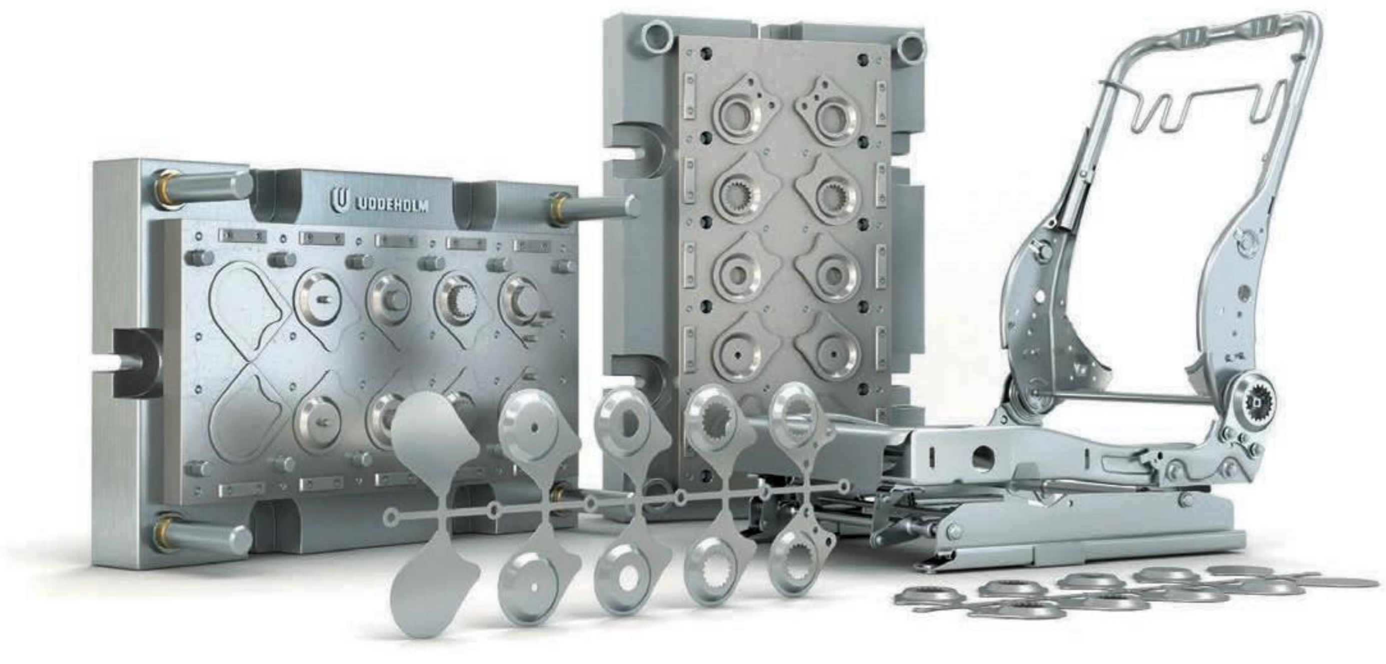
COLD WORK TOOLING



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INTRODUCTION

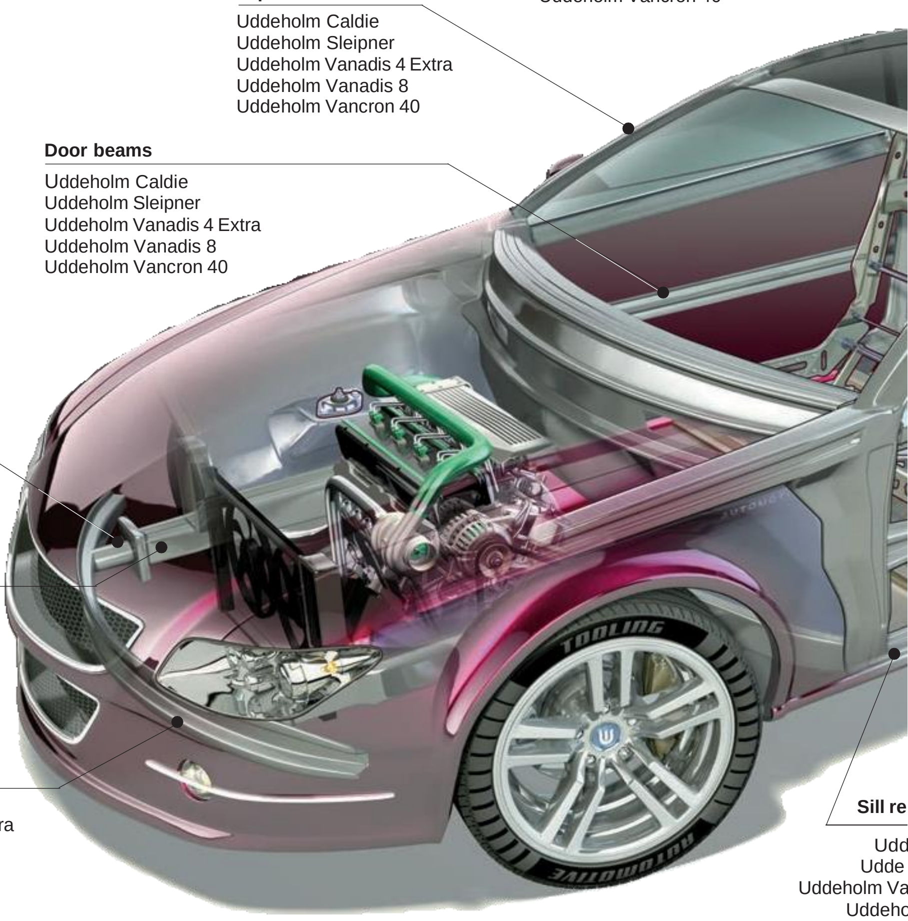
Rows of presses continuously producing the same components were a common sight in earlier times. Unplanned production halts due to tooling problems were not so serious because high levels of work in progress were held. Repairs or new tools could be quickly made by dedicated in-house tool rooms from stocks of one or two steel.

On the whole, work materials were simpler and the operating speeds of presses were slower. Thus major tool failures did not occur so often.

Production technology has, however, advanced very considerably. Equipment and plant are being scrutinised these days because greater accuracy and higher productivity are a must. Much greater emphasis has been placed on profit and reducing production costs. High speed presses producing components just-in-time from more difficult work materials on tools manufactured off-site is becoming more common.

Tool design, the method of tool manufacturing, the tooling material and the work material are all part of the package in trying to optimize productivity and to reduce costs.

Tools are the final link in the hardware chain. To obtain optimum productivity, tool steel that can meet today's demands and a knowledge of tool steel selection are necessary.



TOOL STEEL FUNDAMENTALS

We at Uddeholm can help the tool user in a number of very important ways.

Our world wide marketing organization is able to provide a well balanced programme of high quality tool steel. This programme not only includes a number of standard grades but also grades specifically designed to meet the high requirements now placed on much cold work tooling.

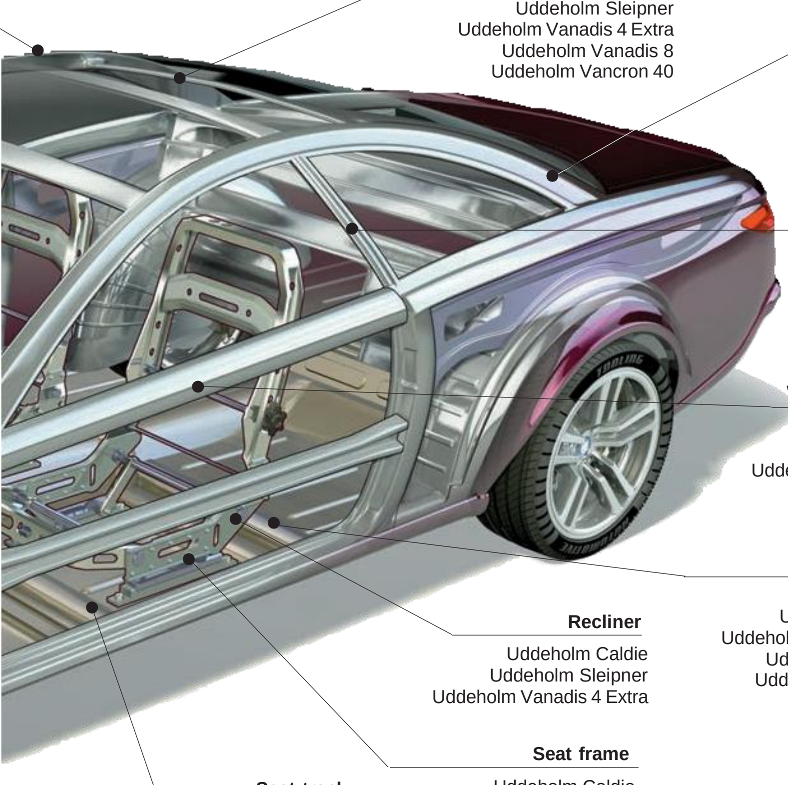
We can help the tool user to choose the right tool steel for the application. We do this by selecting the tool steel grade after identifying the reasons for the tool failure. A selection made in this way will result in lower tooling costs, lower maintenance costs and a less downtime.

DEMANDS ON COLD WORK TOOLING

Choosing the right tool steel for the application becomes more and more important as the demands on the tool increase. What are these demands?

- The tool must have sufficient wear resistance.
- The tool must perform reliably and not fail due to premature chipping, cracking or plastic deformation.

An optimal tooling economy—the lowest possible tooling cost (including maintenance) per part produced—can only be achieved if the correct tool steel for the application in question is used.



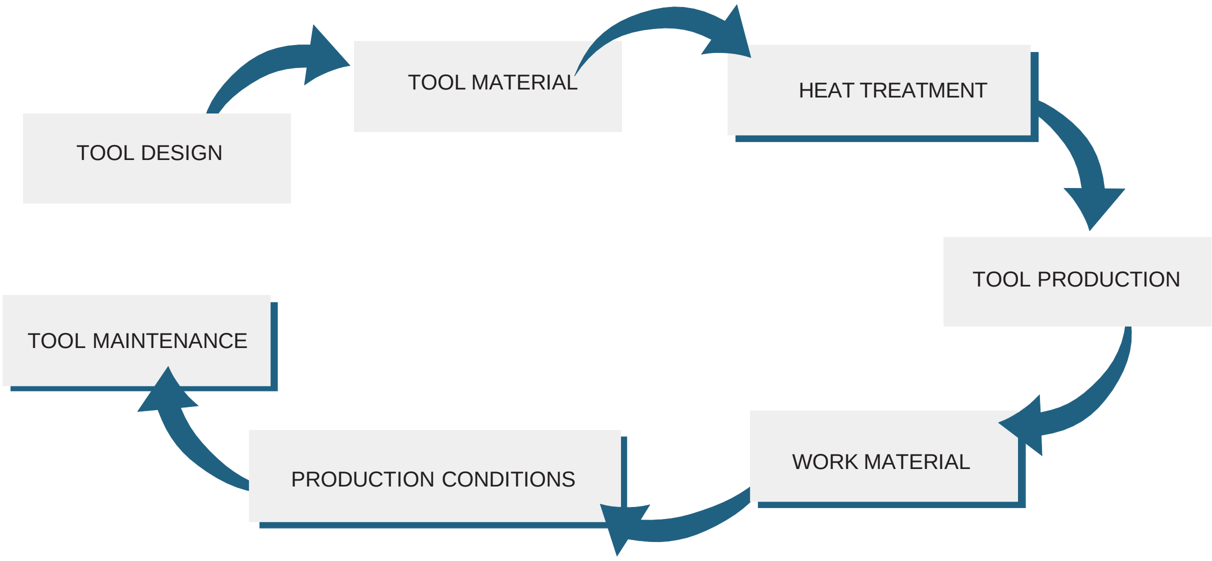


Figure 1. Factors influencing tool life in cold work applications.

TOOL PERFORMANCE

The performance of a cold work tool depends on many factors. These are shown in Figure 1.

The performance of a tool is often monitored by examining the quality of the parts it produces. In most applications, there are special requirements on surface finish and dimensional tolerances etc. for the parts being produced. A worn down or damaged tool usually results in rejection of the parts and the tool must be reconditioned or replaced.

The work material itself has a fundamental influence on the failure mechanisms. The most frequent failure mechanisms in cold work tooling are shown in Figure 3.

RELATIONSHIP BETWEEN FAILURE MECHANISMS AND TOOL STEEL PROPERTIES

In recent years a lot of work has been carried out in this field, especially for the cold work tool steel. A better understanding of the important relationship between failure mechanisms and the tool steel properties has been attained and our knowledge of this is reviewed as follows.

ABRASIVE WEAR

This type of wear dominates when the work material is hard and/or contains hard particles such as oxides or carbides.

These hard particles scour the tool surface as shown schematically in Figure 2. An example of a punch worn by abrasive wear is shown in Photo 1 on page 8.

Abrasive wear is dominant with such work materials as hardened steel, ceramics and wood.

The tool steel properties that are important for good resistance to abrasive wear are:

- high hardness
- high volume of carbides
- high hardness of the carbides
- large carbide size

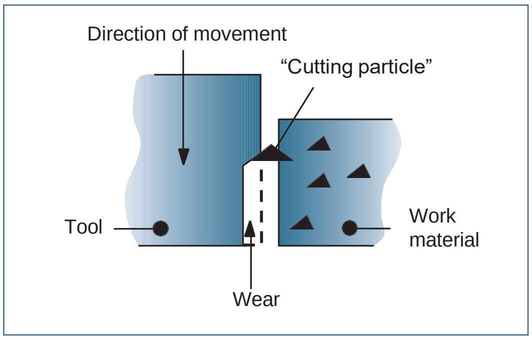


Figure 2. Schematic representation of abrasive wear.

Figure 3. The most frequent failure mechanisms in cold work tooling.

ADHESIVE WEAR AND GALLING

Adhesive wear or galling is a material transfer from one metallic surface to another when they slide over each other and is caused by the process of micro-welding (solid phase welding).

The metallic surfaces are never absolutely smooth—they consist of microscopic asperities. Bonding can occur between the two surfaces at these asperities and this may be stronger than the basic strength of the weaker of the two materials in contact. If there is a relative motion between these two surfaces, the weaker of the two materials in contact will fail and material from it will be transferred to the other contacting surface.

The situation for a tool and production materials is shown in Figure 4. If the microweld fractures on the tool side, small fragments of the tool steel will be torn out of the tool surface and this leads to adhesive wear. If the microwelds break on the production material side, the fragments of production material will gall onto the tool surface.

Adhesive wear may also be the origin of chipping. A fatigue mechanism gradually takes over from the adhesive wear dominant in the early stages.

Microcracks start to nucleate and these will start to deepen and spread. The cracks can then initiate a large scale spalling (chipping) or even lead to a catastrophic failure. An example of a punch worn by adhesive wear is shown in Photo 2 on page 8. Fatigue cracks can be clearly seen.

Adhesive wear and galling are normally associated with soft, adhesive metallic work materials such as aluminium, copper, stainless steel and low carbon steel. However, galling is also a problem encountered during the manufacture of components from high strength production materials such as the advanced high strength steel.

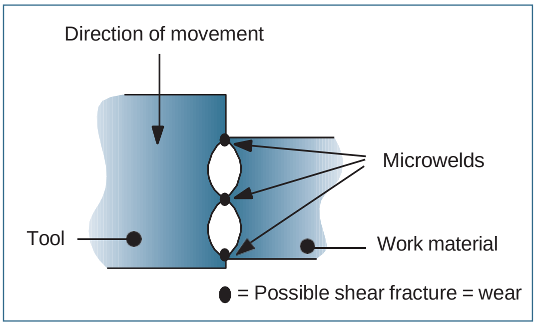


Figure 4. Schematic representation of adhesive wear.

Adhesive wear and galling can be decreased by making the microwelding and/or tearing off mechanisms more difficult. The tool steel properties that are critical for good resistance to adhesive wear and galling are:

- high tool hardness
- a low coefficient of friction (suitable surface topography and the use of a suitable lubricant)
- high tool steel ductility
- use of a surface treatment or coating

The newly developed nitrogen alloyed high performance PM steel Uddeholm Vancron 40 SuperClean has an excellent resistance to galling and adhesive wear. This can often be used in the uncoated condition and frequently performs better than coated tooling.

MIXED WEAR

Sometimes, during adhesive wear, torn off fragments of tool steel stick to the production material and cause abrasive wear on the tool surface. The result is a wear type consisting of a combination of adhesive and abrasive wear and this is referred to as mixed wear. It should be noted that mixed wear can only occur if adhesive wear occurs first.

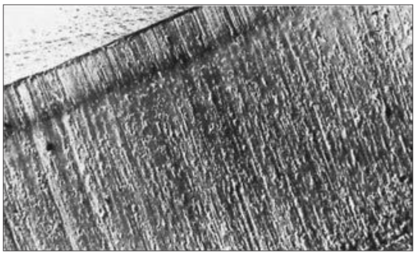


Photo 1. SEM photograph of a D2 punch worn by abrasive wear (work material 1% C-steel at 46 HRC).

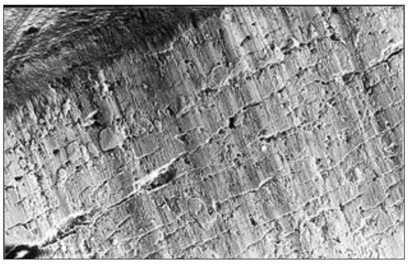


Photo 2. SEM photograph of a D2 punch worn by adhesive wear (work material austenitic stainless steel).

CHIPPING

Chipping often occurs after the tool has been in service for a relatively short time. This failure mechanism is one of low cycle fatigue. Microcracks are initiated in the active surface of the tool, propagate and finally result in pieces chipping out along edges or at corners.

To obtain good resistance to chipping it is important to make microcrack initiation and propagation more difficult. One tool steel property that gives a good resistance to chipping is high ductility.

PLASTIC DEFORMATION

Plastic deformation occurs when the yield strength of the tool steel has been exceeded.

Plastic deformation causes damage to or shape changes on the working surfaces of the tool.

The tool steel property that is important for a good resistance to plastic deformations is high hardness.

Note: Sufficient resistance to chipping and cracking must be taken into account when selecting the working hardness level.

CRACKING

Cracking is a failure mechanism which tends to occur spontaneously and usually means that the tool has to be replaced. Unstable crack propagation is the mechanism causing this type of failure.

The formation of cracks is very much enhanced by the presence of stress concentrators, e.g. grinding marks and machining marks or design features such as sharp corners or radii. EDM layers on the tool surface are also a frequent cause.

The tool steel properties that give a good resistance to cracking are:

- low hardness
- high microstructural toughness

Note: Low hardness will have a detrimental effect on the resistance to the other failure mechanisms. Thus working with a low hardness is not normally a good solution. It is better to use a steel with a good microstructural toughness.

CRITICAL TOOL STEEL PROPERTIES

The resistance a tool steel offers to the various tool failure mechanisms depends on its chemical composition, method of production and the quality of the process used.

The table on page 26 shows the chemical compositions of the tool steel in Uddeholm's standard cold work programme. It includes premium quality standard international grades as well as specially developed shock resistant grades and high performance powder metallur-gical (PM) SuperClean grades.

This well balanced basic programme is sufficient to cover most cold work applications and production run volumes.

The resistance of these steel to the various tool failure mechanisms is shown on a relative scale in Table 1.

CONVENTIONALLY PRODUCED TOOL STEEL

From Table 1 it can be seen that there is an increasing abrasive wear resistance of the standard international grades in the order O1–A2–D2–D6.

For a long time tool wear was considered to be of an abrasive nature. For this reason most of the older, well established high-alloyed cold work grades such as D2 and D6 have a pronounced abrasive profile. Such steel perform a good job in cases where abrasive wear dominates but it is well known that they do not perform well in applications where adhesive wear, chipping or cracking dominate.

The majority of work materials used in cold work operations subject the tooling to adhesive wear, mixed wear and/or chipping and cracking. For this

THE UDDEHOLM STANDARD STEEL FOR THE INACTIVE ELEMENTS OF COLD WORK TOOLS

Uddeholm Steel Grade	AISI	Chemical composition % C	Si	Mn
Sleipner	–	0.9	0.9	0.5
Sverker 21	AISI D2	1.55	0.3	0.4
Formax	–	0.18	0.3	1.3
UHB 11	AISI 1148	0.50	0.2	0.7

Table 2.

Uddeholm h as also introduced a number of conventionally produced shock resistant grades with properties profiles suitable for heavy duty blanking and forming applications. These are Uddeholm Calmax and the two fully Electro-Slag-Remelted grades Uddeholm Unimax and Uddeholm Caldie.

RELATIVE COMPARISON OF THE RESISTANCE TO FAILURE MECHANISMS

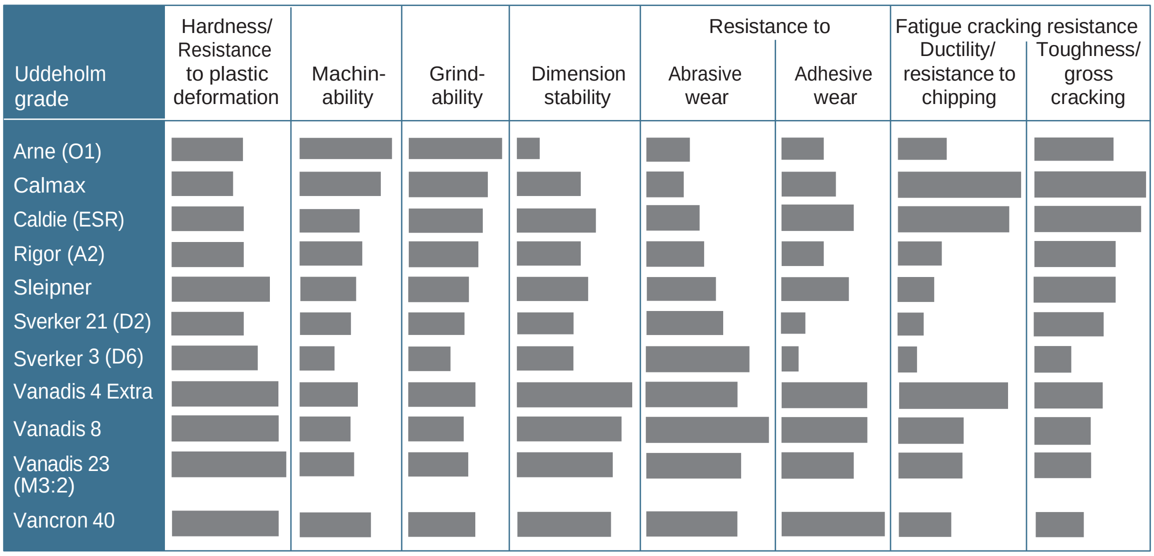


Table 1. The longer the bar, the better the resistance. The Vancron and Vanadis steels mentioned in the table are Uddeholm PM SuperClean tool steels.

INNOVATION IN TOOL STEEL— THE PM STEEL

The need for high performance tool steel has grown dramatically because of constant competitive demands from the markets to achieve the lowest tooling costs per part produced. Their success is based on their powder metallurgy (PM) production route.

Traditionally, tool steel are melted the same way as engineering steel but generally they are cast as smaller ingots. The molten metal is cast into moulds and the resulting ingots are forged and rolled into steel bars. The bars are then soft annealed or prehardened.

Tool for powder compacting.

However, due to the events taking place during the solidification of the liquid steel in the ingots, segregation takes place and carbide networks are formed and these are particularly pronounced with high alloyed tool steel.

These networks are gradually broken down during hot working as shown schematically in Figure 5.

In the finished bars these networks are broken down to form carbide stringers and these adversely affect the mechanical properties of the tool steel, particularly in the transverse and short transverse directions. Despite a high degree of reduction during forging and rolling, tool steel grades like Uddeholm Sverker 3 and Uddeholm Sverker 21 pay heavy toughness penalties for their carbide-influenced abrasive wear resistance.

To avoid segregations and large carbides with their detrimental effect on fatigue life, a totally different way of producing tool steel ingots has to be used. The powder metallurgy (PM) route is the industrial process used to produce macro-segregation free ingots of high alloy tool steel. The PM route is shown schematically in Figure 6. The melt is atomized and the resulting tiny droplets solidify very rapidly to form a powder. The powder is hot isostatically pressed in a capsule. The ingot so produced is then ready for hot working (forging and rolling) into bar form. The PM steel are fully wrought products.

The PM process eliminates the macro-segregation problem and this means that more highly alloyed steel can be manufactured than would be possible by conventional ingot metallurgy. Photo 3 compares the microstructure of a conventionally produced 12%-Cr steel (Uddeholm Sverker 21) with a PM steel (Uddeholm Vanadis 4 Extra SuperClean). In the PM steel, very small and hard alloy carbides greatly increase the wear resistance and at the same time the fatigue life

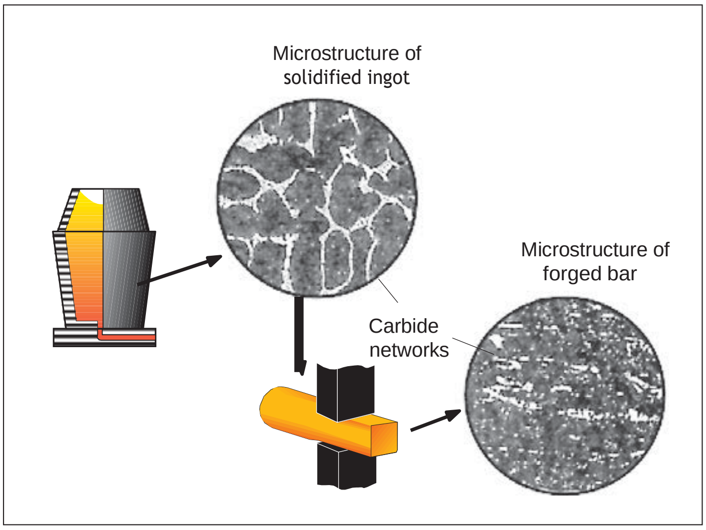
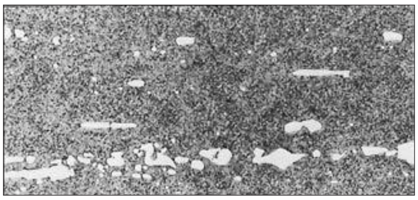


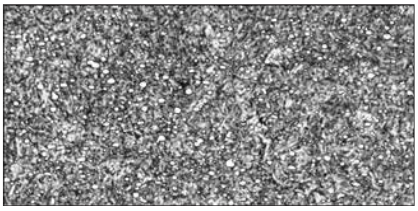
Figure 5. Breakdown of the carbide networks during hot forming.

(which governs chipping and cracking resistance). This is in contrast to the conventionally produced steel where increased chipping and cracking resistance can only be gained by lowering the working hardness which in turn lowers the wear resistance.

Thus in the PM steel shown in Table 1, page 9, there is enhanced resistance to wear (both abrasive and adhesive) but at the same time improved chipping resistance.



Uddeholm Sverker 21



Uddeholm Vanadis 4 Extra SuperClean

Photo 3. Comparison of the microstructures of a conventionally produced 12% Cr-steel (Uddeholm Sverker 21) and a PM cold work steel (Uddeholm Vanadis 4 Extra SuperClean).

In the past the PM steel have been designed mainly to cope with the failure mechanisms of wear and chipping in high performance tooling. The latest innovation in PM technology for producing high performance tool steel is alloying with nitrogen to obtain an excellent galling resistance without having to resort to surface treatments or coatings. The result of this is the high performance PM grade Uddeholm Vancron 40 SuperClean.

All of Uddeholm high performance PM grades are produced with the latest PM technique available and of superclean quality level.

Sintering of powder compacted parts.

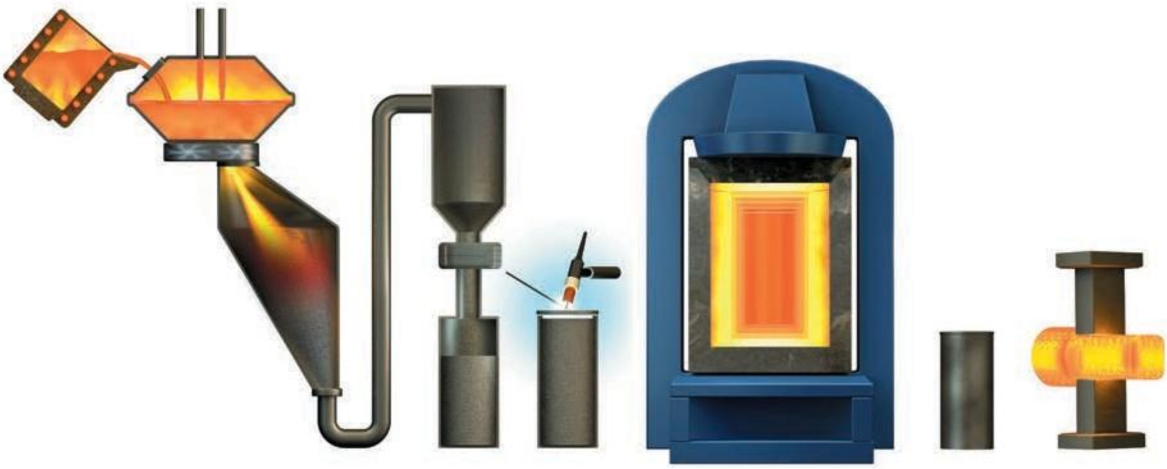


Figure 6. Schematic representation of the powder metallurgy (PM) route for producing tool steel.

TOOL STEEL SELECTION

The selection of a tool steel for a given application will depend on which failure mechanisms dominate.

The choice of a tool steel for a specific application requires more than just a knowledge of the steel properties. The number of parts to be produced, the type of work material, the thickness of the work material and the hardness of the work material must also be taken into consideration.

The basic idea is to select a tool steel with such properties that all the failure mechanisms except wear are eliminated. The wear can then be optimized to match the number of components required.

The following step by step penetration of some simple cases indicates how a tool steel selection should be made.

IDENTIFY THE TYPE OF WEAR

The following production material properties must be considered in order to establish the dominating wear type (abrasive, adhesive or mixed) to be expected:

- type of work material
- hardness of work material
- presence of hard particles in the work material

This is the most fundamental step because it will determine which wear resistance profile the tool steel should have.

OCCURRENCE OF CHIPPING OR PLASTIC DEFORMATION

The following will indicate the extent of the risk for chipping and/or plastic deformation, i.e. whether high chipping resistance (ductility) and/or high hardness are needed:

- type of application
- thickness and hardness of the production material
- geometrical complexity of parts to be produced

The tool user will normally have sufficient experience here.

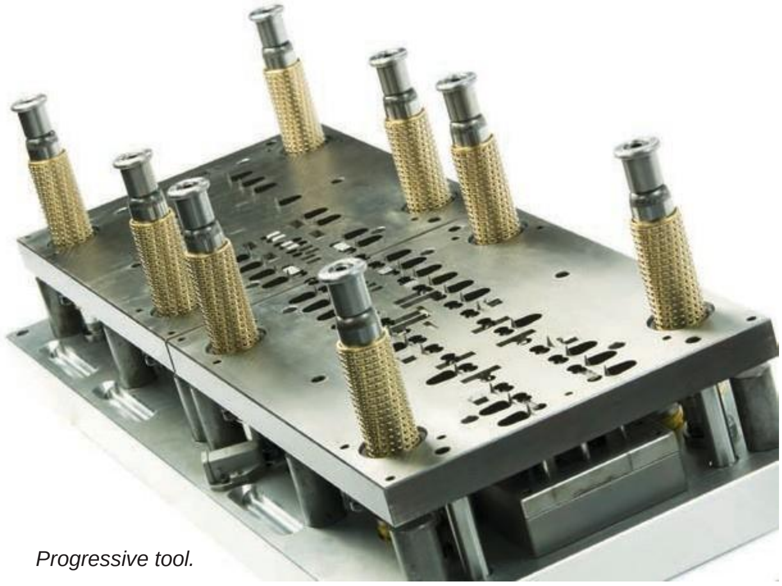
RISK OF CRACKING

The following will give an indication of the risk for cracking, i.e. whether a tough tool steel and/or moderate hardness levels have to be used:

- type of application
- geometry of part to be produced
- tool design and tool size
- thickness and hardness of the production material

NUMBER OF PARTS TO BE PRODUCED

Very long runs often require more than one tool and demand the use of a high performance tool steel to obtain optimum tooling economy. On the other hand, short runs can be made with a lower alloy grade tool steel.



Progressive tool.

SELECTION OF THE TOOL STEEL

The tool steel with the most suitable profile to overcome the dominant failure mechanisms can be selected using the information given in Table 1, page 9.

The procedure for tool steel selection:

1. Blanking of a thin (0.5 mm) hardened strip steel (45 HRC)

- Abrasive wear will be the dominating wear mechanism.
- The risk of chipping or cracking is minimal for geometrically simple parts but rises as the geometry becomes more complicated.
- The risk for plastic deformation is minimal as the production material is thin.

For a short run of parts with a simple geometry, the tool steel Uddeholm Arne would be sufficient for a moderate size tool. For a larger tool a more highly alloyed steel is necessary for reasons of hardenability. Here the steel Uddeholm Calmax would be a good choice.

For a longer run where much more abrasive wear resistance is required, Uddeholm Sverker 21 would be a good choice for parts with a relatively simple geometry. However, for parts with a more complicated geometry, the risk of chipping is higher and Uddeholm Vanadis 8 SuperClean would be a better choice.

For very long runs an extremely high abrasive wear resistance is needed. Here Uddeholm Vanadis 8 SuperClean would be the best choice.

2.Blanking of a thick (5 mm) and soft (150 HV) austenitic stainless steel

- Adhesive wear is the dominating wear mechanism.
- The risk for chipping or cracking is significant.
- There is a moderate risk for plastic deformation but this can be overcome by using a sufficient working hardness.

For short runs of parts with simple or complicated geometries, Uddeholm Calmax would be a good choice.

For longer or very long runs of parts with simple or complex geometries, Uddeholm Vanadis 4 Extra SuperClean would be the obvious choice.

SELECTION OF TOOL STEEL BASED ON PRODUCTION VOLUMES

In the past production volumes have been defined empirically as low, medium or high. Low production volumes have been defined as up to 100,000 parts, medium production volumes as between 100,000 and 1 million parts and high production volumes as over 1 million parts. Such a definition takes however not the influence of hardness and thickness into account, which both increase the risk for chipping and cracking. This problem can be overcome by redefining production volumes as follows:

low production volumes: one tool made of tool steel belonging to the low performance group can produce the required number of parts

medium production volumes: one tool made of medium performance group of steel can produce the required number of parts

high production volumes: more than one tool of the medium performance group is needed to produce the required number of parts. In this case a tool steel from the high performance group always gives the best tooling economy

The cold work steel from Uddeholm can be divided into three groups related to the batch size aimed for low production volumes, medium production volumes and high production volumes according to Table 3, page 14.

Fine blanking. Courtesy of Feintool, Switzerland

Each group contains steel grades with different properties profiles. The selection of a suitable grade for the application in question and the production volume required is determined by the dominating failure mechanisms. Steel selection is very often based on the experiences from an ongoing or similar production.

The properties profiles of the different grades are given in Table 1, page 9.

A general rule for tool steel selection is that chipping and cracking should be avoided as far as possible even if this means an increase in the tool wear. Wear has a number of advantages over chipping and cracking. It is predictable and it results in the cheapest refurbishing costs. If a tool is only wearing, maintenance is easier to plan and more costly production stops can be avoided.

If production experience is lacking, the Table 3 below can be used as a guide for selection of the tool steel to be used.

UDDEHOLM TOOL STEEL SELECTION
FOR DIFFERENT PRODUCTION VOLUMES AND WEAR MECHANISMS

Serial length	Adhesive wear		Mixed wear		Abrasive wear	
Short	Arne	54–56 HRC	Arne Calmax Unimax	54–58 HRC 54–59 HRC 54–58 HRC	Arne Caldie	54–60 HRC 56–62 HRC
Medium	Calmax Unimax Caldie Sleipner	54–58 HRC 54–58 HRC 58–60 HRC 56–62 HRC	Caldie Rigor Sleipner	58–62 HRC 54–62 HRC 58–63 HRC	Sleipner Sverker 21	60–64 HRC 58–62 HRC
Long	Vanadis 4 Extra SuperClean Vancron 40 SuperClean	 58–62 HRC 60–64 HRC	Vanadis 4 Extra SuperClean Vanadis 8 SuperClean	 58–63 HRC 60–64 HRC	Sverker 3 Vanadis 8 SuperClean	58–62 HRC 60–65 HRC

Table 3.

Tool of solid Uddeholm Vancron 40 SuperClean for production of dishwashers.

TOOL MAKING

If a tool is to give an optimum production with a minimum of maintenance and downtime, it is not only necessary to select the correct tool steel for the application. It is just as essential that the tool making is carried out properly. If this is not done, a number of problems can arise during the manufacture of the tool. But this is not all—the performance of the tool in service can be seriously reduced. This is because the failure mechanisms discussed in the previous sections can occur at an earlier stage if the tool making procedures are not correct.

BASIC TOOL DESIGN

It goes without saying that the tool must be designed properly to do the job intended. Tools designed for a particular application and production material thickness may not function if they are later used to perform an operation on a much thicker and/or harder production material as they could be severely overloaded.

The following recommendations concerning design features, although very basic, are intended to avoid premature failure either in heat treatment or in use.

- Use adequate overall dimension to ensure basic tool strength and support.
- Avoid sharp corners – wherever possible, incorporate a generous fillet radius instead.
- Wherever possible, avoid adjacent heavy and light sections in the tool.
- Avoid potential stress raisers, e.g. machining marks, grinding marks and letter stamping.
- Leave sufficient stock thickness between holes and surface edges.
- Complicated tool shapes are often best built up from sections which are safer in heat treatment and easier to refurbish or replace.

DECARBURIZED LAYER

During production of tool steel bars it is virtually impossible to avoid decarburization of the surface layer. The degree to which a bar may be decarburized depends on the steel analysis and also on the practice used during heating of the bar. Sometimes there will be no completely decarburized skin but there may be a surface zone containing less carbon than in the bulk of the bar.

It is important to remove the decarburized layer from the surface of the bar before the steel is used to manufacture the tool. If this is not done, the following can happen:

- the tool may crack during heat treatment (quenching) or in service
- the working surfaces of the tool can plastically deform
- the wear resistance of the tool will be reduced

It is also good practice to remove the decarburized layer from black bar used for EDM starter blocks. These have been known to crack during quenching due to the presence of the decarburized layer.

The amount of skin to be removed depends on the dimensions and shape of the bar. Various organizations such as AISI provide standards to work on.

GRINDING

The use of correct grinding techniques will always have a positive influence on tool making and tool performance. The stress created locally in the tool surface by the combination of high temperatures, friction and pressure during the grinding operation can be kept to a minimum by:

- using properly dressed, free-cutting grinding wheels
- restricting the wheel pressure/metal removal rate or depth of cut
- using plenty of coolant

Tools made from high alloy steel which have been tempered at low temperatures are particularly sensitive during grinding operations. Extra care is demanded here. As a rule of thumb, the harder the steel, the softer the wheel and vice-versa.

Stamping tool for production of medals.

Under unfavourable grinding conditions the tool steel can be affected as follows:

- surface hardness is reduced (temper burn) and this will adversely affect wear resistance
- rehardening of the ground surface may take place and result in the formation of grinding cracks and problems with tool breakage and chipping
- severe stresses are introduced into the tool and these can enhance the risk of failure

After a rough grinding operation it is important that a finish grinding is made so that the stress affected surface layer due to the rough grinding operation is removed. Grinding stresses can also be released by means of a stress tempering operation at about 25°C (50°F) below the previously used tempering temperature.

It should be noted that the risk of surface cracking is high when grinding tools that have been overheated, over-soaked or undertempered during heat treatment. This is caused by the presence of the soft constituent retained austenite in the microstructure. The heat and pressure produced during grinding usually transform this into untempered martensite. The resultant very hard and brittle condition at the tool surface can lead to the formation of surface cracks.

Grinding marks on the working surfaces of the tool can cause problems in service.

- They are potential stress raisers and can lead to chipping or flaking or even cracking.
- They can cause galling, especially if they are transverse to the direction of the metal flow.

Hub cover for truck.

Tool for deep drawing.

When the die surface is finish ground or reground, the feather edge which is created should be carefully removed by a light hand stoning operation. This will reduce the possibility of chipping or flaking of the cutting edge at the beginning of the production run. This is particularly important in tools being used at high hardnesses for cutting of thin materials.

The PM steel Uddeholm Vanadis 4 Extra SuperClean and Uddeholm Vanadis 8 SuperClean, with their extremely small carbides, possess considerably better grindability than one would expect from an equivalent conventionally produced highly alloyed material.

Further details and grinding wheel recommendations can be found in the Uddeholm brochure "Grinding of Tool Steel".

HEAT TREATMENT

The purpose of heat treating a tool is to obtain suitable properties such as wear resistance, toughness and strength. The principal problems that arise in association with heat treatment are:

- distortion
- dimensional changes
- decarburization
- carburization
- grain boundary precipitation (proeutectoid carbide)

DISTORTION

Distortion of tools following heat treatment may result from:

- machining stresses
- thermal stresses
- transformation stresses

In order to reduce machining stresses, the tool should always be stress relieved after rough machining. In this way the stresses introduced by the machining operation are reduced. Any distortion can then be adjusted during finish machining prior to heat treatment.

Thermal stresses are created when the tool is heated. They increase if heating takes place rapidly or unevenly. The fundamental rule for heating to hardening temperature is that it should take place slowly so that the temperature remains virtually equal through the piece. A number of preheating stages are normally used.

What has been said about 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.

DIMENSIONAL CHANGES

Transformation stresses arise when the microstructure of the steel is transformed. Dimensional changes due to transformations in the steel are difficult to influence except by changing to another steel grade.

Dimensional changes occur both in hardening and tempering. In estimating size changes, the effects of hardening and tempering should be added together. Uddeholm's product brochures contain data on these dimensional changes.

DECARBURIZATION

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. Decarburization will result in loss of wear resistance.

CARBURIZATION

Carburization is a result of pick-up of carbon in the surface of the steel when the medium used to protect the tool during hardening contains free carbon. It results in a hard, brittle layer on the surface of the tool and increases the risk of chipping or cracking.

GRAIN BOUNDARY PRECIPITATION

Carbides can precipitate out during quenching if the quench is carried out too slowly. The carbide precipitates out mainly at the grain boundaries of the tool steel and results in loss of toughness and final hardness.

For further information on heat treatment see the Uddeholm brochure "Heat Treatment of Tool Steel".

ELECTRIC DISCHARGE MACHINING —EDM

When EDM'ing, one or two very important points should be noted in order to obtain satisfactory results. During the operation the surface layer of the heat treated steel is rehardened and consequently in a brittle state. This very often results in chipping, fatigue cracking and a shortened tool life. To avoid this problem the following precautions should be taken.

- Finish the EDM operation by "fine" sparking (i.e. low current, high frequency). Correct dimensioning of the "fine" sparking electrode is essential to ensure removal of the surface layer (see Photo 4) produced by the "rough" sparking operation.
- The surface layer produced by "fine" sparking operation should, if possible, be removed by polishing or stoning.
- If there is any doubt about the complete removal of the surface affected layer, the tool should be re-tempered at a temperature 15–25°C (25–45°F) below the last used tempering temperature.

WIRE EDM

This process makes it easy to cut complicated shapes from hardened steel blocks. However, hardened steel always contain stresses and when larger volumes of steel are removed in a single operation, this can sometimes lead to distortion or even cracking of the part. The problem of cracking during wire EDM is normally encountered in cross sections over 50 mm (2").

Photo 4. Surface of Uddeholm Sverker 21 after rough spark EDM. The white layer is brittle and contains cracks.

The risk of cracking can be reduced by:

- lowering the overall stress level in the part by tempering at a high temperature. This assumes the use of a steel grade which exhibits a secondary peak in its tempering curve
- correct hardening and double tempering is important. A third tempering is advisable for heavy cross sections
- a conventional machining of the work-piece before heat treatment to a shape near to the final form.
- drilling several holes in the area to be removed and connect them by saw-cutting before hardening and tempering

The rehardened surface layer produced by wire EDM'ing is normally relatively thin and can be compared more to "fine-sparking" EDM. However, it is often thick enough to cause chipping or cracking problems, especially on more geometrically sensitive tooling with high hardness levels. It is, therefore, advisable to make at least one "fine" cut after rough cutting. One or more fine cuts are often necessary anyway to achieve the required dimensional tolerances.

For further information see the Uddeholm brochure "Electric Discharge Machining (EDM) of Tool Steel".

SURFACE TREATMENT

GAS NITRIDING

Gas nitriding gives a hard surface layer with good resistance to abrasion. However, the hard nitrided case is brittle and can chip or spall if the tool is subjected to impact or rapid temperature changes. The risk increases with the thickness of the case. Prior to nitriding, the tool must be hardened and tempered. The tempering temperature should be about 25°C (45°F) higher than the nitriding temperature.

NITRO-CARBURIZING

The nitrided case produced by the nitro-carburizing process is normally thinner than the case produced by ion or normal gas nitriding. It is also considered to be tougher and to have lubricating properties.

It has been found that nitro-carburized punches give particularly good results in the cutting of thin, adhesive materials such as austenitic stainless steel. The nitrided case reduced adhesion between the punch and work material.

The following Uddeholm cold work tool steel can be nitrided:
Rigor, Caldie, Sleipner, Unimax, Calmax, Sverker 21, Sverker 3, Vanadis 4 Extra SuperClean, Vanadis 8 SuperClean and Vanadis 23 Super-Clean.

The case hardness is 900–1250 HV_{10}, depending on the grade and nitriding process.

SURFACE COATING

Surface coating of tool steel may be used for many types of cold work tooling.

The hard material deposited on the tool surface is often titanium nitride, titanium carbide or titanium carbonitride. However, nowadays there are many other recently developed coatings to choose from. The very high hardness and low friction properties of the coating give a wear resistant surface that lowers the risk for galling. The coating method, tool geometry and tolerance requirements place certain demands on the tool material.

- **PVD** (Physical Vapour Deposition) is a method of applying a wear resistant surface coating at temperatures around 500°C (930°F). Even lower temperatures can be used for deposition today. A base material with sufficient hardness after high temperature tempering is necessary and the coating is put on as the last operation.
- **CVD** (Chemical Vapour Deposition) is used for applying wear resistant surface coatings at temperatures of around 1000°C (1830°F). With CVD coating, it is necessary to carry out hardening and tempering (in a vacuum furnace) after the coating operation. With this procedure, there is a risk of dimensional changes taking place, making it less suitable for tools with very tight tolerance demands.

The Uddeholm cold work steels Vanadis 4 Extra SuperClean, Vanadis 8 SuperClean and Vanadis 23 SuperClean have been found to be particularly suitable for titanium carbide and titanium nitride coatings. The uniform carbide distribution in these steel facilitates bonding of the coating and reduces the spread of dimensional changes resulting from hardening. This, together with the materials' high strength, improves the bearing properties of the surface layer deposited.

Uddeholm Vancron 40 SuperClean is normally used in the uncoated condition to prevent galling. However, sometimes it is necessary to coat if the contact pressure in the application in question is particularly high. Excellent results can then be obtained.

The surface coating of tools should be discussed for specific applications, taking into account the type of coating, tolerance demands, etc., and it is recommended that you contact your Uddeholm representative for further information.

PVD coated punch and die.

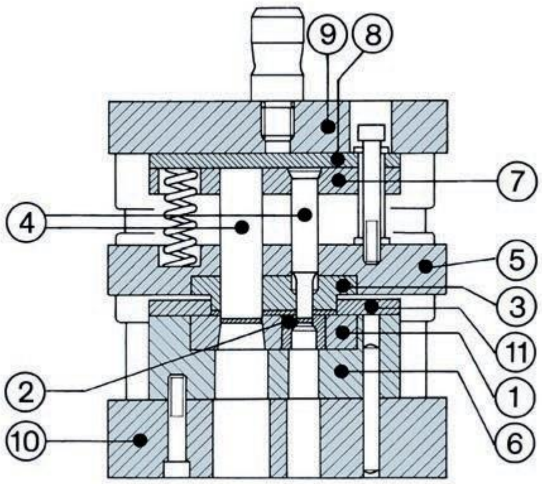
PUNCH/DIE CLEARANCES

The optimum punch/die clearance will naturally be decided at the tool design stage and will take into account the thickness and hardness of the work material. Tool users will be aware that insufficient or excessive clearance can be responsible for severe tool wear. Having established the optimum clearance, care must naturally be taken to ensure that the punch is properly located in relation to the die aperture to avoid uneven cutting pressures, leading to uneven wear and possibly premature tool failure.

GENERAL RECOMMENDATIONS—BLANKING DIE SET

PART	UDDEHOLM STEEL GRADE	HRC
1 Die-block	Arne, Caldie, Sleipner, Rigor, Sverker 21, Sverker 3, Vanadis 4 Extra, Vanadis 8, Vanadis 23, Vancron 40	54–65
2 Die-insert	Sverker 21, Sverker 3, Caldie, Sleipner, Unimax, Vanadis 4 Extra, Vanadis 8, Vanadis 23, Vancron 40	58–65
3 Stripper plate	UHB 11 – Fine-machined, Ground Flat Stock	
4 Punches	Arne, Caldie, Sleipner, Rigor, Sverker 21, Sverker 3, Unimax, Vanadis 4 Extra, Vanadis 8, Vanadis 23, Vancron 40	54–65
5 Backing plate	UHB 11	—
6 Die support	UHB 11	—
7 Punch holder plate	Arne – Ground Flat Stock	—
8 Punch backing plate	Arne	58–60
9 Top plate	UHB 11, Formax	—
10 Bottom plate	UHB 11, Formax	—
11 Strip guide	UHB 11 – Fine-machined, Ground Flat Stock	—

Table 4. The Vancron and Vanadis steels mentioned in the table are Uddeholm SuperClean cold work tool steels.



PRODUCT PROGRAMME

AVAILABILITY OF UDDEHOLM COLD WORK TOOL STEEL

From our long experience serving the cold working industry we have become familiar with sizes, grades and tolerances most frequently used.

The ready availability is determined by local stocks, reliable delivery service and comprehensive product and size ranges.

LOCAL STOCKS

The location of stock is important if good delivery service is to be maintained.

With our world wide marketing organization we place great emphasis on matching our stock size programme and our stock levels to the local needs of each individual market.

RELIABLE DELIVERY SERVICE

Our widespread network of Uddeholm warehouses and our complete range of products form the basis for our delivery service. Each of our stock locations has a well established distribution system.

TAKE THE SHORT CUT TO PRODUCTIVITY!

Purchasing steel in a prefinished form is a smart way of releasing tool making capacity for the more skilled machining operations. Our steel grades are obtainable in a number of forms and finishes. And many of them have been pre-machined to a greater or lesser degree. Uddeholm tool steel are available as machined and fine machined bars.

It is always possible to find a suitable stock size for the work in hand and thus reduce the amount of unnecessary and expensive machining.

In all cases a plus machining allowance is made on all sizes to allow for final finishing to a standard dimension.

- No machining costs for removal of the decarburized surface layer are involved.
- The manufacturing time is shortened, which makes planning simpler and calculations more accurate.

MACHINED STEEL PLATES

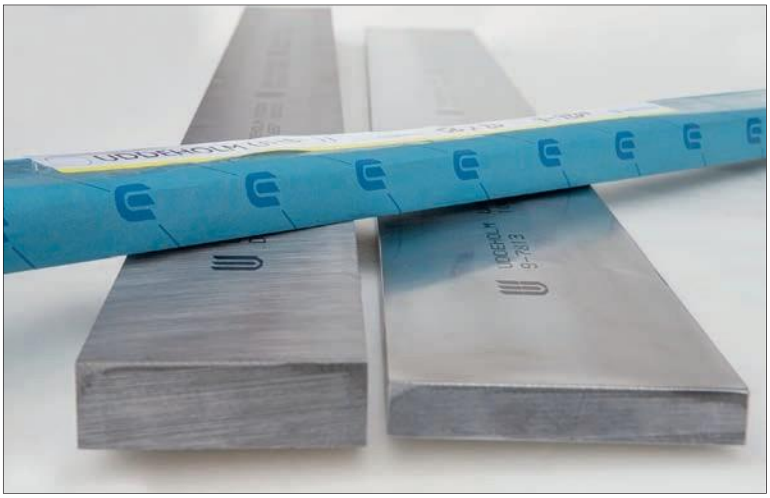
Machining costs can be reduced already at the design stage. One way of doing this is to construct a tool from machined steel plates, i.e. ground or fine milled to specific dimensions on all sides.

Uddeholm Service Centres are equipped with a full line of processing machinery, including grinders, milling machines, cut-off saws and other equipment.

FINE MACHINED STEEL

Uddeholm's long experience with tooling materials has shown that the most important requirements stipulated by users of fine machined bars and plates (apart from carefully controlled analysis and proper microstructure) are:

- flatness and thickness variation within specified tolerances
- minimum risk of shape changes due to the release of residual stresses during further machining
- technically acceptable surface finish



Fine machined bars.

As a result of an extensive development and investment programme, Uddeholm can now supply an entire range of fine machined bars and plates.

In addition to the advantages for machined material mentioned above, the use of fine machined material offers the following advantages:

- machining down to final external dimensions is reduced to a minimum
- given a suitable tool design, machining down to final external dimensions may be eliminated completely

The fine machined bar is delivered roller marked and wrapped in protective paper in convenient and easy to handle 1030 mm lengths.

Fine machined materials are available in all major grades.

WELDING ELECTRODES

Welding consumables are available for the Uddeholm tool steel grades Calmax, Carmo, Caldie and Unimax.

Uddeholm Calmax/Carmo Weld and Uddeholm Caldie Weld basic coated electrodes are available in the dimensions 2.5 mm (0.10 inch) and 3.2 mm (0.13 inch) Ø.

Uddeholm Calmax/Carmo Tig-Weld filler rod is available in 1.6 mm (0,06 inch) Ø.

Uddeholm Caldie Tig-Weld filler rod is available in the dimensions 1 mm (0,04 inch) and 1.6 mm (0.06 inch) Ø.

Uddeholm Unimax Tig-Weld filler rod is available in the dimension 1.6 mm (0.06 inch) Ø.

UDDEHOLM TOOL STEEL GRADES FOR COLD WORK TOOLING

UDDEHOLM STEEL	
Uddeholm Arne (AISI O1, W.-Nr. 1.2510)	Uddeholm Arne is a general purpose tool steel suitable for a wide variety of cold work applications. Its main characteristics include good machinability and a good combination of high surface hardness and toughness after hardening and tempering. These characteristics combine to give a steel suitable for the manufacture of short run tooling, back-up and punch holder plates.
Uddeholm Rigor (AISI A2, W.-Nr. 1.2363)	Uddeholm Rigor is a tool steel characterized by good machinability, high compressive strength, good hardenability, moderate toughness and medium wear resistance (mixed type of wear profile). These characteristics combine to give a steel suitable for the manufacture of medium run tooling.
Uddeholm Sleipner	Uddeholm Sleipner is a tool steel characterized by very high compressive strength, good hardenability, good machinability and grindability, good WEDM'ability, good resistance to both adhesive and abrasive wear and high resistance to chipping. Uddeholm Sleipner has a very wide properties profile and can be used for many different cold work applications in medium production runs. It is particularly suited for blanking and forming of plates with high/ultra high strength.
Uddeholm Sverker 3 (AISI D6, W.-Nr. 1.2436)	Uddeholm Sverker 3 is a tool steel characterized by high compressive strength, high surface hardness after hardening, good through hardening properties and very high wear resistance (abrasive type of wear profile). These characteristics combine to give a steel suitable for the manufacture of long run tooling for applications where the work material is particularly abrasive and the demands on toughness are low, e.g. blanking of trans-former plate and pressing of ceramics.
Uddeholm Sverker 21 (AISI D2, W.-Nr. 1.2379)	Uddeholm Sverker 21 is a tool steel characterized by high compressive strength, high surface hardness after hardening, good though-hardening properties and high wear resistance (abrasive type of wear profile). These characteristics combine to give a steel suitable for the manufacture of medium run tooling for applications where abrasive wear is dominant and the risk of chipping or cracking is not so high, e.g. for blanking and forming of thinner, harder work materials.
Uddeholm Calmax (W.-Nr. 1.2358)	Uddeholm Calmax is a tool steel characterized by high compressive strength, high surface hardness after hardening, good through hardening properties, extremely good toughness, good wear resistance (adhesive profile), good flame and induction hardenability and easy repair welding. These characteristics combine to give a steel suitable for the manufacture of short to medium run tooling for a very wide range of cold work applications where adhesive wear dominates and where the risk of chipping or cracking is very high, e.g. for heavy duty blanking and forming.
Uddeholm Unimax	Uddeholm Unimax is a tool steel characterized by very good chipping and cracking resistance (toughness and ductility are almost the same in all directions), good hardenability, good machinability and grindability, good WEDM'ability, good resistance to adhesive wear and adequate resistance to abrasive wear. Uddeholm Unimax is a unique problem solver for tooling for medium production volumes in severe applications such as heavy duty blanking and cold forging where a very high chipping and cracking resistance are needed.

Uddeholm Caldie	Uddeholm Caldie is a tool steel characterized by extremely good combination of high compressive strength and chipping resistance, good hardenability, good machinability and grindability, good WEDM'ability, good resistance to adhesive wear and rather good resistance to abrasive wear. Uddeholm Caldie is a unique problem solver in severe cold work applications in medium production runs where a very good combination of high compressive strength and chipping resistance is needed. Cold forging of difficult work materials and geometries and blanking and forming of advanced high strength sheets are good examples. Uddeholm Caldie is also very suited as substrate material at all types of surface coatings.
Uddeholm Vanadis 4 Extra SuperClean	Uddeholm Vanadis 4 Extra SuperClean is a PM (Powder Metallurgical) tool steel which is characterized by high compressive strength, high surface hardness after hardening, very good through hardening properties, very high chipping resistance, very good wear resistance (adhesive wear profile) and very good stability in hardening. These characteristics combine to give a steel suitable for the manufacture of long run tooling for a very wide range of applications where adhesive wear is dominant and/or the risk of chipping or cracking is very high, e.g. for blanking and forming of thicker work material such as austenitic stainless steel, mild carbon steel, copper, advanced high strength steel and aluminium, etc. Uddeholm Vanadis 4 Extra SuperClean is a particularly good substrate for CVD coatings.
Uddeholm Vanadis 8 SuperClean	Uddeholm Vanadis 8 SuperClean is a PM (Powder Metallurgical) tool steel characterized by extremely high wear resistance (abrasive wear profile), high compressive strength, high surface hardness after hardening, very good through hardening properties, good toughness and very good stability in hardening. These characteristics combine to give a steel suitable for the manufacture of very long run tooling where abrasive wear is dominant, e.g. blanking and forming of abrasive material, blanking of electrical steel sheet, blanking of gaskets, paper and foil slitting, granulator knives, extruder screws, etc.
Uddeholm Vanadis 23 SuperClean (AISI M3:2, W.-Nr. 1.3395)	Uddeholm Vanadis 23 SuperClean is a PM (Powder Metallurgical) high speed steel characterized by high compressive strength, high surface hardness after hardening, very good through hardening properties, good toughness, very good wear resistance (mixed/abrasive wear profile), very good stability in hardening and very good tempering resistance. These characteristics combine to give a steel suitable for the manufacture of long run tooling for a very wide range of applications where mixed or abrasive wear is dominant and where the risk of a plastic deformation of the working surfaces of the tool is high, e.g. blanking of cold rolled steel or hard materials. Uddeholm Vanadis 23 SuperClean is a particularly good substrate for PVD coatings.
Uddeholm Vancron 40 SuperClean	Uddeholm Vancron 40 SuperClean is a PM (Powder Metallurgical) tool steel characterized by very high galling resistance, very high adhesive wear resistance, good chipping and cracking resistance, high compressive strength, good through hardening properties and good dimensional stability in hardening. Uddeholm Vancron 40 SuperClean's anti-galling profile means that it is an ideal steel for high volume production tooling where coatings would normally be needed to prevent galling. It is often not necessary to coat Uddeholm Vancron 40 SuperClean tooling.

UDDEHOLM HOLDER STEEL	
Uddeholm Formax	Uddeholm Formax is a low carbon bolster steel suitable for large top and bottom plates and medium strength supports. Uddeholm Formax is easy to flame cut, weld and case harden.
Uddeholm UHB 11 (AISI 1148, W.-Nr. 1.1730)	Uddeholm UHB 11 is a medium-carbon bolster steel suitable for top and bottom plates and higher strength support parts.

EXECUTIONS AND PRODUCTS

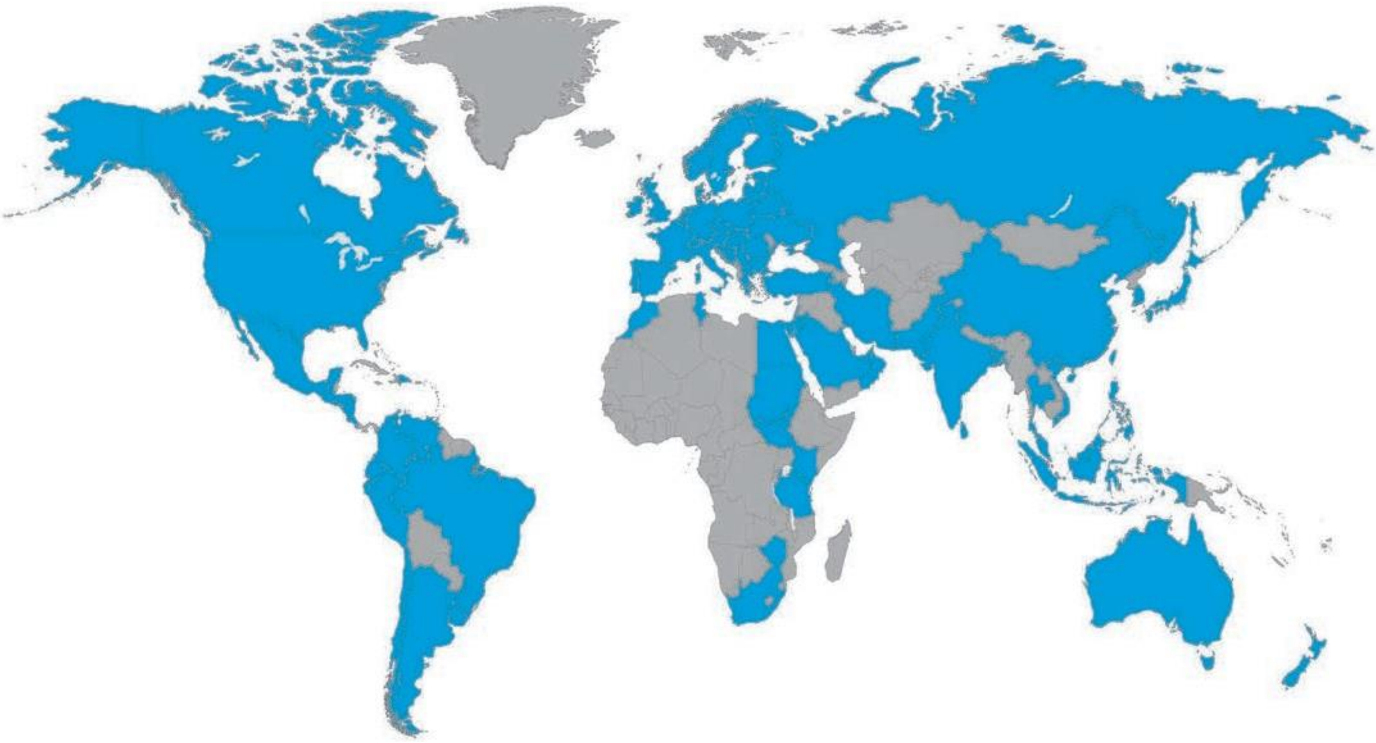
UDDEHOLM STEEL	BAR EXECUTIONS					HER TYPES OF PRODUCTS	
	UN-MACHINED	ROUGH MACHINED	HOLLOW BARS	FINE MACHINED	PRECISION MACHINED	PLATES	WELD ELECTRODES
Arne	X	X		X	X	X	
Rigor	X	X		X		X	
Sleipner	X	X		X		X	
Sverker 3	X	X		X			
Sverker 21	X	X	X	X		X	
Calmax	X	X		X			X
Unimax	X	X					X
Caldie	X	X		X			X
Vanadis 4 Extra*	X	X		X	X	X	
Vanadis 8*	X	X		X		X	
Vancron 40*		X					
Vanadis 23*	X	X		X		X	
UDDEHOLM HOLDER STEEL							
Formax	X	X		X	X	X	
UHB 11	X	X		X	X	X	

* PM SuperClean tool steels

CHEMICAL COMPOSITION

UDDEHOLM STEEL	C	Si	Mn	Cr	Mo	W	V	S	SUPPLIED HARDNESS max. Brinell
				ANALYSIS %					
Arne	0.95	0.3	1.1	0.6	–	0.55	0.1	–	220
Rigor	1.0	0.3	0.6	5.3	1.1	–	0.2	–	235
Sleipner	0.9	0.9	0.5	7.8	2.5	–	0.5	–	240
Sverker 3	2.05	0.3	0.8	12.7	–	1.1	–	–	260
Sverker 21	1.55	0.3	0.4	11.3	0.8	–	0.8	–	235
Calmax	0.6	0.35	0.8	4.5	0.5	–	0.2	–	212
Unimax	0.5	0.2	0.5	5.0	2.3	–	0.5	–	200
Caldie	0.7	0.2	0.5	5.0	2.3	–	0.5	–	215
Vanadis 4 Extra*	1.4	0.4	0.4	4.7	3.5	–	3.7	–	270
Vanadis 8*	2.3	0.4	0.4	4.8	3.6	–	8.0	–	≤ 270
								N	
Vancron 40*	1.1	0.5	0.4	4.5	3.2	3.7	8.5	1.8	300
Vanadis 23*	1.28	0.5	0.3	4.2	5.0	6.4	3.1	–	260
UDDEHOLM HOLDER STEEL									
Formax	0.18	0.3	1.3	–	–	–	–	–	230
UHB 11	0.50	0.2	0.7	–	–	–	–	–	210

* PM SuperClean tool steels



NETWORK OF EXCELLENCE

Uddeholm is present on every continent. This ensures you high-quality Swedish tool steel and local support wherever you are. Our goal is clear – to be your number one partner and tool steel provider.

UDDEHOLM

UDDEHOLM 10.2017.300 / STROKIRK-LANDSTRÖMS, Karlstad

Uddeholm is the world's leading supplier of tooling materials. This is a position we have reached by improving our customers' everyday business. Long tradition combined with research and product development equips Uddeholm to solve any tooling problem that may arise. It is a challenging process, but the goal is clear – to be your number one partner and tool steel provider.

Our presence on every continent guarantees you the same high quality wherever you are. We act worldwide. For us it is all a matter of trust – in long-term partnerships as well as in developing new products.

For more information, please visit www.uddeholm.com

UDDEHOLM