongation and the reduction of area can be seen in *Figure 5*. These values are an indication of the deformability of the steel.

Ovahyd 650 has an elongation of more than 18% and a reduction of area exceeding 70%. The values in *Figure 3 and 5* are from production and laboratory tests and involve, as all of the mechanical tests, a single tempering at various temperatures from an as-rolled microstructure.

Charpy Toughness

Toughness is the ability of a metal to absorb energy and deform plastically before fracturing. The amount of energy absorbed during deformation and fracture is a measure of the toughness of the metal.

Normally a defined value of the energy (often 27 Joules) is chosen to distinguish between a fibrous, ductile fracture from a crystalline fracture.

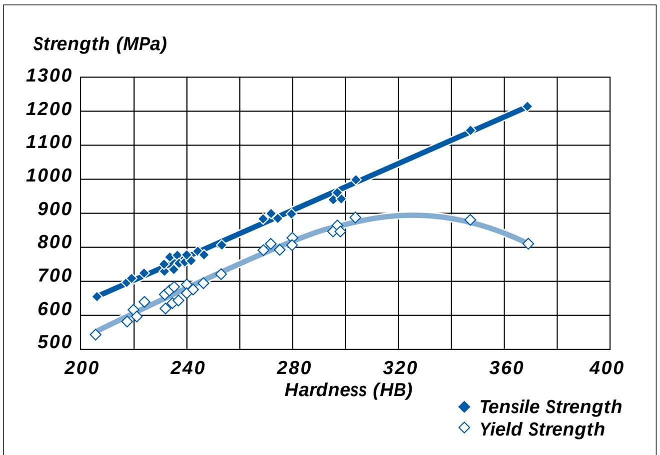

Figure 3 – Yield strengths and tensile strengths for various hardnesses for Ovahyd material.

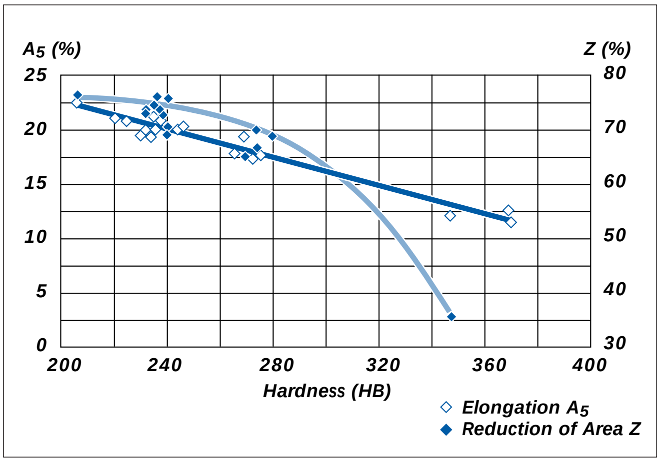

Figure 5 – Elongations and reduction of area for Ovahyd material at various hardnesses.

For the testing of Ovahyd material, a Charpy Impact testing machine, with an instrumented striking edge has been used. This instrumentation records the force over time, which enables not only the measurement of the energy absorption, but also distinguishes between a brittle or ductile fracture.

Two impact test results from Ovahyd material can be seen in *Figure 6*, where also the range of brittle (elastic) and ductile (plastic) are shown. The test was performed on samples taken from the transverse direction of a tube. Both tests indicate a ductile fracture behaviour, although the harder material (tempered at a lower temperature) exhibits unstable crack propagation at shorter times. This has resulted in a reduction of the total energy absorption, 46 J instead of 156 J for the more ductile fracture.

Results from various tube sizes of Ovahyd 650 can be seen in *Figure 7*. Tube wall thickness of 12 mm to 30 mm have been evaluated, both from the production as well as from laboratory tests and average results are presented. All of the tests showed more or less plastic deformation behaviour.

Results from bars produced in different diameters can be seen in *Figure 8*. These results are from bar diameters between 90 mm and 160 mm. The results in the longitudinal direction are an average of the core and surface tests. There were no major differences in the results from different bar sizes, so an average of all bar sizes is presented. All of the tests showed more or less plastic deformation behaviour.

A summary of average Charpy results in the transverse direction for various hardnesses can be seen in *Figure 9*. These are results from tubes with wall thicknesses between 12 mm and 30 mm. In order to fulfil the toughness value of 27 Joule at – 40° C, a maximum hardness of 280HB can be used for a single tempering of an as-rolled product. As expected the toughness will increase with lower hardness.

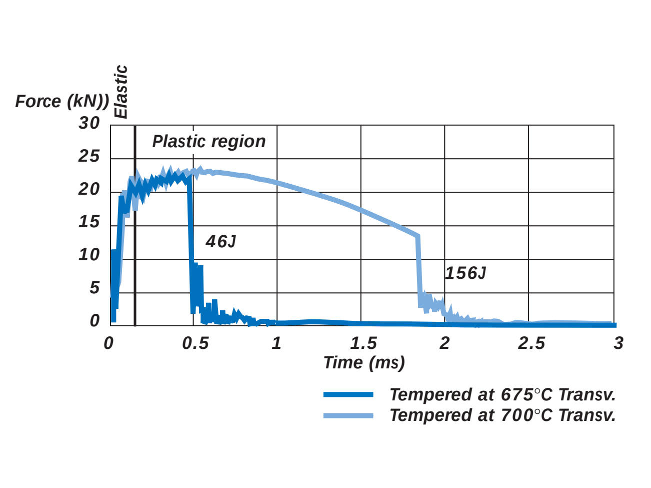

Figure 6 – Results from instrumented Charpy tests of Ovahyd 650 material tested in the transverse direction for two different tempering temperatures. Testing temperature was –20° C.

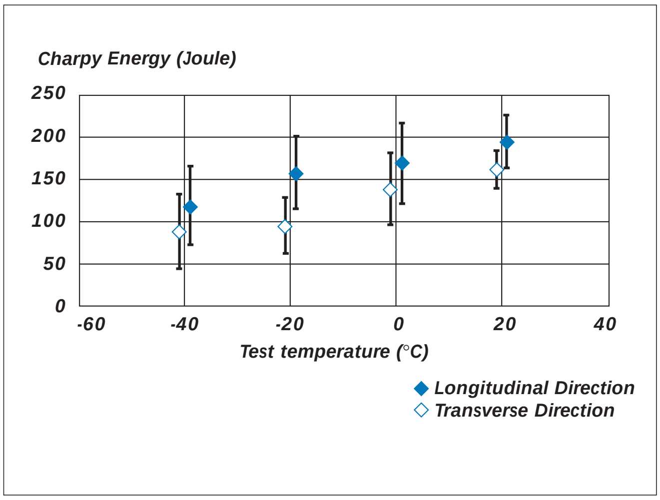

Figure 7 – Average Charpy toughness results for various tube sizes of the Ovahyd 650 material.

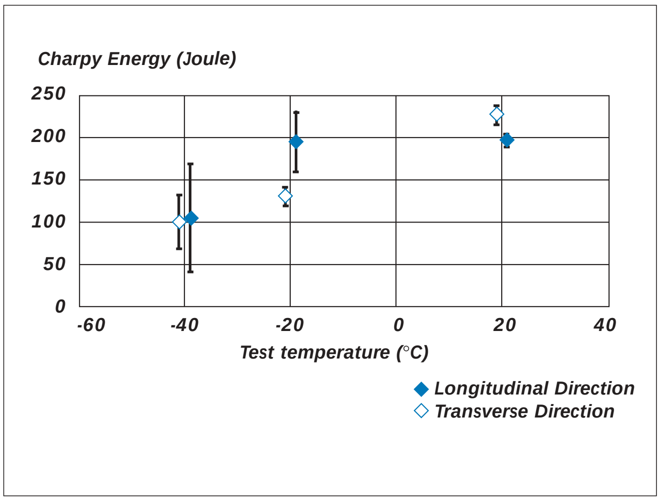

Figure 8 – Average Charpy toughness results for various bar sizes of the Ovahyd 650 material.

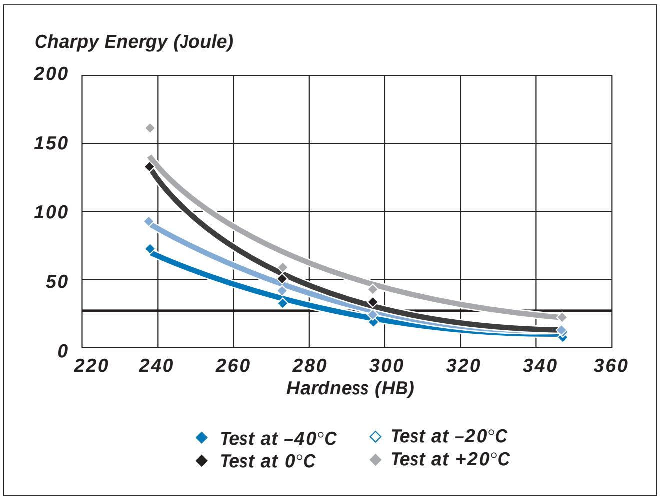

Figure 9 – Average Ovahyd 650 tube Charpy results for different hardnesses. This is from specimens taken in the transverse direction.

Non-metallic inclusion measurements

To meet the increasing demands from the hydraulic industry, the Ovahyd 650 steel with a modified non-metallic inclusion population has been developed.

The particles that control the toughness of these steel types, in the transverse direction, in the hardness range examined, are the non-metallic inclusions. This is due to the fact that the small carbides generated in the Ovahyd martensitic/bainitic microstructure do not significantly affect the toughness. Images of a standard steel and modified Ovahyd 650 non-metallic inclusion population can be seen in *Figures 10 and 11*.

The automatic non-metallic inclusion measurements within this project have been performed on steel samples, using a LEO Scanning Electron Microscope, incorporating the 'Feature' software package, from Oxford Instruments. This involves the capture of a backscatter electron image, which is subsequently processed using standard image analysis techniques and finally, the identification of each inclusion present is made with EDS analysis.

Results from Ovahyd 650 material and standard material have been evaluated.

The inclusion populations have been measured on Charpy specimens with an examined area of approximately 300 mm². The results (see *Figure 12)* show the accumulated number of inclusions per mm². The main difference between the steels can be seen in the longitudinal (length) direction, which is the rolling direction

To correlate the Charpy values to the amount of non-metallic inclusions is difficult. The Charpy value depends on the microstructure and the ability of the metal crystals to deform as well as the amount of particles that acts as crack nuclei. A total length of the inclusions in longitudinal and transverse direction has been normalised by the area. This can be seen in *Figure 13*. This evaluation gives a first indication if the steel can reach high impact strength or not.

Charpy tests carried out on these two materials can be seen in *Figure 14.* Apparently for these steels with a martensitic/bainitic microstructure, in the

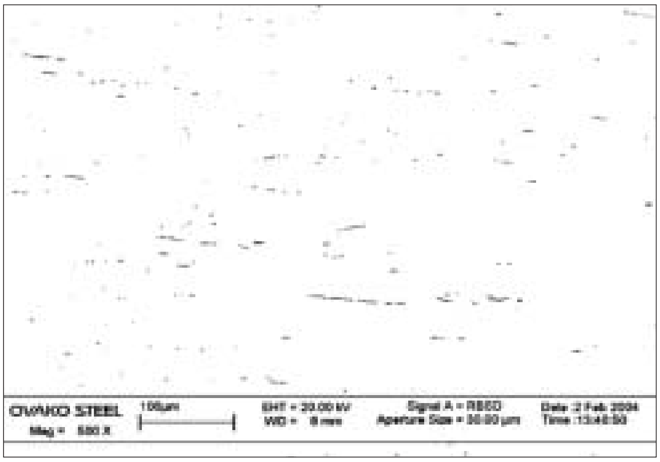

Figure 10 – Steel with standard non-metallic inclusion population. Photo taken in the longitudinal direction.

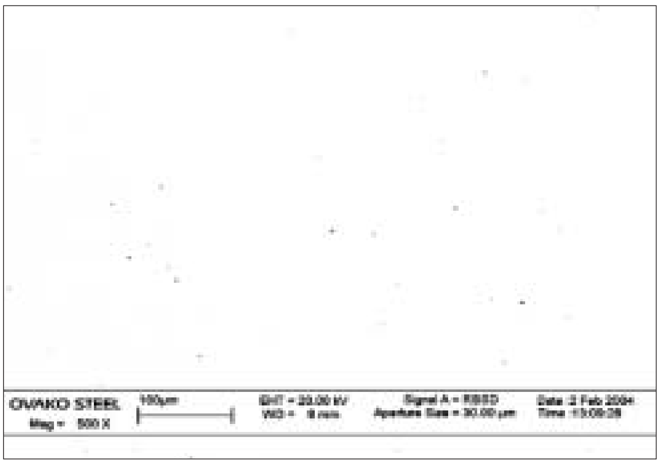

Figure 11 – Ovahyd 650 material with a modified non-metallic inclusion content. Photo taken in the longitudinal direction.

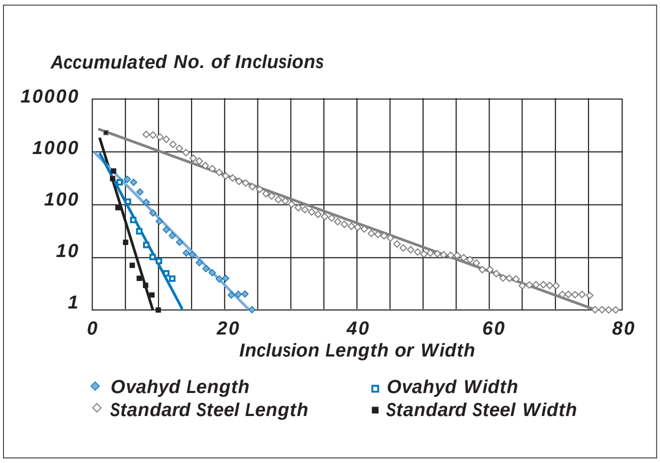

Figure 12 – Non-metallic inclusions evaluation for Ovahyd 650 material and a standard steel.

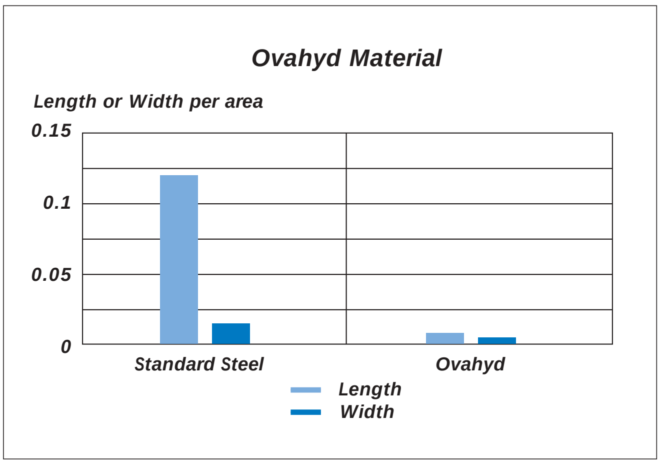

Figure 13 – Summary of non-metallic inclusion measurements for Ovahyd 650 material and a standard steel.

temperature range tested, an inclusion evaluation value of less than 0.020 length or width per area seem not to adversely affect the toughness value. However, a value of 0.12 per mm^2 affects the toughness drastically, but exactly at what value the non-metallics come into play will be explored in more detail in the future. This value will probably depend on steel grade and material strength.

The toughness in the transverse direction of the steel with a standard non-metallic inclusion content is what can be expected for existing grades of constructional steels.

The transverse Charpy test of these steel types is the only test where a totally crystalline fracture appears. This can be seen in *Figure 15*, where the force-time plots of the various tests are displayed and specimens from these steel in the transverse direction cracks in the elastic region although this material has a slightly lower strength or hardness. The three transverse tested specimen with a standard non-metallic inclusion population cracks after approximately 0.2ms.

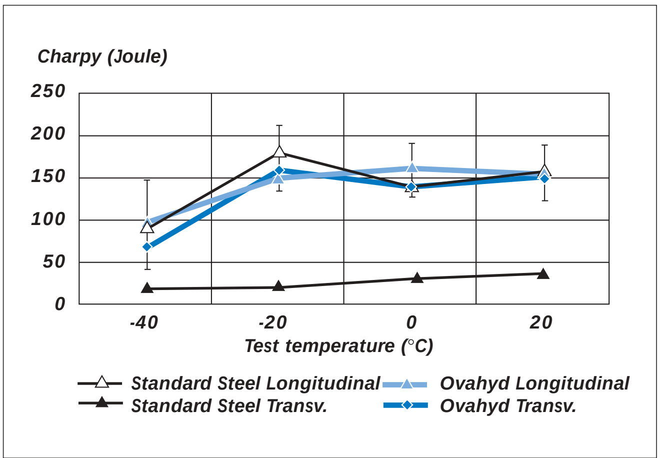

Figure 14 – Charpy results for a standard steel and a modified (Ovahyd 650) non-metallic inclusion population.

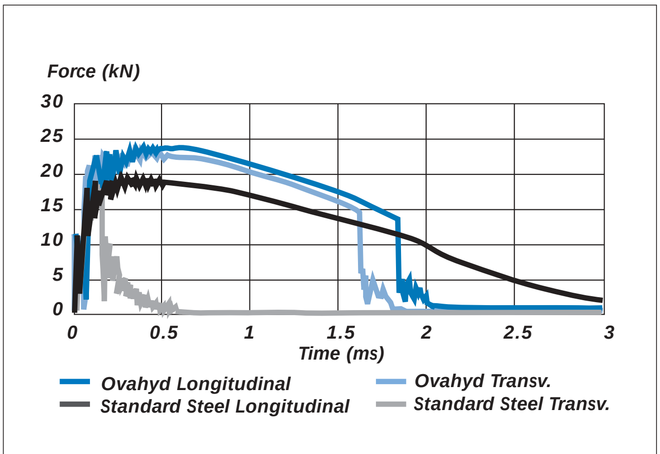

Figure 15 – Force-Time plots for the same steel with different non-metallic inclusion populations.

This example shows also another reason why force-time recordings are very useful. The maximum force is an indication of the strength or the hardness of the material and hardness outliers can easily be spotted. The improved toughness, in the transverse direction for the modified Ovahyd material is only due to the reduced amount of non-metallic inclusion.

Weldability

Tests have been performed in order to evaluate the weldability of the Ovahyd material.

It has been established that Ovahyd 650 can readily be welded, the results for a 'Tekken test' with a combined wall thickness of 54 mm, gave the following recommendations.

Ferritic electrode material should be used along with the moderate preheating temperature of 175° C, when combined with a heat input (Q) of 1.7 kJ/mm.

The hardness requirements according to EN 288-3 were fulfilled for a test with a heat input of 0.9 kJ/mm. A rise of approximately 50 hardness units, HV (1), was measured.

Machinability

Results from machinability tests, performed in accordance with ISO 3685 can be seen in *Figure 16*. Ovahyd 650 has high machinability for its strength level. Wear analysis in drilling has also been performed and the conclusions were that tool life and chip formation are fully accepable both for HSS and carbide drills. Carbide drills are a good choice for this material.

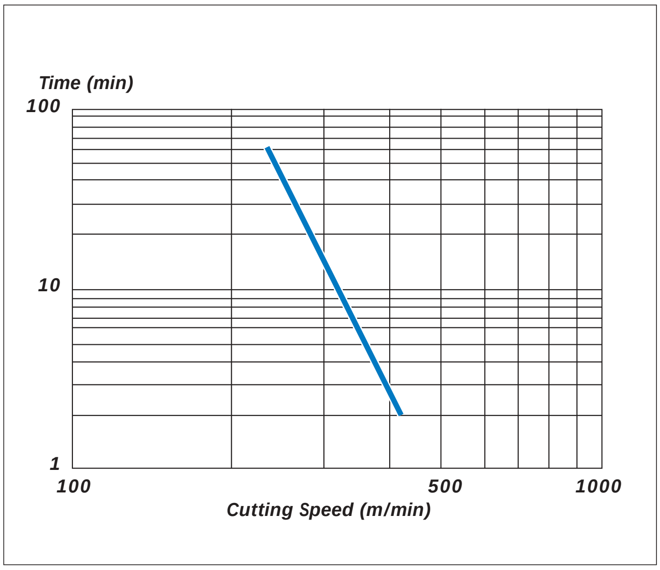

Figure 16 – Tool life data for Ovahyd 650 material.

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