HEAT TREATMENT OF TOOL STEEL

UDDEHOLM

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The purpose of this brochure is to provide some idea of how tool steel is heat treated and how it behaves.

Special attention is paid to hardness, toughness and dimensional stability.

What is tool steel?

Uddeholm has concentrated its tool steel range on high alloyed types of steel, intended primarily for purposes such as plastics moulding, blanking and forming, die casting, extrusion, forging and wood-working.

Conventional high speed steels and powder metallurgy (PM) steels are also included in the range.

Tool steel is normally delivered in the soft annealed condition. This is to make the material easy to machine with cutting tools and to give it a microstructure suitable for hardening.

The microstructure consists of a soft matrix in which carbides are embedded. In carbon steel, these carbides consist of iron carbide, while in the alloyed steel they are chromium (Cr), tungsten (W), molybdenum (Mo) or vanadium (V) carbides, depending on the composition of the steel. Carbides are compounds of carbon and these alloying elements and are characterized by very high hardness. A higher carbide content means higher resistance to wear.

In alloy steels, it is important that the carbides are evenly distributed.

Other alloying elements are also used in tool steel, such as cobalt (Co) and nickel (Ni), but these do not form carbides. Cobalt is normally used to improve red hardness in high speed steels, nickel to improve through-hardening properties.

Hardening and tempering

When a tool is hardened, many factors influence the result.

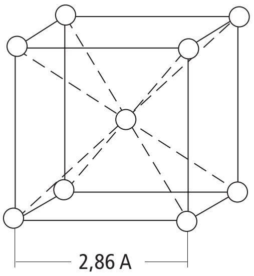
SOME THEORETICAL ASPECTS

In soft annealed tool steel, most of the alloying elements are bound up with carbon in carbides. In addition to these there are the alloying elements cobalt and nickel, which do not form carbides but are instead dissolved in the matrix.

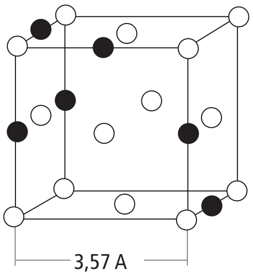
When the steel is heated for hardening, the basic idea is to dissolve the carbides to such a degree that the matrix acquires an alloying content that gives the hardening effect—without becoming coarse grained and brittle.

○ = Iron atoms

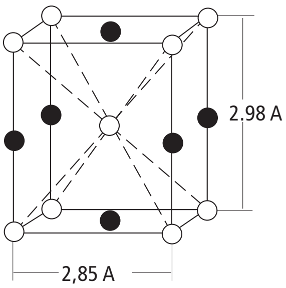
● = Possible positions for carbon atoms



Unit cell in a ferrite crystal
Body centred cubic (BCC)



Unit cell in an austenite crystal
Face centred cubic (FCC)



Unit cell in a martensite crystal

Note that the carbides are partially dissolved. This means that the matrix becomes alloyed with carbon and carbide-forming elements.

When the steel is heated to the hardening temperature (austenitizing temperature), the carbides are partially dissolved, and the matrix is also altered. It is transformed from ferrite to austenite. This means that the iron atoms change their position in the atomic lattice and make room for atoms of carbon and alloying elements. The carbon and alloying elements from the carbides are dissolved in the matrix.

If the steel is quenched sufficiently rapid in the hardening process, the carbon atoms do not have time to reposition themselves to allow the reforming of ferrite from austenite, i.e. as in annealing. Instead, they are fixed in positions where they really do not have enough room, and the result is high microstresses that can be defined as increased hardness. This hard structure is called martensite. Thus, martensite can be seen as a forced solution of carbon in ferrite.

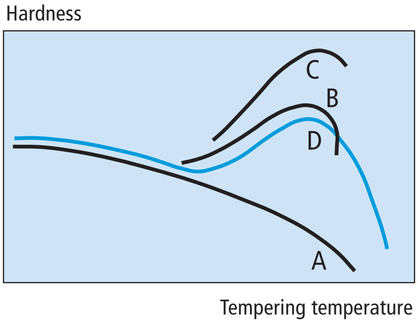
When a steel is hardened, the matrix is not completely converted into martensite. Some austenite is always left and is called "retained austenite". The amount increases with increasing alloying content, higher hardening temperature and longer soaking times.

After quenching, the steel has a microstructure consisting of martensite, retained austenite and carbides. This structure contains inherent stresses that can easily cause cracking. But this can be prevented by reheating the steel to a certain temperature, reducing the stresses and transforming the retained austenite to an extent that depends upon the reheating temperature. This reheating after hardening is called tempering. *Hardening of a tool steel should always be followed immediately by tempering.*

It should be noted that tempering at low temperatures only affects the martensite, while tempering at high temperature also affects the retained austenite.

After one tempering at high temperature, the microstructure consists of tempered martensite, newlyformed martensite, some retained austenite and carbides.

Precipitated secondary (newly formed) carbides and newly formed martensite can increase hardness during high-temperature tempering. Typical of this is the so called secondary hardening of e.g. high speed steel and high alloyed tool steels.



A = martensite tempering
B = carbide precipitation
C = transformation of retained austenite to martensite
D = tempering diagram for high speed steel and high alloy tool steel
A+B+C = D

The diagram shows the influence of different parameters on the secondary hardening.

Tool steel should always be double-tempered. The second tempering takes care of the newly formed martensite formed after the first tempering. Three tempers are recommended for high speed steel with a high carbon content.

Tempered once.

Tempered twice. 1000x

Uddeholm Rigor, hardened and tempered.

HOW HARDENING AND TEMPERING IS DONE IN PRACTICE

Distortion due to hardening must be taken into consideration when a tool is rough-machined. Rough machining causes local heating and mechanical working of the steel, which gives rise to inherent stresses. This is not serious on a symmetrical part of simple design, but can be significant in asymmetrical machining, for example of one half of a die casting die. Here, stress relieving is always recommended.

Stress relieving

This treatment is done after rough machining and entails heating to 550–650°C (1020–1200°F). The material should be heated until it has achieved uniform temperature all the way through and then cooled slowly, for example in a furnace.

The idea behind stress relieving is that the yield strength of the material at the elevated temperature is so low that the material cannot resist the inherent stresses. The yield strength is exceeded and these stresses are released, resulting in a greater or lesser degree of distortion.

The correct work sequence is: rough machining, stress relieving and semifinish machining.

The excuse that stress relieving takes too much time is hardly valid. Rectifying a part during semifinish machining of an annealed material is with few exceptions cheaper than making dimensional adjustments during finish machining of a hardened tool.

Heating to hardening temperature

The fundamental rule for heating to hardening temperature is that it should take place slowly. This minimizes distortion.

In vacuum furnaces and furnaces with controlled protective gas atmosphere, the heat is increased gradually. When molten salt baths are used, preheating is employed, whereas heating is automatically slow in a muffle furnace when steel is packed in castiron chips.

In a fluidized bed the advantages of salt bath and protective atmosphere are combined. Heating and cooling rates can be compared with salt bath. The Al-oxides and gas used as protective atmosphere are less detrimental to the environment than salt bath.

It is important that the tools are protected against oxidation and decarburization. The best protection is provided by a vacuum furnace, where the surface of the steel remains unaffected.

Furnaces with a controlled protective gas atmosphere or salt baths also provide good protection.

If an electric muffle furnace is used, the tool can be protected by packing it in spent charcoal or cast iron chips.

It should be observed that these packing materials can have a carburizing effect if the steels have a low carbon content, such as conventional hot work steels.

Vacuum furnace

Salt bath furnace

Batch type furnace with a controlled atmosphere

Wrapping in stainless steel foil also provides good protection when heating in a muffle furnace.

Decarburization results in low surface hardness and a risk of cracking.

Carburization results in a harder surface layer, which can have negative effects.

Holding time at hardening temperature

It is not possible to state exact recommendations briefly to cover all heating situations.

Factors such as furnace type, furnace rating, temperature level, the weight of the charge in relation to the size of the furnace etc., must be taken into consideration in each case.

We can, however, give one recommendation that is valid in virtually all situations:

- when the steel has reached hardening temperature through its entire thickness, hold at this temperature for 30 minutes. An exception to this rule is for thin parts heated in salt baths at high temperature, or high speed steel. Here the entire period of immersion is often only a few minutes.

Quenching

The choice between a fast and slow quenching rate is usually a compromise; to get the best microstructure and tool performance, the quenching rate should be rapid; to minimize distortion, a slow quenching rate is recommended.

Slow quenching results in less temperature difference between the surface and core of a part, and sections of different thickness will have a more uniform cooling rate.

This is of great importance when quenching through the martensite range, below the M_S temperature. Martensite formation leads to an increase in volume and stresses in the material. This is also the reason why quenching should be interrupted before room temperature has been reached, normally at 50–70°C (120–160°F).

However, if the quenching rate is too slow, especially with heavier cross-sections, undersirable transformations in the microstructure can take place, risking a poor tool performance.

Water is used as a quenching medium for unalloyed steels. 8–10% sodium chloride (salt) or soda should be added to the water in order to achieve optimum cooling efficiency. Water hardening can often cause problems in the form of distortion and quench cracks. Oil hardening is safer, but hardening in air or martempering is best of all.

Oil should be used for *low alloyed steels.* The oil should be of good quality, and preferably of the rapid quenching type. It should be kept clean and must be changed after a certain period of use. Hardening oils should have a temperature of 50–70°C (140–160°F) to give the best cooling efficiency. Lower temperatures mean higher viscosity, i.e. the oil is thicker.

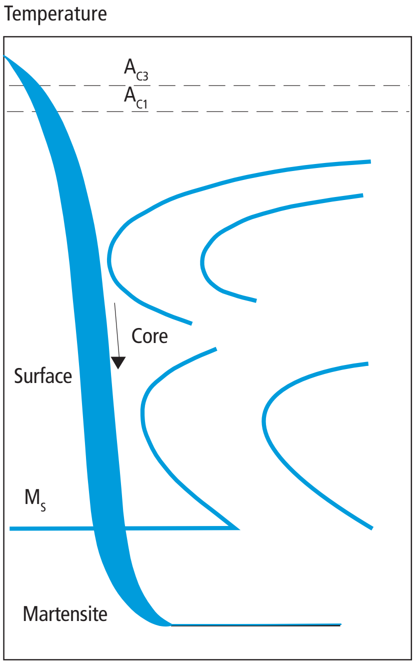
Hardening in oil is not the safest way to quench steel, in view of the risks of distortion and hardening cracks. These risks can be reduced by means of *martempering*. In this process, the material is quenched in two steps. First it is cooled from hardening temperature in a salt bath whose temperature is just above the M_S temperature. It is kept there until the temperature has equalized between the surface and the core, after which the tool can be allowed to cool freely in air down through the martensite transformation range.

When martempering oil hardening steels, it should also be kept in mind that the material transforms relatively rapid and should not be kept too long at the martempering bath temperature. This can lead to excessive bainite transformation and the risk of low hardness.

High alloy steels can be hardened in oil, a martempering bath or air. The advantages and disadvantages of the different methods can be discussed.

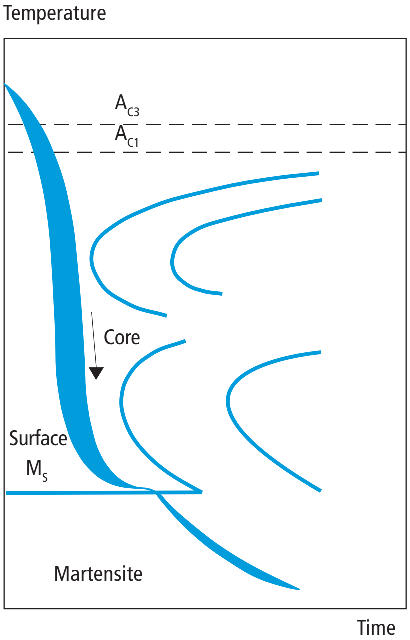
Oil gives a good finish and high hardness, but it also maximizes the risk of excessive distortion or cracking. In the case of thick parts, quenching in oil is often the only way to achieve maximum hardness.

Martempering in salt bath produces a good finish, high hardness and less risk of excessive distortion or cracking. For certain types of steel, the temperature of the salt bath is normally kept at about 500°C (930°F). This temperature ensures a relatively mild thermal shock, but a sufficient cooling rate to avoid phase transformations.



The quenching process as expressed in a TTT graph

Full martensite transformation has, in many cases, time to occur when the steel is cooled in air from the martempering bath temperature. However, if the dimensions are big, it is often necessary to use a forced quenching rate depending of the hardenability of the steel.

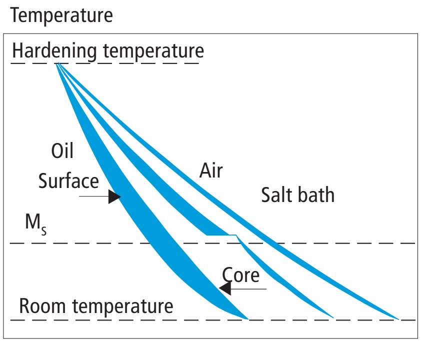


Martempering

Air quenching entails the least risk of excessive distortion. A tendency towards lower hardness is noticeable at greater thicknesses. One disadvantage is a poorer finish.

Some oxidation takes place when the material comes into contact with air and cools slowly from the high hardening temperatures.

The choice of quenching medium must be made from job to job, but a general recommendation could perhaps be made as follows:



Cooling rates for various media

A martempering bath is the safest in most cases.

Air is used when dimensional stability is crucial.

Oil should be avoided and used only when it is necessary to achieve satisfactory hardness in heavy sections.

Three well known quenching methods have been mentioned here. Some new concepts have been introduced with modern types of furnaces, and the technique of quenching at a controlled rate in a *protective gas atmosphere* or in a *vacuum furnace with gas* is becoming increasingly widespread. The cooling rate is roughly the same as in air for protective gas atmosphere, but the problem of oxidized surfaces is eliminated. Modern vacuum furnaces have the possibility to use overpressure during quenching which increases the quenching speed. The surfaces are completely clean after a vacuum hardening,

With these techniques, as with quenching in air, the risks of excessively slow cooling must be borne in mind, even for vacuum furnaces if no overpressure is used. The effect is that surface hardness is normally lower than expected. Hardness in the centre of heavy sections is even lower.

This effect can be critical with high speed steel and hot work steel, where a centre section can be cooled so slowly that carbide precipitation takes place on the way down. Here, the matrix becomes depleted of carbon and carbide-forming alloying elements. The result is reduced hardness and strength of the core.

Tempering

The material should be tempered immediately after quenching. Quenching should be stopped at a temperature of 50–70°C (120–160°F) and tempering should be done at once. If this is not possible, the material must be kept warm, e.g. in a special "hot cabinet", awaiting tempering.

The choice of tempering temperature is often determined by experience. However, certain guidelines can be drawn and the following factors can be taken into consideration:

- hardness
- toughness
- dimension change.

If maximum hardness is desired, temper at about 200°C (390°F), but never lower than 180°C (360°F). High speed steel is normally tempered at about 20°C (36°F) above the peak of the secondary hardening temperature.

If a lower hardness is desired, this means a higher tempering temperature. Reduced hardness does not always mean increased toughness, as is evident from the toughness values in our product brochures. Avoid tempering within temperature ranges that reduce toughness. If dimensional stability is also an important consideration, the choice of tempering temperature must often be a compromise. If possible, however, priority should be given to toughness.

How many tempers are required?

Two tempers are recommended for tool steel and three are considered necessary for high speed steel with a high carbon content, e.g. over 1%.

Two tempers are always recommended. If the basic rule in quenching is followed—to interrupt at 50–70°C (120–160°F)—then a certain amount of austenite remains untransformed when the material is to be tempered. When the material cools after tempering, most of the austenite is transformed to martensite. It is untempered. A second tempering gives the material optimum toughness at the hardness in question.

The same line of reasoning can be applied with regard to retained austenite in high speed steel. In this case, however, the retained austenite is highly alloyed and slow transforming. During tempering, some diffusion takes place in the austenite, secondary carbides are precipitated, the austenite becomes lower alloyed and is more easily transformed to martensite when it cools after tempering. Here, several temperings can be beneficial in driving the transformation of the retained austenite further to martensite.

Holding times in connection with tempering

Here also, one should avoid all complicated formulae and rules of thumb, and adopt the following recommendation: *After the tool is heated through, hold the material for at least 2 hours at full temperature each time.*

Convection type tempering furnace

Dimensional and shape stability

DISTORTION DURING THE HARDENING AND TEMPERING OF TOOL STEEL

When a piece of tool steel is hardened and tempered, some warpage or distortion normally occurs. This distortion is usually greater at high temperature.

This is well known, and it is normal practice to leave some machining allowance on the tool prior to hardening. This makes it possible to adjust the tool to the correct dimensions after hardening and tempering by grinding, for example.

How does distortion take place?

The cause is stresses in the material. These stresses can be divided into:

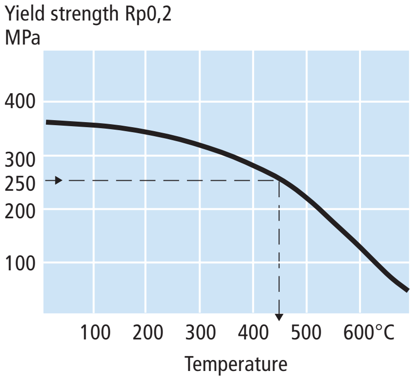
- machining stresses
- thermal stresses
- transformation stresses.

Machining stresses

This type of stress is generated during machining operations such as turning, milling and grinding. (For example, such stresses are formed to a greater extent during cold forming operations such as blanking, bending and drawing.)

If stresses have built up in a part, they will be released during heating. Heating reduces strength, releasing stresses through local distortion. This can lead to overall distortion.

In order to reduce this distortion while heating during the hardening process, a stress relieving operation can be carried out prior to the hardening operation. It is recommended that the material be stress relieved after rough machining. Any distorsion can then be adjusted during semifinish machining prior to the hardening operation.

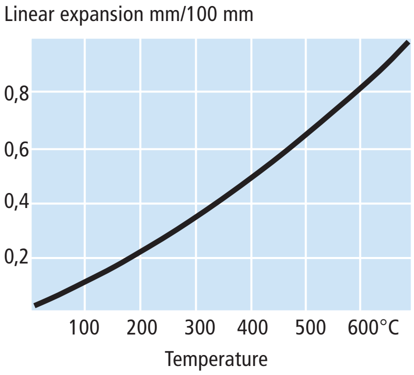


Effect of temperature on the yield strength of Uddeholm Orvar 2 Microdized, soft annealed

Thermal stresses

These stresses are created when a piece is heated. They increase if heating takes place rapidly or unevenly. The volume of the steel is increased by heating. Uneven heating can result in local variations in volume growth, leading to stresses and distortion.

As an alternative with large or complex parts, heating can be done in preheating stages in order to equalize the temperature in the component.



Effect of temperature on the linear expansion of Uddeholm ORVAR 2 Microdized, soft annealed

An attempt should always be made to heat slowly enough so that the temperature remains virtually equal throughout the piece.

What has been said regarding heating also applies to quenching. Very powerful stresses arise during quenching. As a general rule, the slower that quenching can be done, the less distortion will occur due to thermal stresses.

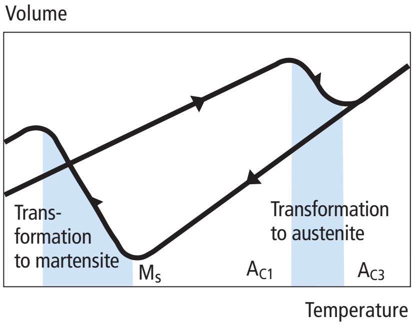
It is important that the quenching medium is applied as uniformly as possible. This is especially valid when forced air or protective gas atmosphere (as in vacuum furnaces) is used. Otherwise temperature differences in the tool can lead to significant distortion.

Transformation stresses

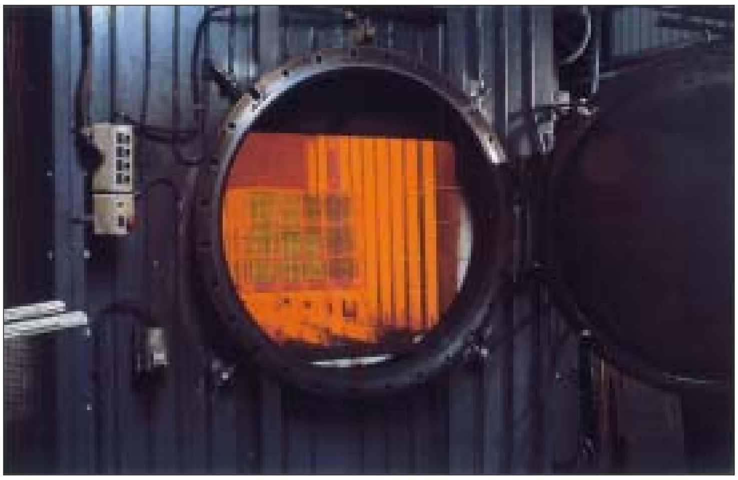
This type of stress arises when the microstructure of the steel is transformed. This is because the three microstructures in question—ferrite, austenite and martensite—have different densities, i.e. volumes.

The greatest effect is caused by transformation from austenite to martensite. This causes a volume increase.

Excessively rapid and uneven quenching can also cause local martensite formation and thereby volume increases locally in a piece and give rise to stresses in this section. These stresses can lead to distortion and, in some cases, quenching cracks.



Volume changes due to structural transformation



HOW CAN DISTORTION BE REDUCED?

Distortion can be minimized by:

- keeping the design simple and symmetrical
- eliminating machining stresses by stress relieving after rough machining
- heating slowly during hardening
- using a suitable grade of steel
- quenching the piece as slowly as possible, but quick enough to obtain a correct microstructure in the steel
- tempering at a suitable temperature.

The following values for machining allowances can be used as guidelines.

Grade of steel	Machining allowance on length and diameter as % of dimension
UDDEHOLM ARNE	0,25 %
UDDEHOLM RIGOR	0,20 %
UDDEHOLM SVERKER 21	0,20 %
UDDEHOLM SVERKER 3	0,20 %
UDDEHOLM CARMO	0,20 %
UDDEHOLM SLEIPNER	0,25 %
UDDEHOLM CALDIE	0,25 %
UDDEHOLM VANADIS 4 Extra	0,15 %
UDDEHOLM VANADIS 6	0,15 %
UDDEHOLM VANADIS 10	0,15 %
UDDEHOLM VANADIS 23	0,15 %
UDDEHOLM VANCRON 40	0,20 %
UDDEHOLM CALMAX	0,20 %
UDDEHOLM GRANE	0,15 %
UDDEHOLM STAVAX ESR	0,15 %
UDDEHOLM MIRRAX ESR	0,20 %
UDDEHOLM ELMAX	0,15 %
UDDEHOLM CORRAX	0,05–0,15 %
UDDEHOLM ORVAR 2 Microdized	0,20 %
UDDEHOLM ORVAR SUPREME	0,20 %
UDDEHOLM VIDAR SUPERIOR	0,20 %
UDDEHOLM QRO 90 SUPREME	0,30 %
UDDEHOLM HOTVAR	0,40 %
UDDEHOLM DIEVAR	0,30 %
UDDEHOLM ROLTEC SF	0,15 %
UDDEHOLM TOUGHTEC SF	0,15 %
UDDEHOLM WEARTEC SF	0,15 %

Note: Uddeholm Corrax is a precipitation hardening steel. Machining allowance is needed to compensate for shrinkage during ageing. The shrinkage depends on ageing temperature (see product information brochure). No distortion occurs.

SUB-ZERO TREATMENT

Tools requiring maximum dimensional stability in service can be sub-zero treated as follows:

Immediately after quenching, the tool should be sub-zero treated to –70 to –80°C (–95 to –110°F), soaking time 1–3 hours, followed by tempering.

The sub-zero treatment leads to a reduction of retained austenite content. This, in turn, will result in a hardness increase of 1–2 HRC in comparison to not sub-zero treated tools if low temperature tempering is used. For high temperature tempered tools there will be little or no hardness increase and when referencing the normal tempering curves, a 25 to 50°C (45 to 90°F) lower tempering temperature should be chosen to achieve the required hardness.

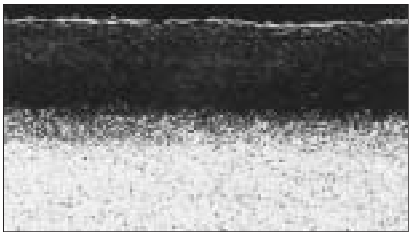
Tools that are high temperature tempered, even without a sub-zero treatment, will normally have a low retained austenite content and in most cases, a sufficient dimensional stability. However, for high demands on dimensional stability in service it is also recommended to use a sub-zero treatment in combination with high temperature tempering.

For the highest requirements on dimensional stability, sub-zero treatment in liquid nitrogen is recommended after quenching and after each tempering.

Surface treatment

NITRIDING

The purpose of nitriding is to increase the surface hardness of the steel and improve its wear properties. This treatment takes place in a medium (gas or salt) which gives off nitrogen. During nitriding, nitrogen diffuses into the steel and forms hard, wear resistant nitrides. This results in an intermetallic surface layer with good wearing and frictional properties.



Nitrided case shown at a magnification of 100X Uddeholm Orvar 2 Microdized

Nitriding is done in gas at about 510°C (950°F) and in salt or gas at about 570°C (1060°F) or as ion nitriding, normally at around 500°C (930°F). The process therefore requires steels that are resistant to tempering in order not to reduce the core strength.

Examples of applications

- Nitriding is used in some cases on prehardened plastic moulds in order to prevent indentation and defects on the parting faces. It should be noted, however, that a nitrided surface cannot be machined with cutting tools and can only be ground with difficulty. A nitrided surface will cause problems in weld repairing as well. Nitriding can also have a stress relieving effect. Heavily machined parts may, therefore, undergo some distortion during nitriding due to the release of residual stresses from machining and in such a case, a stress relieving between rough and finish machining is recommended.
- The life of forging dies can be increased by nitriding. It must be noted, though, that the treatment can give rise to higher susceptibility to cracking in sharp corners. Furthermore, the edge of the flash land must be given a rounded profile.
- Extrusion dies of Uddeholm Orvar 2 Microdized can be nitrided to advantage—especially in the case of aluminium alloys. Exceptions can be profiles with sharp corners and thin sections of the dies.

NITROCARBURIZING

A widely known method is nitriding in a salt bath.

The temperature is normally 570°C (1060°F). Due to aeration the cyanate content of the bath can be better controlled and the nitriding effect is very good.

A nitrocarburizing effect can also be achieved in gas atmosphere at 570°C (1060°F). The results after these methods are comparable.

The total nitriding time must be varied for different tool types and sizes. In the case of large sizes, the heating time to the specified nitriding temperature can be considerably longer than in the case of small tools.

ION NITRIDING

This is a new nitriding technology. The method can be summarized as follows:

The part to be nitrided is placed in a process chamber filled with gas, mainly nitrogen. The part forms the cathode and the shell of the chamber the anode in an electric circuit. When the circuit is closed, the gas is ionized and the part is subjected to ion bombardment. The gas serves both as heating and nitriding medium.

The advantages of ion nitriding include a low process temperature and a hard, tough surface layer. The depth of diffusion is of the same order as with gas nitriding.

Ion nitriding plant

CASE HARDENING

In this method, the steel is heated in a medium that gives off carbon (gas, salt or dry carburizing compound). The carbon diffuses into the surface of the material and after hardening this gives a surface layer with enhanced hardness and wear resistance. This method is used for structural steel, but is not generally recommended for alloy tool steels.

HARD CHROMIUM PLATING

Hard chromium plating can improve the wear resistance and corrosion resistance of a tool. Hard chromium plating is done electrolytically. The thickness of the plating is normally between 0,001 and 0,1 mm (0,00004–0,004 inch). It can be difficult to obtain a uniform surface layer, especially on complex tools, since projecting corners and edges may receive a thicker deposit than large flat surfaces or the holes. If the chromium layer is damaged, the exposed steel may corrode rapidly.

Another advantage of the chromium layer is that it greatly reduces the coefficient of friction on the surface.

During the chromium plating process, hydrogen absorption can cause a brittle surface layer. This nuisance can be eliminated by tempering immediately after plating at 180°C (360°F) for 4 hours.

SURFACE COATING

Surface coating of tool steel is becoming more common. Not only for cold work applications, but also for plastic moulds and hot work dies.

The hard coating normally consists of titanium nitride and/or titanium carbide. The very high hardness and low friction gives a very wear resistant surface, minimizing the risk for adhesion and sticking.

To be able to use these properties in an optimal way one has to choose a tool steel of high quality or a powder metallurgy manufactured steel as substrate. The two most common coating methods are:

- **PVD coating:** performed at 200–500°C (390–930°F) (PVD = Physical Vapour Deposition).
- **CVD coating:** performed at about 1000°C (1830°F) (CVD = Chemical Vapour Deposition).

Certain demands are put on the tool steel depending on: coating method, the design of the tool and the tolerances needed. PVD coating is used for the highest demands on tolerances. When using this method a tool steel with high tempering resistance must be used and the surface coating has to be performed as the last operation, after the heat treatment. At CVD coating, hardening and tempering are done after the coating. When using the CVD method there is a risk for dimensional changes. The method is therefore not recommended for tools with requirements of very narrow tolerances.

The most suitable steels for the mentioned methods are Uddeholm Vanadis 4 Extra, Uddeholm Vanadis 6, Uddeholm Vanadis 10, Uddeholm Vanadis 23 and Uddeholm Caldie.

Surface coating of tools and moulds should be discussed from case to case considering the application, coating method and tolerance requirements .

Coated tools

Testing of mechanical properties

When the steel is hardened and tempered, its strength is affected, so let us take a closer look at how these properties are measured.

HARDNESS TESTING

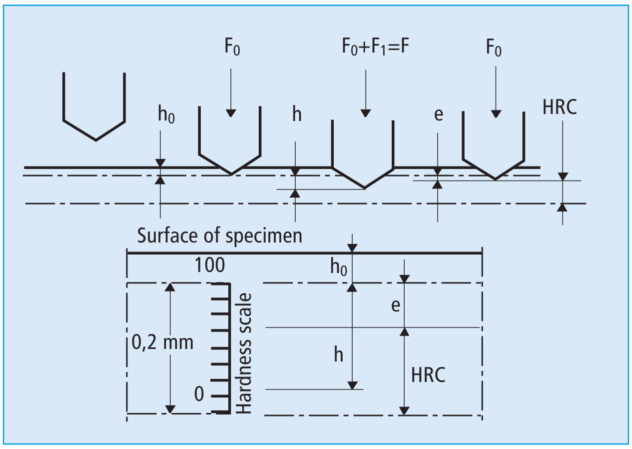
Hardness testing is the most popular way to check the results of hardening. Hardness is usually the property that is specified when a tool is hardened.

It is easy to test hardness. The material is not destroyed and the apparatus is relatively inexpensive. The most common methods are Rockwell C (HRC), Vickers (HV) and Brinell (HBW).

We shouldn't entirely forget the old expression "file-hard". In order to check whether hardness is satisfactory, for example above 60 HRC, a file of good quality can provide a good indication.

Rockwell (HRC)

In Rockwell hardness testing, a conical diamond is first pressed with a force F_0, and then with a force F_0+F_1 against a specimen of the material whose hardness is to be determined. After unloading to F_0, the increase (e) of the depth of the impression caused by F_1 is determined. The depth of penetration (e) is converted into a hardness number (HRC) which is read directly from a scale on the tester dial or read-out.

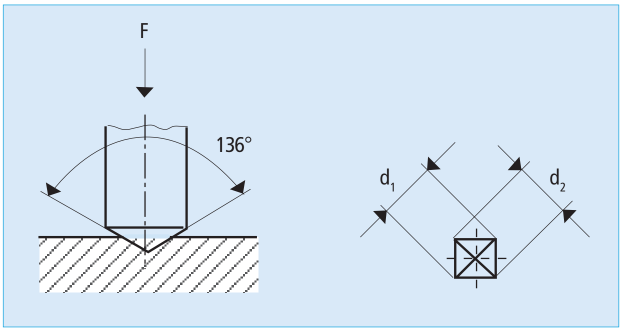


Principle of Rockwell hardness testing

Vickers (HV)

In Vickers hardness testing a pyramid-shaped diamond with a square base and a peak angle of 136° is pressed under a load F against the material whose hardness is to be determined. After unloading, the diagonals d_1 and d_2 of the impression are measured and the hardness number (HV) is read off a table.

When the test results are reported, Vickers hardness is indicated with the letters HV and a suffix indicating the mass that exerted the load and (when required) the loading period, as illustrated by the following example: HV 30/20 = Vickers hardness determined with a load of 30 kgf exerted for 20 seconds.

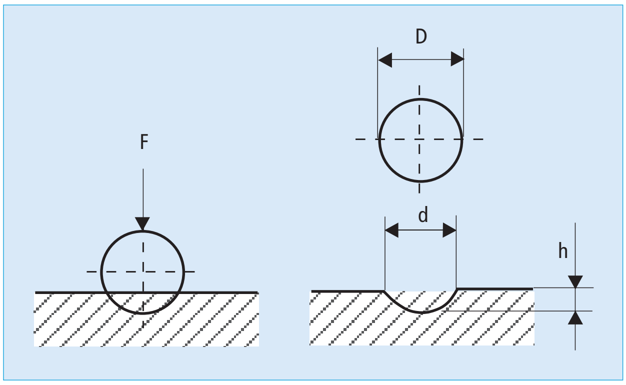


Principle of Vickers hardness testing

Brinell (HBW)

In Brinell hardness testing, a Tungsten (W) ball is pressed against the material whose hardness is to be determined. After unloading, two measurements of the diameter of the impression are taken at 90° to each other (d_1 and d_2) and the HBW value is read off a table, from the average of d_1 and d_2.

When the test results are reported, Brinell hardness is indicated with the letters HBW and a suffix indicating ball diameter, the mass with which the load was exerted and (when required) the loading period, as illustrated by the following example: HBW 5/750/15 = Brinell hardness determined with 5 mm Tungsten (W) ball and under load of 750 kgf exerted for 15 seconds.



Principle of Brinell hardness testing

TENSILE STRENGTH

Tensile strength is determined on a test piece which is gripped in a tensile testing machine and subjected to a successively increasing tensile load until fracture occurs. The properties that are normally recorded are yield strength $R_{p0,2}$ and ultimate tensile strength R_m, while elongation A_5 and reduction of area Z are measured on the test piece. In general, it can be said that hardness is dependent upon yield strength and ultimate tensile strength, while elongation and reduction of area are an indication of toughness. High values for yield and ultimate tensile strength generally mean low values for elongation and reduction of area.

Tensile tests are used mostly on structural steels, seldom on tool steels. It is difficult to perform tensile tests at hardnesses above 55 HRC. Tensile tests may be of interest for tougher types of tool steel, especially when they are used as high strength structural materials. These include e.g. Impax Supreme and Orvar 2 Microdized.

IMPACT TESTING

A certain quantity of energy is required to produce a fracture in a material. This quantity of energy can be used as a measure of the toughness of the material, a higher absorption of energy indicating better toughness. The most common and simplest method of determining toughness is impact testing. A rigid pendulum is allowed to fall from a known height and to strike a test specimen at the lowest point of its swing. The angle through which the pendulum travels after breaking the specimen is measured, and the amount of energy that was absorbed in breaking the specimen can be calculated.

Several variants of impact testing are in use. The various methods differ in the shape of the specimens. These are usually provided with a V- or U-shaped notch, the test methods being then known as Charpy V and Charpy U respectively.

For the most part, tool steel has a rather low toughness by reason of its high strength. Materials of low toughness are notch sensitive, for which reason smooth, un-notched specimens are often used in the impact testing of tool steels. The results of the tests are commonly stated in joules, or alternatively in kgm (strictly speaking kgfm), although J/cm^2 or kgm/cm^2 is sometimes used instead, specially in Charpy U testing.

There are several other variants of impact testing which are used outside Sweden, e.g. DVM, Mesanger and—especially in English speaking countries—Izod.

Some words of advice to tool designers

CHOICE OF STEEL

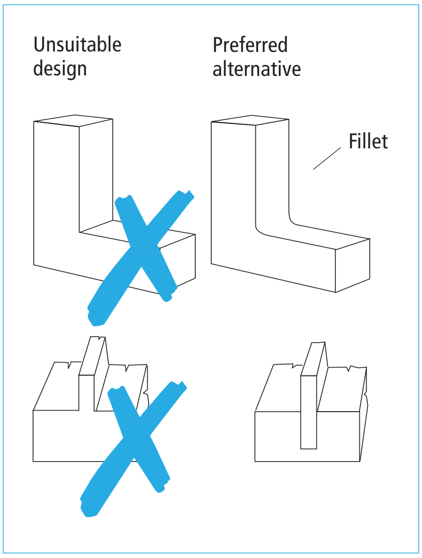
Choose air-hardening steels for complex tools.

DESIGN

Avoid:

- sharp corners
- notch effects
- large differences in section thicknesses.

These are often causes of quench cracks, especially if the material is cooled down too far or allowed to stand untempered.



HEAT TREATMENT

Choose suitable hardnesses for the application concerned. Be particularly careful to avoid temperature ranges that can reduce toughness after tempering.

Keep the risk of distortion in mind and follow recommendations concerning machining allowances.

It is a good idea to specify stress relieving on the drawings.

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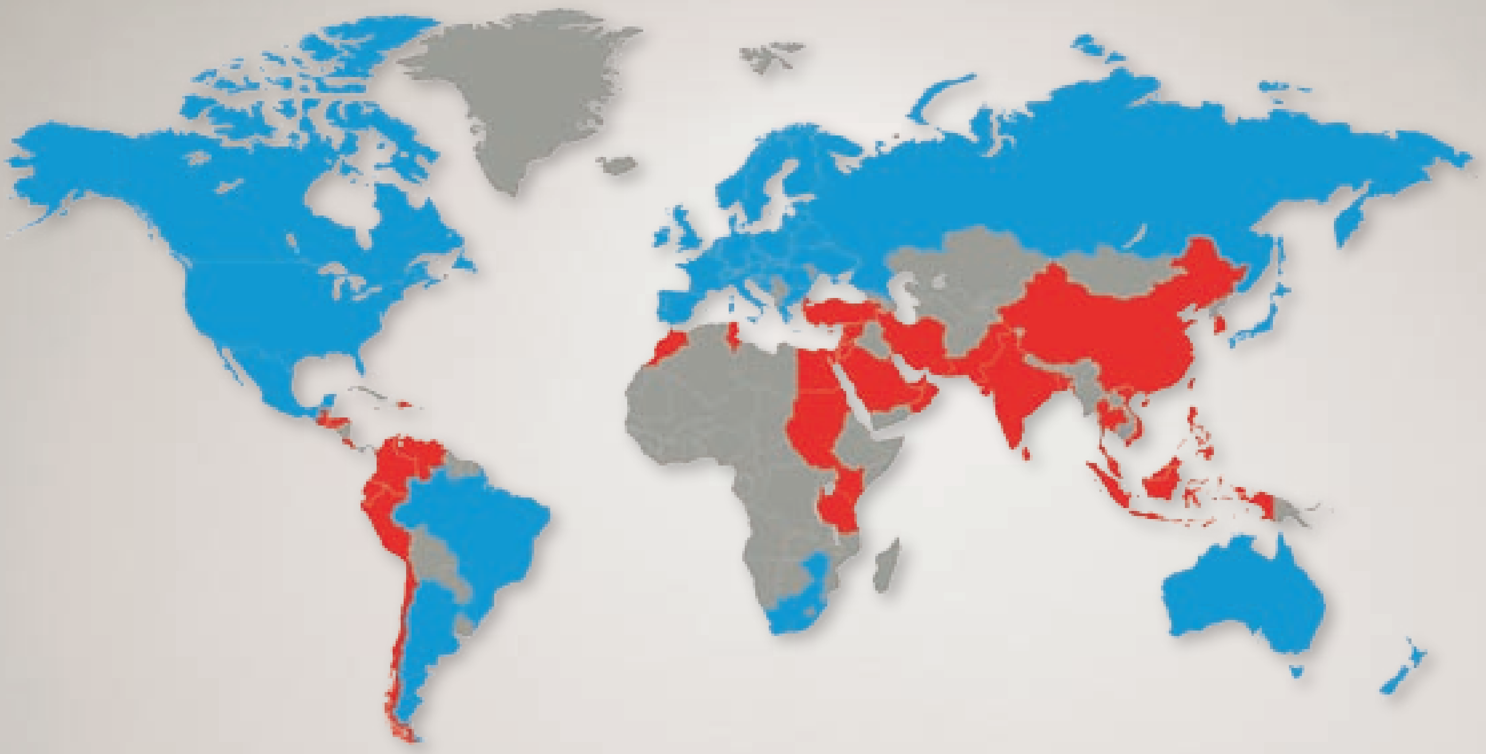

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Uddeholm is present on every continent. This ensures you high-quality Swedish tool steel and local support wherever you are. Assab is our wholly-owned subsidiary and exclusive sales channel, representing Uddeholm in various parts of the world. Together we secure our position as the world's leading supplier of tooling materials.

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For more information, please visit www.uddeholm.com or www.assab.com

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