ERASTEEL

SURFACES

Influence of surface quality on
high-performance ASP® tools

Introduction

New high-performance tool materials, such as the latest generation of ASP® steels, make operations such as cutting and forming increasingly more effective. However, high-performance tool materials of high hardness provide inevitably a lower toughness. This lower toughness calls for a material with smaller and fewer imperfections so that the strength of the tool can be kept high. Smaller and fewer imperfections mean, in practice for high speed steels, that there is a need to reduce the size and amount of oxides, non-metallic inclusions, carbide clusters, etc. At Erasteel we have worked continuously with this during the last 30 years. First, with the introduction of the powder metallurgy process (ASP) and then through various developments to reduce the amount of non-metallic inclusions, such as the ESH process and Dvalin™. In this way we have managed to continuously achieve a considerably finer microstructure of the steel and, hence, a steel of increasingly higher strength. As the bulk material has now reached a high level of per-formance, owing to the refinement in the production of ASP grades, we see an increasing trend of failures initiated at the surface of the tools. These failures are often linked to the processing and manufacturing of tools – presently about 1/3 of the failed tools we receive. This demonstrates that a level has been reached where the surface finish is critically important in taking full advantage of the latest material develop-ment. The intention of this brochure is to raise the awareness and the understanding of the importance of surface and surface quality for tools made of the latest generation of high performance ASP grades.

ASP® is a registered trade mark of Erasteel.
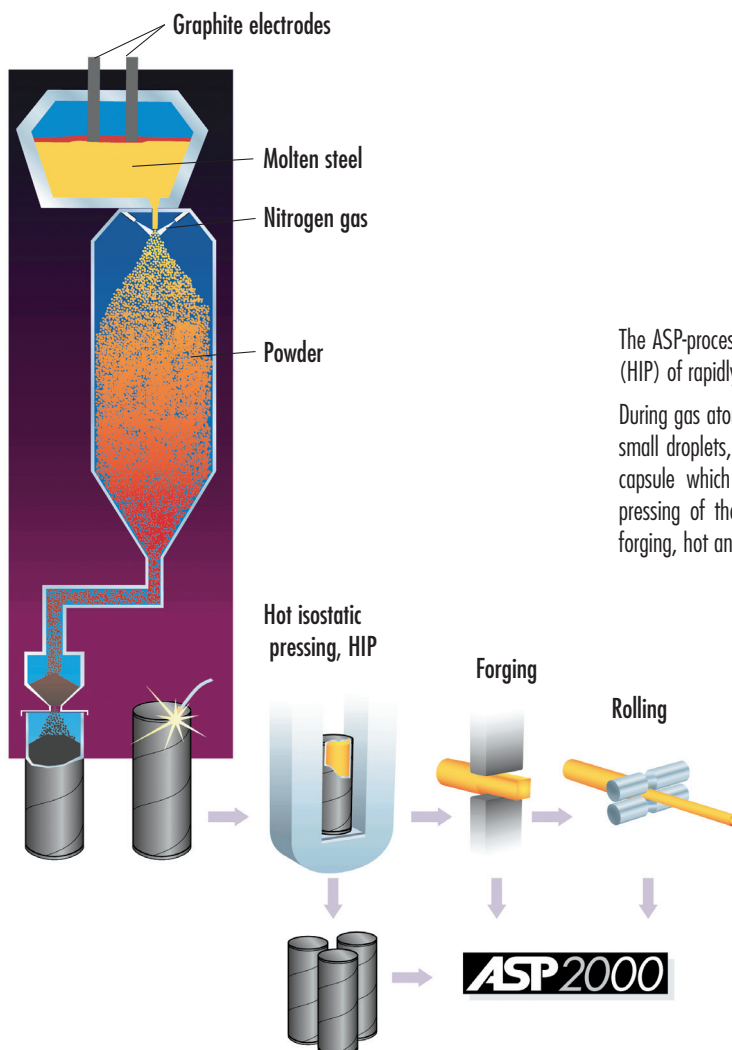
AVOID TOOL FAILURES BY
TAKING A CLOSER LOOK
AT THE SURFACES

HSS basics

High speed steel (HSS) combines, in a unique manner, high strength with high hardness, and is thus an ideal material in such diverse applications as cutting tools, cold forming tools, wear parts, etc. The unique properties of HSS are derived from the iron-carbon matrix alloyed with Mo, W, V and Cr, which, after tempering, contains evenly distributed nano-meter-sized carbides which strengthen the steel. The HSS also contains between 2-20 volume percent of larger carbides, about 1-10 µm large, which are either of MC type (mainly vanadium in addition to carbon) or of M_6C type (mainly molybdenum, tungsten and iron in addition to carbon). The hardness of these carbides is about 2800 HV for the MC carbides

and about 1600 for the M_6C carbides. These so-called primary carbides provide the high wear resistance of the HSS and to a lesser degree the hardness. Additionally, some HSS grades contain up to 15 wt. % of cobalt in order to give some additional hardness and hot-hardness.

Traditionally, manufacturing of HSS has been carried out using casting and forging techniques to manufacture conventional HSS. A substantial improvement in the properties of HSS was achieved from the introduction of the Erasteel powder metallurgy process – ASP steels. With the powder metallurgy process, the microstructure of the ASP steel is much refined with a very even distribution of finer primary carbides. This results in an improved combination of strength and hardness in comparison to 'conventional' HSS.

Graphite electrodes

Molten steel

Nitrogen gas

Powder

Hot isostatic pressing, HIP

Forging

Rolling

ASP 2000

The ASP-process is a powder metallurgy technique, comprising hot–isostatic pressing (HIP) of rapidly solidified gas atomised powder.

During gas atomisation the melt is disintegrated by powerful jets of nitrogen gas into small droplets, which solidify at a very high rate. The powder is collected in a steel capsule which subsequently is evacuated and welded. Finally, after hot-isostatic pressing of the ASP-powder, bars, wire rods, strips and sheets are obtained from forging, hot and cold rolling and wire drawing.

Defects and their influence on tool properties

One of the most distinct advantages of ASP steels compared to other tool materials, such as cemented carbides, is their high strength. This allows tool makers to make not only sharp tools but also their customers to use these tools under high loads, i.e. high feeds and work material removal rates. The reason for the high strength of ASP steels is the extremely low level of internal material defects, owing to the unique combination of fine microstructure with high cleanliness.

Because of the low level and size of internal material defects in ASP steels, there is a high probability that surface defects owing to the processing of the tools, and not the 'intrinsic' quality of the steel, provide the larger defects. This implies that the high strength expected from the high quality of the bulk material is not always achieved owing to defects at the surface introduced during manufacturing of the tool. As the tool surface is often the part of the tool that is under the highest stress, defects at the surface are very often a limiting factor for the tool life.

At a given hardness, the strength of high speed steel is inversely proportional to the largest imperfection in that part of the material under high tensile stress. In other words, as the size of the largest imperfection increases the strength decreases as:

$$\sigma_F \propto \frac{K_{Ic}}{\sqrt{d}}$$

Here σ_F is the strength, K_{Ic} the fracture toughness and d is the size of the imperfection initiating the fracture. The imperfections may, for instance, be large carbides, carbide clusters and strings of carbides, as found in conventional HSS, and also, non-metallic inclusions and defects related to the surface such as grooves (grinding marks, scratches) and thermal damage. Of these imperfections, it is the largest one which will determine the strength of the tool edge. This means that the strength of tool materials is controlled by imperfections or defects.

Fracture toughness (K_{Ic}), or, more specifically the sensitivity to stress raising imperfections, also influences the strength of the tool material. The fracture toughness has been found to decrease almost linearly with the hardness of the steel, whereas the properties of the microstructure, like carbide size and distribution, usually have only a minor influence. Thus, the fracture toughness may be regarded as constant for a given hardness level for both HSS and ASP steels.
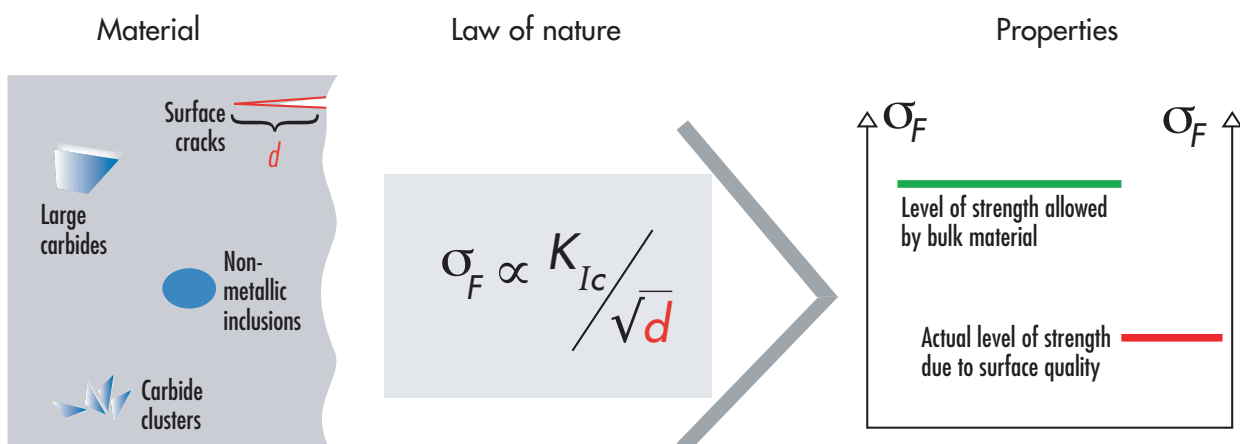

The largest imperfection, in the part of the material under high stress, sets the maximum strength of the tool. Often, for the latest generation of ASP steels, the bulk material is free from larger imperfections, and surface defects such as scratches or structural changes owing to the processing of the tool are the limiting factors.
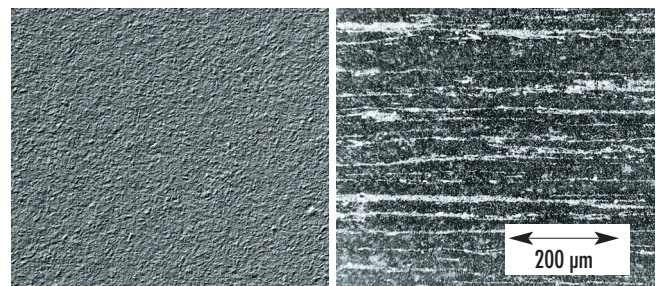
Ground surface and high performance material (ASP 2023)
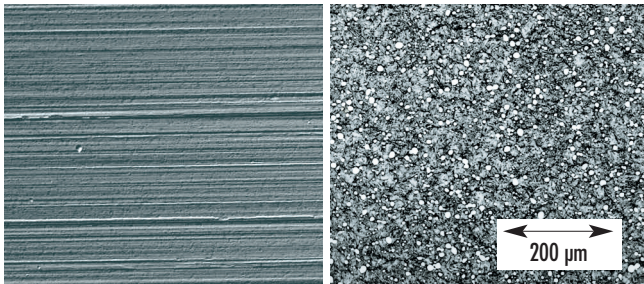
High quality surface and high performance material (ASP 2023)
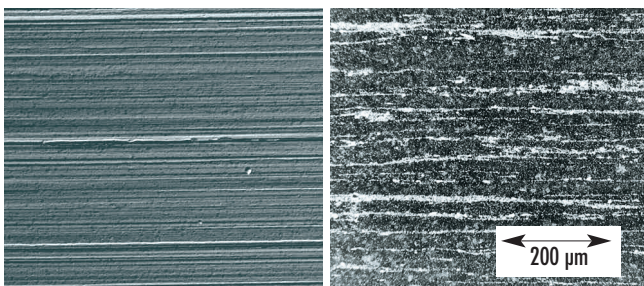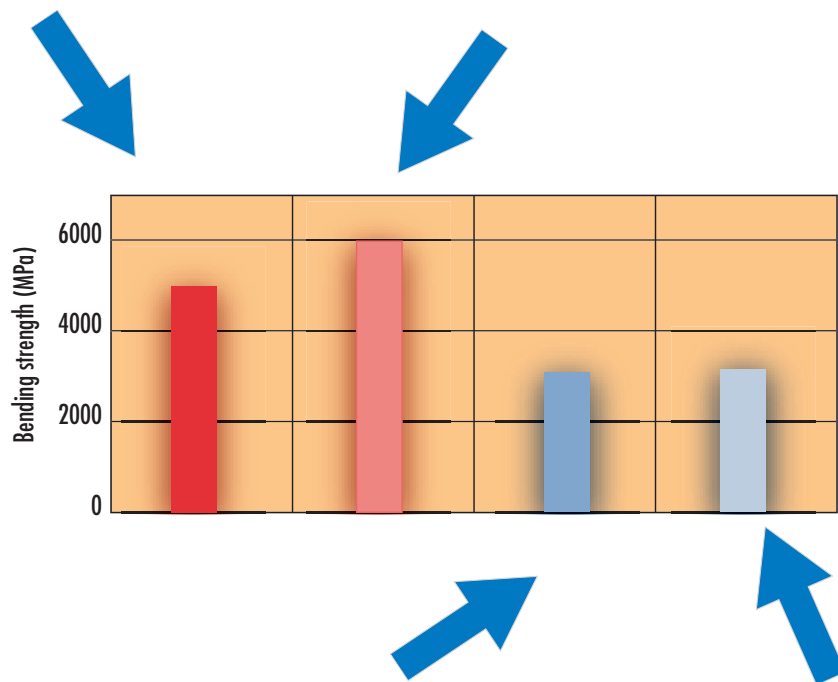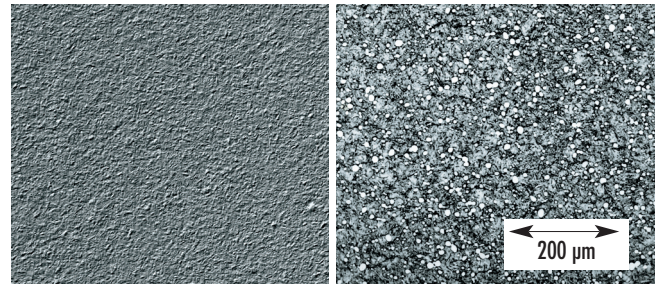
Ground surface and conventional HSS (M2)

High quality surface and conventional HSS (M2)

In the present example, a substantial increase in bending strength is observed for ASP 2023 from the use of a high quality surface preparation whereas for M2 (a standard HSS made by conventional casting) there is no or very little influence from high quality surface preparation.

This example shows that the surface quality should be matched to the microstructure, and a surface of high quality is needed to take full advantage of the latest generation of ASP steels. This is because the largest defect in the volume under high mechanical stress sets the maximum strength of the material. For high performance materials, with homogeneous and fine microstructure, such as ASP grades, the largest defect is often a surface defect (grooves, tensile residual stresses etc) whereas for HSS made by conventional casting technique, or PM-HSS of low cleanness, the largest defect is often found within the body of the material.

Surface Quality Basics

The surface quality of a tool is the result of the different processing steps during the manufacture of the tool, such as heat-treatment, grinding, final surface preparation, etc.

The final performance of the tool is strongly dependent on the surface quality of the tool. The surface quality is achieved from a combination of the:

- *Geometrical properties* of the surface: surface roughness, presence of surface defects such as scratches

- *Structural, mechanical and chemical alterations* of the material close to the surface compared to the bulk material: phase transformation, heat-affected zone, carburisation, decarburisation, oxidation, residual stresses, plastic deformation etc.

- Other defects such as *burr*.

Surface roughness

Surface roughness refers to the fine irregularities (peaks and valleys) formed on the surface by the tool manufacturing process. The most common statistical description of the surface roughness is the roughness average R_a, which is obtained by sliding a stylus tip over the surface, measuring the surface profile and calculating the average deviation from the mean line. It should be pointed out that R_a values are just a rough description of the surface roughness as it does not take into account the possibility of directionality (like grinding grooves) and the fact that different surface profiles may have the same R_a. Therefore, one often encounters examples of material with similar R_a values but different surface related properties.
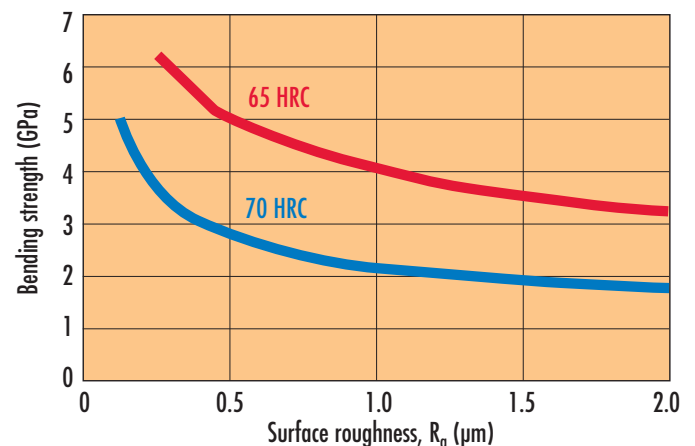

Bending strength vs. surface roughness for standard (65 HRC) and high performance (70 HRC) material. High hardness inevitably implies a lower fracture toughness (K_{Ic}), however, the same high level of strength is achievable for both types of materials, provided that the surface of the high performance material is prepared with a sufficiently high surface finish.
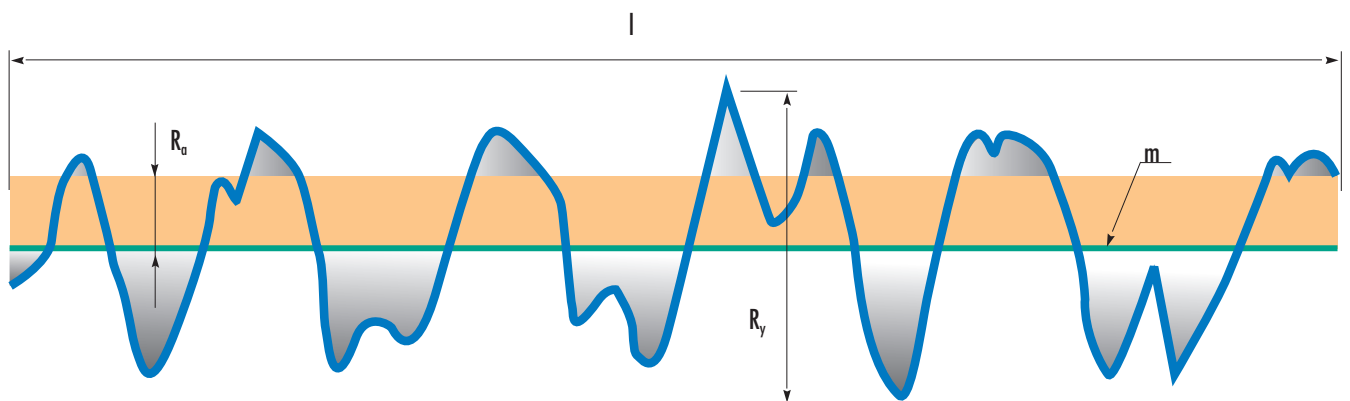

A common measure of the surface roughness is the R_a-value, which is a measure of the average deviation from the mean line in a specific direction. Other examples are the R_y, which is the maximum deviation in a specific length l, and R_z, which is the average of the five highest peaks and the five deepest valleys in a specific length l.

Ground surface (R_a = 0.12 µm),
5000 MPa bending strength
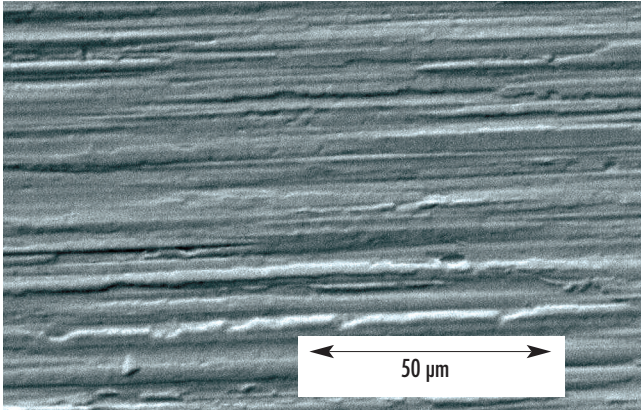
Homogeneous surface (R_a = 0.18 µm),
6000 MPa bending strength
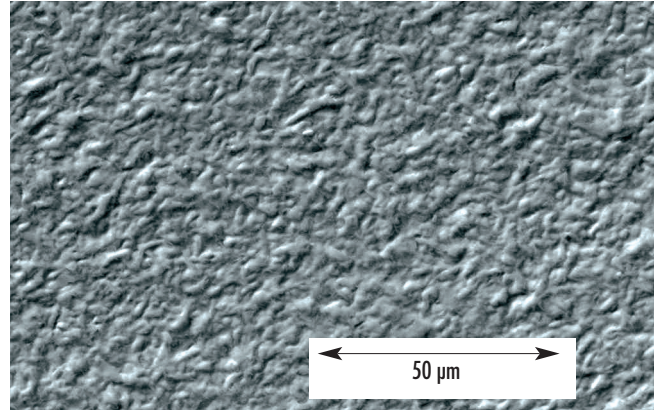
Different surface homogeneity but similar R_a values of two otherwise identical ASP 2023 tool materials. In this particular example the lower R_a value of the material to the left could lead one to believe wrongly that this material should be less influenced by the surface, and hence have a higher strength, than the material to the right. Evidently, R_a values alone should be used with caution when judging the surface finish.

Structural alterations

Too high surface temperature during tool manufacturing can result in structural alterations of the material closest to the surface. This may be, for instance, phase transformations, softening, etc. These alterations are generally more difficult to detect and to characterise than the surface roughness but may have a dramatic influence on the overall properties of the tool. Grinding, heat treatment, Electric Discharge Machining (EDM) etc., are examples of techniques which can alter the structure of the material immediately adjacent to the surface.

For high speed steels, temperatures between 500-900 °C at the surface result in an over tempering (softening of the material), temperatures between 900-1200 °C in a rehardening (phase trans-formation as austenite is formed) whereas yet higher temperatures result in melting of the surface. The cooling, following removal from the high temperature, is generally rapid as it is often only a few hundred micrometers of the surface which is heated during surface preparation. Fast cooling from hardening or melting temperatures of HSS results in the formation of very brittle non-tempered martensite. In this brittle martensite, cracks propagate easily giving a material of low toughness and strength.

Chemical alterations

Variation of chemical composition within the material is another type of structural alteration. Typically for high speed steels, if heat-treated incorrectly, is a depletion of carbon at the surface (decarburisation), which results in a softening of the surface. This may be due to high temperatures during surface preparation in air or heat treatment with poor control of the atmosphere or media (often in salt baths).

Related also to decarburisation is the formation of a thick oxide layer at the surface or even oxide penetration. This happens if the atmosphere contains oxygen and the surface is at an elevated temperature, but can also occur in salt bath heat treatment.

Residual stresses

Residual stresses at the surface of a tool may be of both compressive and tensile type or some combination of the two. Residual stresses of tensile type may be revealed as cracks after etching, whereas compressive stresses and measurements of stress profiles call for the use of more involved techniques such as X-ray diffraction.

Tools under high mechanical loads, such as in grinding, peening, turning etc., often show compressive stresses in the surface. If the mechanical load is not too high, these compressive stresses may have a slightly positive and beneficial effect on the performance of the tool.
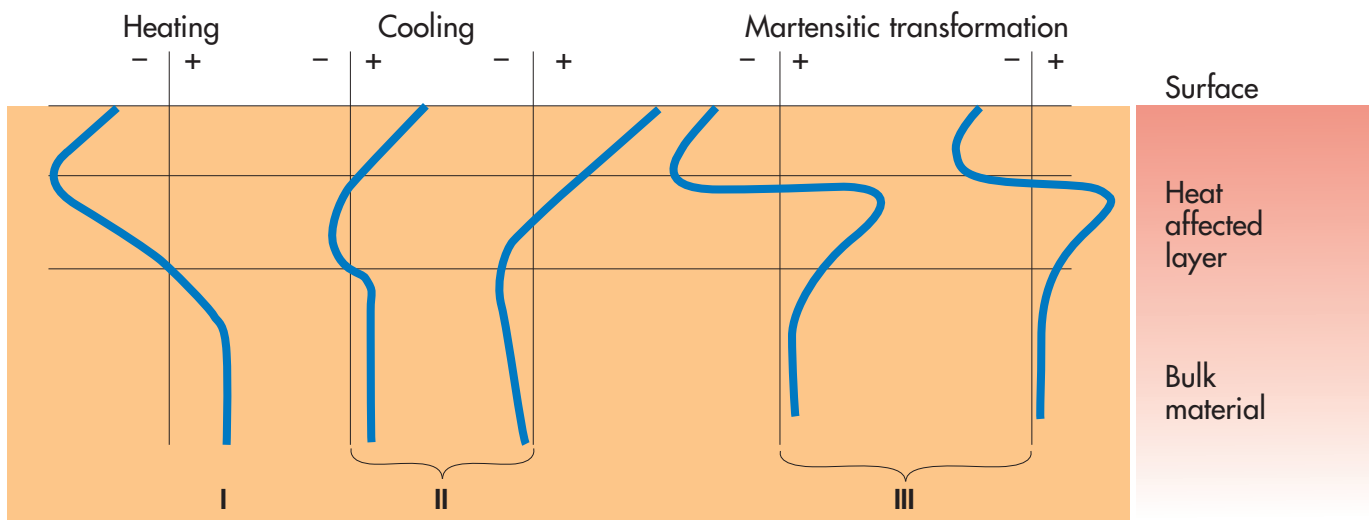
'+' is for tensile and '−' is for compressive stresses.

Complicated stress profiles in high speed steels may result when the temperature is sufficiently high to initiate an austenitic phase transformation at the surface.

I Heat is generated at the surface resulting in a phase transformation but also expansion and hence compressive stresses at the surface.

II The surface cools and shrinks and thus tensile stresses are initiated.

III An austenitic transformation to martensite, which results in an expansion of the outermost part of the surface and consequently compressive stresses in this part of the material.

As seen, the final stress profile is complicated with both high tensile and compressive stresses and a steep stress gradient in between.

This surface layer will provide an ideal place for fracture initiation as the untempered martensite is brittle and the surface is under high tensile stresses with steep stress gradients. It is therefore very important to remove surface layers of untempered martensite before the tool is put into use.

Tool surfaces exposed to fast temperature gradients often show tensile stresses owing to the initial heating of the surface followed by a cooling and heat transfer to the bulk of the tool. If the heating of the surface is sufficiently high, phase transformations may take place which can result in complex combinations of tensile and compressive stresses.
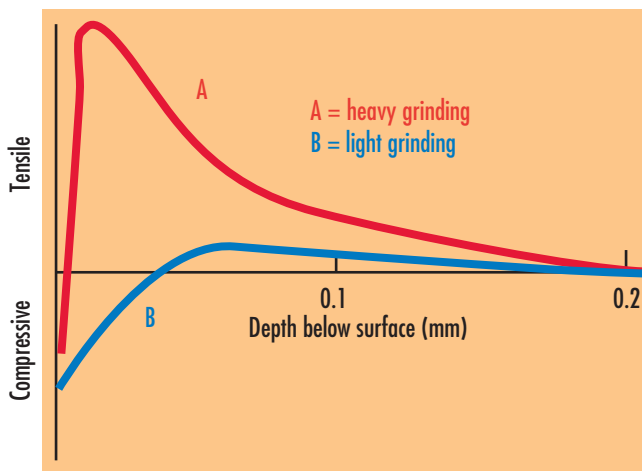
Residual stresses are found at the surface of most ground tools. Compressive stresses may have a positive influence on the tool performance whereas tensile stresses, owing to heavy grinding, decreases tool life and can cause cracking of the surface

Burr

Burr is formed by plastic deformation of the material during machining at elevated mechanical loads and/or temperatures in both cutting and grinding operations. Burr formation is more frequent when dull tools are used and this calls for the use of, for instance, sharp grinding wheels. Burr on a tool implies that the surface finish of the work material will be poor. In addition, the burr will eventually break off and leave fracture surfaces of low surface finish which may act as initiation points for further fracture. The negative influences of burr is amplified if the tools are coated. The removal of burr by fracture in this case results in fracture surfaces which are non-coated resulting in accelerated wear at these parts of the tool. To minimise burr formation, one should use a sharp tool or decrease the forces during machining. Alternatively, manual deburring, sand blasting, and water deburring can be used.
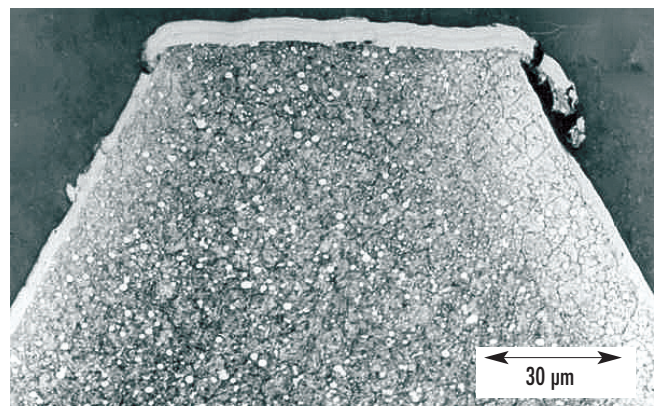
In this example a tool with burr at the tool edges has been coated. Eventually, the burr will break off, which will result in a non-coated fracture area which will experience accelerated wear and also act as an ideal point for crack initiation.
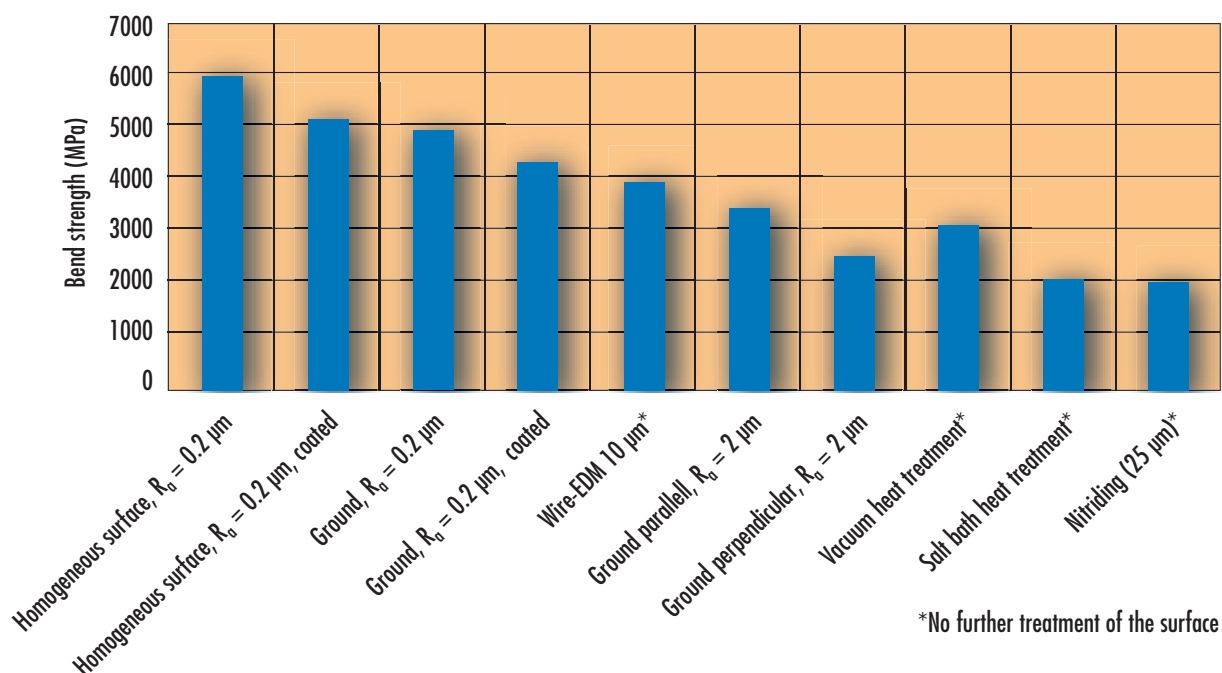
Influences of tool manufacturing techniques on the surface condition

Today, there is a wide range of different techniques for tool manufacturing. The resulting surface conditions vary greatly from method to method owing to the very different characteristics of the manufacturing techniques. This in turn implies that performance and mechanical properties of tools depend also on the type and quality of the manufacturing technique. In this chapter we will explore some of the most common techniques related to tool manufacturing and their influence on tool performance. The high hardness of tool materials sets certain constraints on manufacturing and this limits the choices. In this part, only techniques appropriate for tool materials will be covered.

EDM

Electrical Discharge Machining (EDM) is one of the few methods available to machine high hardness materials. EDM removes material by spark discharges which raise the temperature high enough to melt or even vaporise the uppermost layer of the work piece. The spark discharges are generated from a solid tool-shaped electrode, as in die sinker EDM, or from a continuously moving wire, as in electrical discharge wire cutting (EDWC). The major disadvantage with EDM is the high temperature at the surface of the work piece, which gives rise to melting, resolidification and subsequently rehardening of the work piece surface. The rehardened surface is very brittle and may contain additional defects such as surface cracks and porosity. For that reason, a post treatment of the EDM machined surface is always needed for high performance tools in order to remove the heat affected layer. The post treatment may include grinding, tempering and/or shot blasting.

BEND STRENGTH VS. SURFACES FOR ASP 2023 AT 66 HRC


*No further treatment of the surface

High performance, high hardness tool materials are sensitive to surface quality. In the present case this is illustrated by a large variation in bend strength between material prepared using different tool manufacturing techniques.
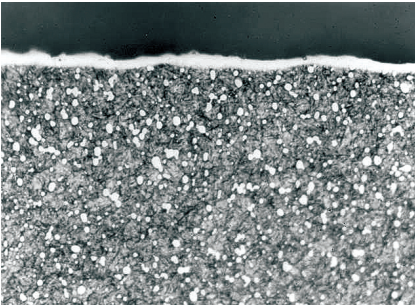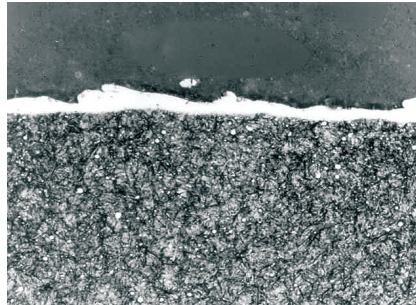
EDM 4 µm   EDM 9 µm   EDM 18 µm
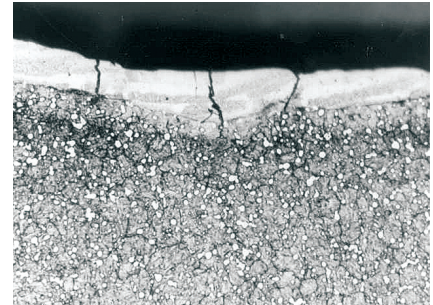
An uppermost melted and resolidified layer, often referred to as the "white layer", is always found after EDM-machining. The thickness of the layer can vary owing to, for instance, the discharge energy. For HSS, this uppermost layer should be removed as it contains very brittle non-tempered martensite which will lower the properties and the performance of the tool.

Depending upon the type of EDM machining and strength of the discharge energy, the final surface quality and hence the final mechanical properties of the ASP steel will vary. From the figure to the right one may conclude that die sinker EDM has more severe influence on surface quality than wire cutting EDM (EDWC) and that increased discharge energy decreases the surface quality and hence the bend strength.
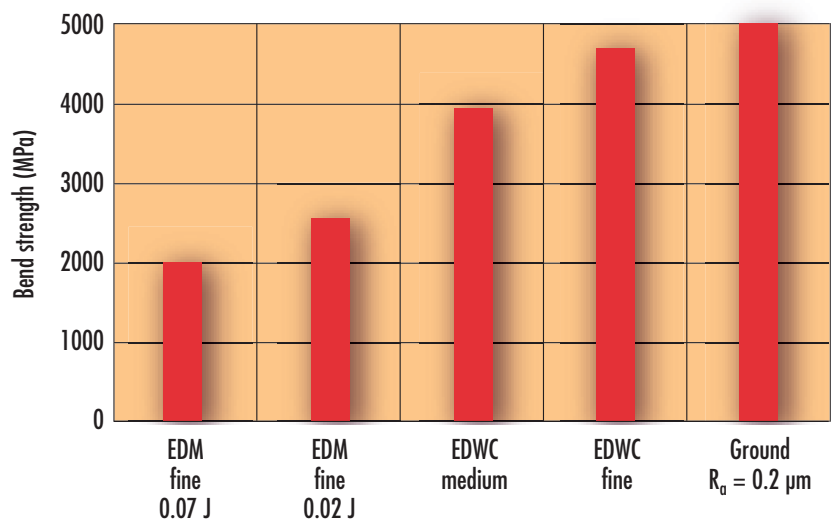
In Electric Discharge Machining (EDM), the temperature at the surface layer can be very high.

In this example, the temperature has been high enough to melt the outermost area of the surface, further down in the material to form a rehardening zone and finally cause an over tempered zone.

This heat affected zone, which in total stretches some hundred µm down in the material, has a severe influence on the mechanical properties as the resolidification cracks in the melted zone provide excellent fracture initiation points, the rehardening zone contains very brittle untempered martensite and the overtempered zone gives a softening of the tool.

Clearly, it is very important to remove the entire heat affected zone before the tool can be used.

20 µm

400 600 800 1000 HV

Melted and resolidified layer

Rehardened layer

Over tempered layer

Unaffected material
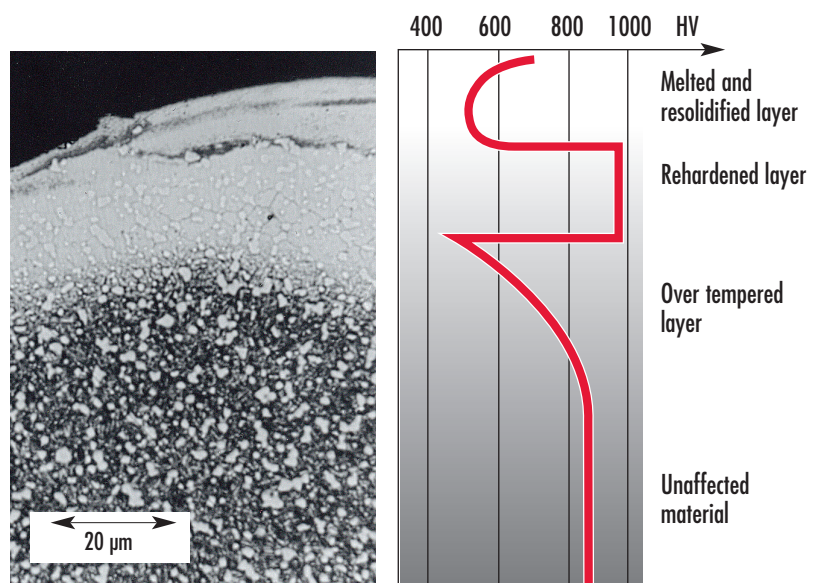
Heat treatment

All high speed steels are heat treated and the heat treatment operation can have a major influence on the surface finish if not carried out properly. Heat treatment, or more specifically hardening, is carried out either in vacuum or salt bath furnaces. Vacuum furnace heat treatment, if carried out in a correct manner, should have a minor influence on
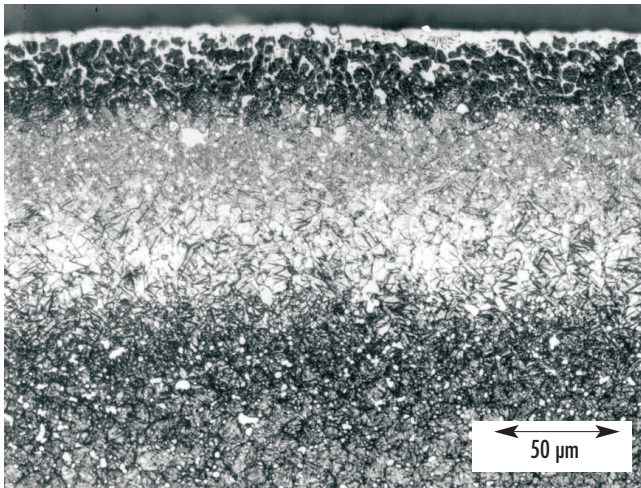
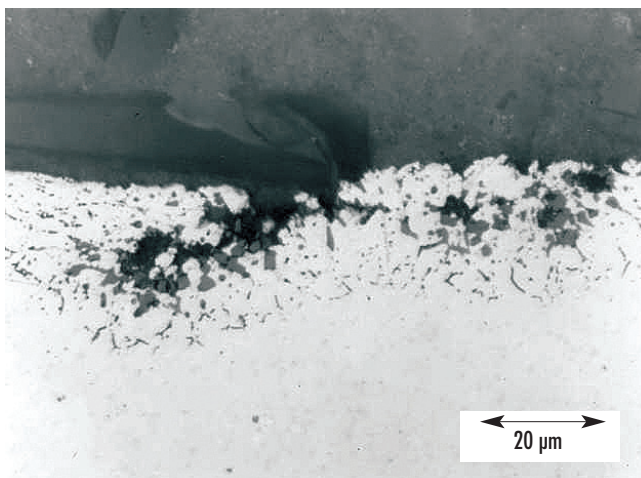Surface quality is, in most cases, better after vacuum than salt bath heat treatment. However, in this particular case, the tool has not been cleaned properly and oil at the surface caused a carburisation of the surface during vacuum furnace heat treatment. Effective cleaning of the tool surface is important or the surface quality may be ruined.

Surface finish is often worsened by salt bath heat treatment. This image shows severe oxide penetration.

the surface quality. Even so, it is very important to clean the tool thoroughly prior to vacuum heat treatment, as dirt on the surface may give raise to carburisation of the surface and thus a brittle surface layer. Salt bath heat treatment is more aggressive to the surface, and corrosion and oxide penetration are commonly observed. Generally, surface related heat treatment problems are made worse with increasing temperature. Often the tool is ground after heat treatment. However, surface defects introduced at hardening can go deep into the material and are sometimes not removed completely by grinding.
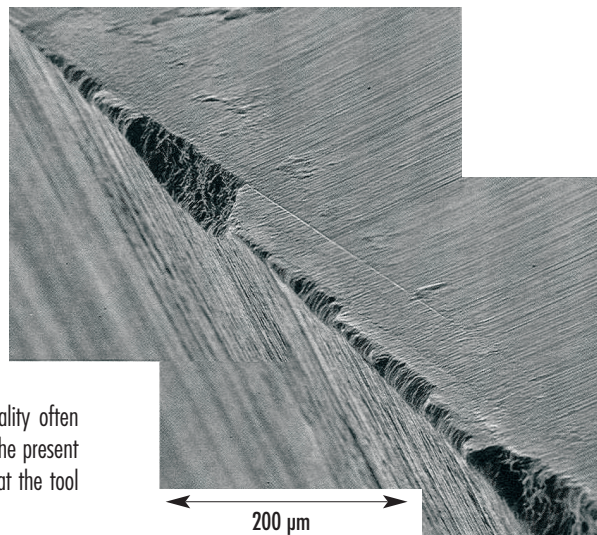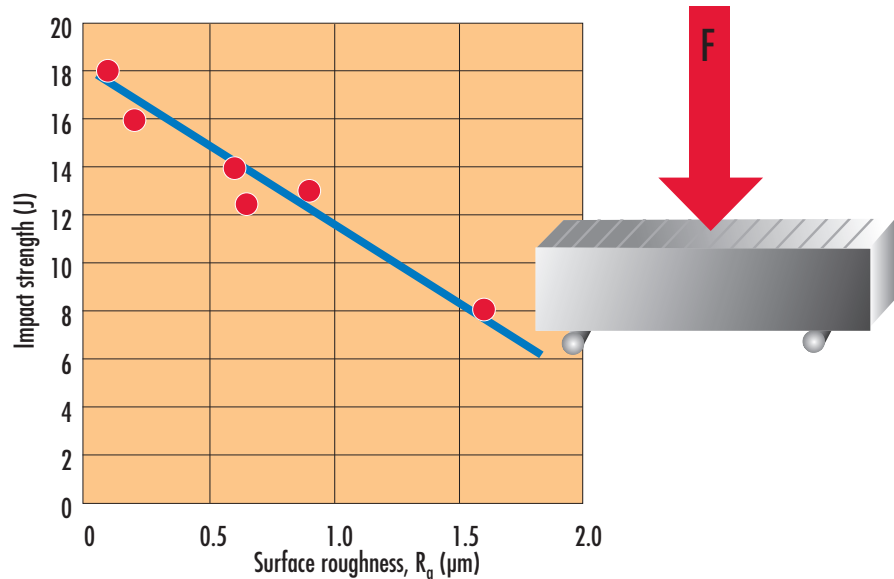
Grinding

Grinding is one of the most common methods used in the manufacture of tools and their surfaces. When the grinding operation is carried out carefully, its only major influence should be on the surface roughness. However, grinding is very often forced for economic reasons such as higher productivity, and this may cause burning of the surface owing to too high a temperature at the surface or to the generation of high residual stresses in the surface. Burning of the sample can give rise to a soft surface owing to over tempering (surface temperatures between 500-900 °C) or a brittle surface owing to rehardening (surface temperatures above 900 °C). Both these examples give an increased risk of tool failure and hence a reduced tool life. Burning of the surface can be revealed from the oxide layer that is often found on a surface that has been at too high a temperature. In this case the colour of the oxide layer may be used as an indicator to the temperature. However, it is very important to realise that the heat affected zone stretches much further down into the material than the thickness of the oxide layer would indicate. So removing the oxide layer only will not result in a surface of good quality.
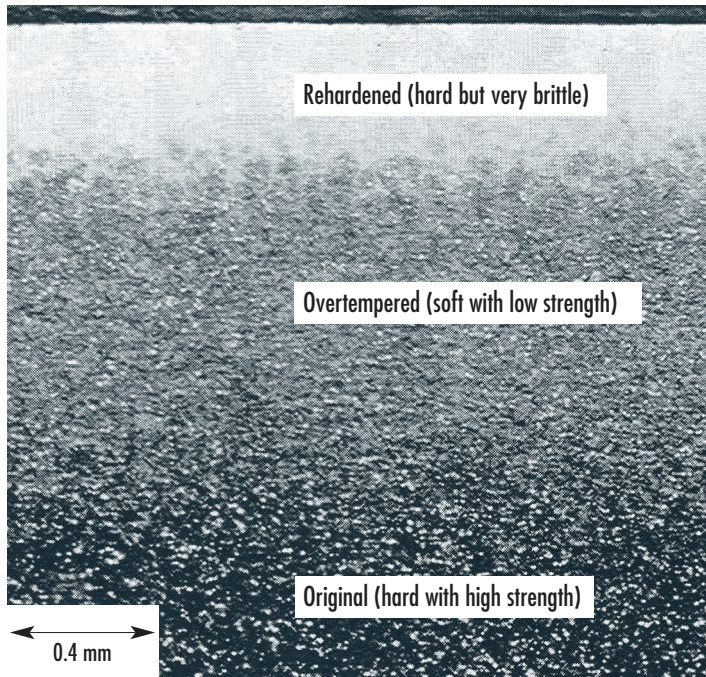
A rough surface after grinding may lead to micro-chipping starting from grinding marks at the tool edge and consequently a reduced tool life owing to accelerated tool wear. Also, fracturing of a tool is often initiated at large grinding marks. In connection to this, one should stress that it is dangerous to judge the surface finish from a measure of the average surface roughness only, for instance an R_a value. It is the largest grinding mark at that part of the material which is under high mechanical load, and not the average surface roughness, which is important for the strength of the tool material. So the R_a value can be used only as a measure of the probability for fracture at a specific stress level and not as an absolute measure directly related to strength.

Fracture is often initiated at grinding marks. In this figure it is shown by the influence of surface roughness on impact strength. However, it is the largest grinding mark which sets the strength of the material. But a high R_a value generally indicates an increased probability of large grinding marks, and hence we observe a decrease in impact strength with increasing R_a value.

In real life, low impact strength owing to poor surface quality often implies micro-chipping or even fracture of the tool edge. In the present example micro-chipping has started from grinding scratches at the tool edge in milling application.

Rehardened (hard but very brittle)

Overtempered (soft with low strength)

Original (hard with high strength)

0.4 mm

Micro-chipping (mm²)

0.1
0.08
0.06
0.04
0.02
0

N   B

B = Burned as in the figure to the left

N = Normal non-burned surface

Burning of the surface during grinding may give rise to a rehardened zone of very brittle non-tempered martensite at the surface. In the present case with ASP 2030, this was revealed from an increased frequency of micro chipping for tools with burned surfaces in comparison to tools with non-burned surfaces.

The drill above to the left has been ground with improved cooling whereas the one in the bottom has been ground with a standard cooling nozzle. The non-optimum cooling has resulted in tensile stresses at the surface which, after etching, are revealed as large surface cracks.
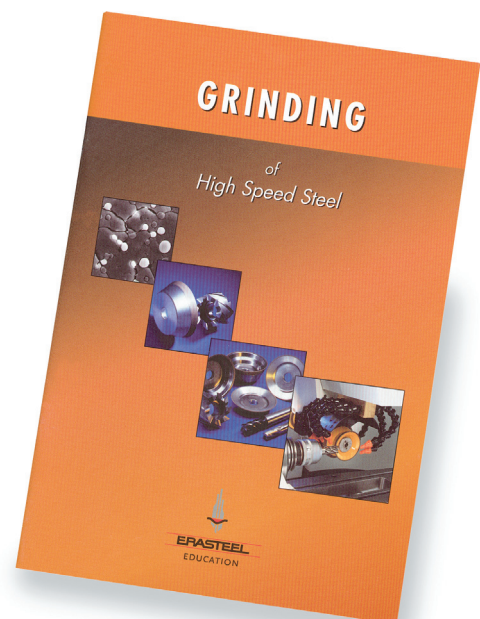
The grinding operation is of great importance for the performance of tools made of high hardness tool materials such as ASP steels. For that reason, Erasteel has produced a brochure covering the essentials of grinding in general and with focus on the grinding of HSS, both conventional and ASP, in particular.

Techniques for deburring and surface finishing

To utilise fully the performance of HSS materials it is important to remove burrs from edges and smooth working surfaces before using the tool. If burrs are not removed and the surface finish is not optimised, there is a greater risk of edge chipping and crack initiation, which will lower the performance of the tool. The extent of deburring and surface finishing required is dependent on the application.

Some of the most important deburring and surface finishing techniques are described below.

Mass finishing

Abrasive tumbling is a general expression which encompasses a wide variety of different mass finishing or deburring techniques using the same basic principle. It is a low-pressure process performed by abrading and deforming the work piece surface by placing it in a moving chamber with abrasive media in a compound, together with a liquid. Although the method is relatively slow, costs are low and operation simple. In addition, for some of the mass finishing techniques extremely smooth surfaces can be achieved.

Abrasive tumbling deburrs the edges and improves the surface roughness by a sliding and rolling effect of the abrasive media. This action usually results in deburring of all edges and generates a subsequent improvement in surface finish. In addition, undesirable residual tensile stresses can be lowered, eliminated or even changed into compressive stresses. A drawback of mass finishing techniques is that the process affects all surfaces of the tool. It is not possible to give preferential treatment to specified areas. In addition, owing to the rolling effect on the surface it is not always recommended to PVD coat tumbled surfaces. This is because the rolling effect may encapsulate porosity or media used in the finishing process, which could be detrimental to coating adhesion.
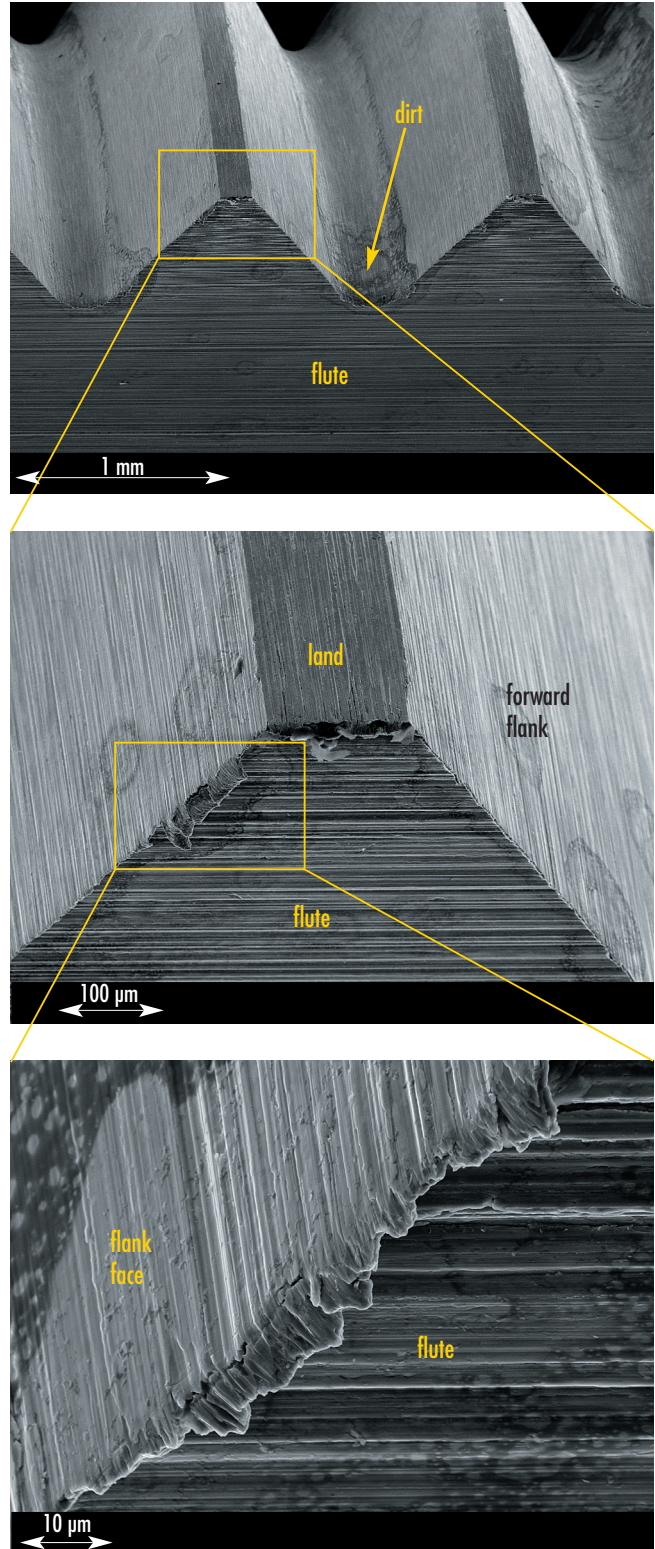
A close up of the cutting edge of a tap after grinding. Dirt, burrs and grinding scratches can be seen.

Blasting

Blasting with particles is used widely for removing burrs from edges, cleaning, smoothing of surfaces and removing sharpness of edges. Abrasive media used in blasting can be:

- Soft or hard (from soft and gentle sodium bicarbonate to extremely hard ceramic particles)
- Round or angular (Angular particles cut. Round particles deburr and smoothen)
- Big or small particles (few microns to 1/10 of millimetre in diameter)

The rule of thumb is that a significantly harder media than the work piece will have a cutting effect and a softer media a more deforming and breaking effect on burrs and peaks on surfaces.

In the case of applying a PVD coating on HSS components, it is important to deburr as well as to remove and smooth surfaces. Therefore it is recommended to do a two stage blasting procedure: first deburring by using coarser and, preferably, relatively soft particles and secondly, surface finishing using micro blasting with small and much harder particles.

Particles for deburring

Today glass beads, plastic shots and steel shots are used for deburring of HSS tools.

Glass beads can sometimes fracture and fragments can contaminate the surface as they are easily embedded in the deformed surface layer. *The rule of thumb is that the pressure used when blasting with glass beads should not exceed 4 bar in order to lower the risk of fracturing the glass beads.*

Plastic shots are used mainly for cleaning of moulds for injection moulding. Owing to the low hardness and weight, plastic shots are also used for mild deburring of HSS tools. However, if burrs are relatively large then plastic shots will not be able to remove them completely.

Steel shots are mainly made of stainless steel or other soft steel grades, which are softer than the work piece. The shots will produce a slight smoothening effect on the surface, as they have the ability to deform as well as break burr. The method also has a cleaning effect as the steel shots adhere easily to oxides and other contaminants on the surface. In the case of sharp edges it is important to use soft steel grades which do not strain harden, otherwise there is a risk of buckling and deformation of edges. In such cases, it is recommended to use plastic shots or to change technique to, for example, water jet deburring.
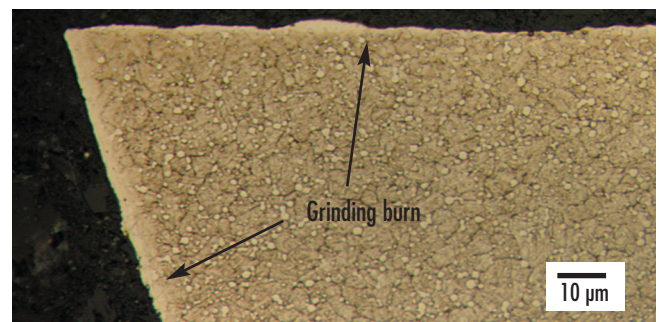
Above is a cutting edge after edge preparation. Most edge and surface preparation techniques do not remove grinding burns.

Particles for removal of material

Media containing hard particles like aluminium oxide and silicon carbide usually consist of angular particles, which provide an abrasive cutting action on most work pieces. These particles are used primarily to remove some material from the surface, typically less then a micron. The blasting has to be well controlled as uncontrolled blasting with abrasive media can quickly remove far too much material.

Brushing

Brushing operations can today be used for many different purposes, i.e. deburring, cleaning, edge preparation and polishing or texturising of surfaces.

For deburring of HSS it is possible to use carbon steel wire, stainless steel wires and nonferrous materials like brass and nylon. Also vegetable

fibres like "Tampico" may be suitable for deburring. Brushes made of these materials can also be used in combination with abrasives pastes. It is also possible to use nylon filaments containing hard particles like aluminium oxide or silicon carbide for deburring or surface finishing. The advantages with these brushes are that the abrasive process can be run dry and be used to give preferential preparation of edges.

Magnetic finishing

Magnet finishing is a technique, which can be used for surface finishing as well as for deburring of HSS details. The work piece is placed in between two magnet poles and the gap between the two poles is filled with magnetic abrasive media. Each grain of the media is made up of an abrasive and a magnet component. The magnet component holds the powder in the magnet field while the abrasive performs the grinding or polishing action.

Smooth surfaces can be achieved in combination with edges free from burrs. The surface created using magnet finishing offers a good base for a PVD coating, provided that the rolling action of the abrasives have not been exaggerated, as this can give unnecessarily high stresses in the surface, which may, in turn, reduce the strength of the interface between the PVD coating and the HSS.
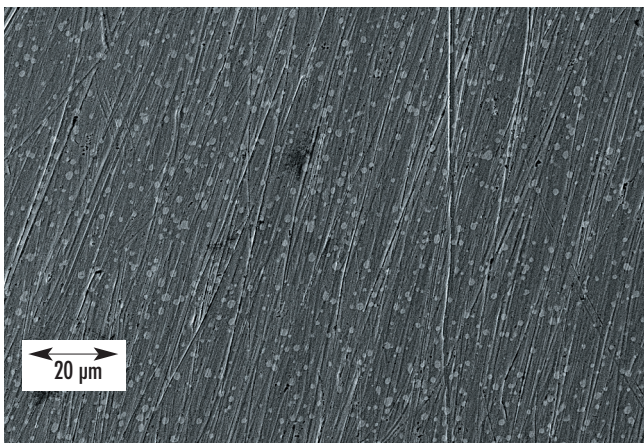
Abrasive Flow Machining (AFM)

AFM is a deburring, edge preparation and polishing process, which involves extruding an abrasive semi-solid media through a work piece passage. This process is suitable for holes and complex geometries and if mirror finish of the tool is required.

The AFM technique consists of the machine, the work piece and the abrasive media. By choosing the most appropriate abrasive media it is possible to abrade the vast majority of materials using AFM. AFM is a versatile and controllable finishing process because the work piece is held stationary and the abrasive media is directed to, and often through, the passages of the tool to be finished by the extrusion. The surface produced can be of highest quality and smoothness.

Water jet deburring

High-pressure jets (about 200 MPa), can be used to deburr both metallic and non-metallic parts. The advantage of this method is that it leaves sharp corners with no increased radius. As cycle times are significantly longer for burrs of larger sizes, the process is best suited for fine deburring applications. The process can be automated easily.
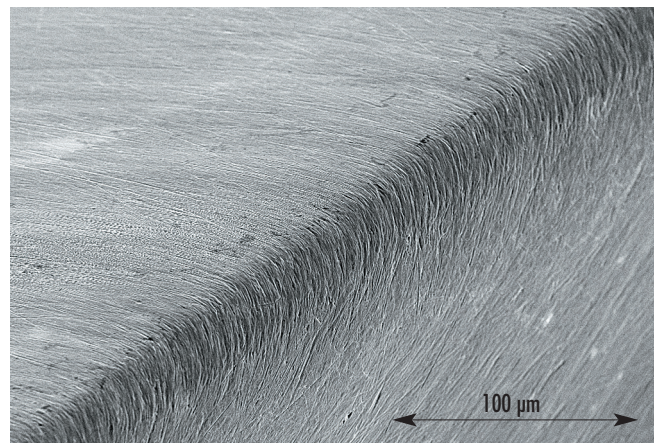
SEM micrographs of a flute and an edge of a HSS drill with optimal surface and edge preparation. The surface roughness in the flute is approximately 0.08 µm R_a.

Electrochemical polishing (ECP)

In electrochemical polishing, a solution such as phosphoric acid is combined with an electrical current to remove burrs. Burrs and other surface peaks attract the electrical power, resulting in greater material removal on these areas than on plane surfaces.

This process is most often used in high volume production for removing of small burrs on precision parts.

A problem with ECP is uneven etching or polishing of high alloyed materials like HSS. Different phases are affected differently by the polishing solution. We only recommend ECP for ASP 2012 and ASP 2017. If ECP is carried out successfully the surface obtained is an extremely good base for a PVD coating.

Thermal energy method

In the thermal energy method (TEM) the work piece is placed in a gas filled chamber (pressure vessel). The gases are then ignited and the intense heat (which last for only microseconds) burns or evaporates thin burrs and surface peaks. Using optimal conditions, only a small radius will be left on the edge. The TEM method is ideal to deburr blind and intersecting holes and internal surfaces, which are difficult to reach, by other methods.

Although the temperature of a work piece seldom exceeds 150 °C, the temperature at the surface will be much higher, often so high that re-hardening will occur. A thin oxide layer is often formed on the surface. Therefore, it is recommended to combine TEM with, for example, micro blasting, in order to remove oxide and damaged surface material. This is especially important if the tools are to be PVD coated subsequently, otherwise it will probably cause problems with coating adhesion.

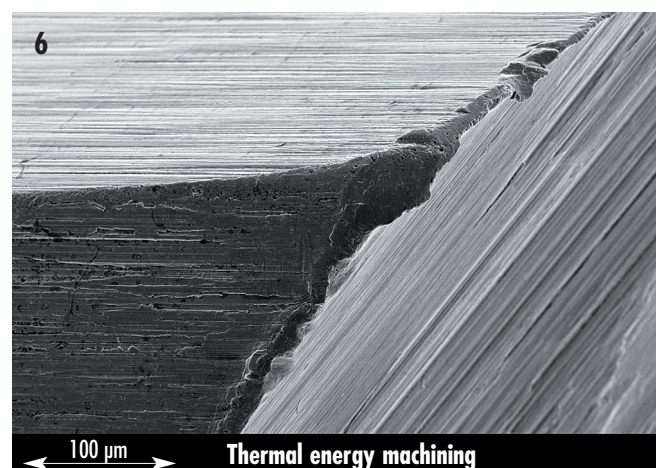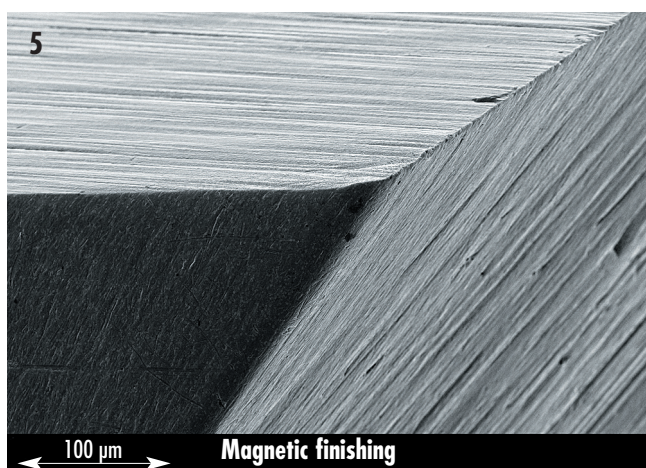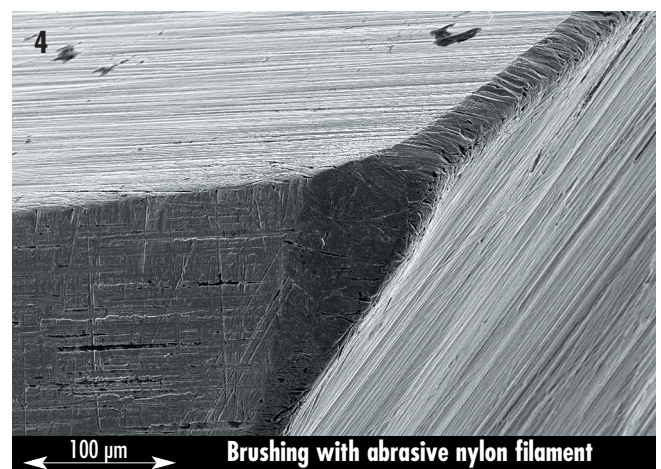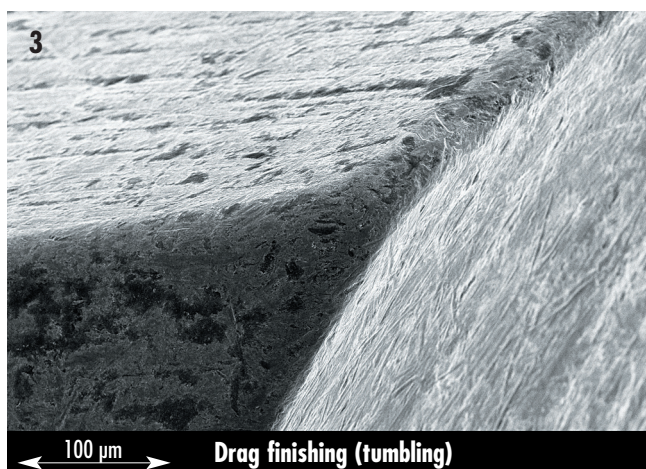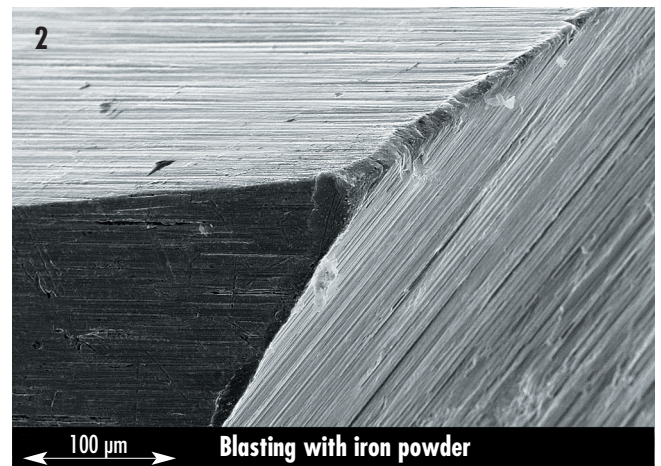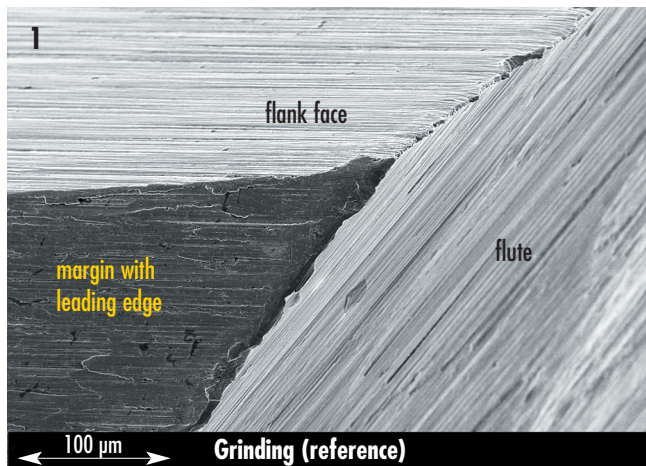| Deburring method	Area of interest	Pcs*/ hour	Example of application
Mass finishing	external cylindrical parts	60-120	machine elements, drills, mills
Blasting (glass beads)	external edges, surface finish	60-120	punches, drills, taps, etc
Blasting (plastic shots)	external edges	60-120	taps, precision parts, etc
Blasting (steel shots)	external edges	60-120	larger machine elements, larger cutting tools, etc
Micro blasting	external edges, surface finish	60-120	all kind of cutting tools, machine elements, etc
Brushing	external edges, internal holes, blind features	60-120	machine elements, drills
Magnetic finishing	high finish parts with small burrs	50-100	dies, complex parts, drills, taps, end mills
Abrasive flow machining	intersecting holes, machining, high finish	1-10	dies, medical parts, etc irregular contours,
Water jet deburring	external edges, thin burrs	50-250	plastic moulds, engines, etc
Electrochemical polishing	high finish parts	20-200	precision parts, valves, etc
Thermal energy method	external burrs and some internal thin burrs	50-100	automotive parts, gears, castings, aircraft components, etc

* Estimated treatment of a HSS drill 8 mm diameter and length 100 mm using a standard equipment.

Comparison of different edge preparation techniques

A number of different deburring techniques where investigated for edge preparation of taps and drills. The resulting edges on the drills can be seen in the photos on the right. Description of the techniques and the parameters used are found below. With other parameters and types of tools the results would be different. The methods cleaned the surface of loose particles and surface burr, but none of them improved the surface roughness in any significant way.

No.	Technique	Parameters
1	Grinding	Normal tool grinding.
2	Blasting with a water atomised iron powder	A technique used for deburring. Particles: min 99.0 Fe, max 0.011 O, max 0.010 C, typical particle size: 150-212 6.0%, 75-150 39%, 45-75 31%, -45 24%. Pressure: 3 bar. Process time per tool: 30 sec.
3	Drag finishing (tumbling)	A patented technique, Walther Trowal GmbH, used for deburring, polishing and edge preparation. The tools are attached to a special fixture and "dragged" in a planetary movement through a bed of grinding and polishing media. Process time: 60 sec.
4	Brushing	A technique used for deburring and edge preparation. Brushing using abrasive nylon filaments, 320 mesh SIC Brushing speed: approximately 250 m/min. Processing time per tool: approx. 10 sec.
5	Magnet finishing	A patented technique, KMM Oberflächenbearbeitung GmbH, used for deburring, polishing and edge preparation. The tools is rotated in a magnetic abrasive powder while it simultaneously is held between two magnetic poles. Process time per tool: approx. 60 sec.
6	Thermal energy machining	A patented technique, Extrude Hone, used for deburring, polishing and edge preparation. The tools are sealed in a pressurized chamber with a mixture of an explosive gas and oxygen. The gas mixture is then ignited by a spark plug, which creates an intense, rapid burst of heat. Burrs and flash, because of their high ration of surface area to mass, quickly rise to a temperature well above their auto-ignition point and burst into flames. Process time per tool: approx. 10 sec.

1 — flank face / margin with leading edge / flute — 100 μm — **Grinding (reference)**

2 — 100 μm — **Blasting with iron powder**

3 — 100 μm — **Drag finishing (tumbling)**

4 — 100 μm — **Brushing with abrasive nylon filament**

5 — 100 μm — **Magnetic finishing**

6 — 100 μm — **Thermal energy machining**

The corner of the cutting edge of the drill after edge preparations.

COATINGS

The function of PVD coatings in machining applications

When the tempering temperature of the HSS is exceeded, the hardness decreases quickly and rapid wear occurs.

PVD coatings are very hard and chemically stable materials, which give a relatively low friction against most materials, provided that coating is deposited on a smooth substrate. This decreases the cutting force compared to an uncoated tool considerably, for the same cutting data. The heat generation is consequently lower on the coated tool surface.

The coating also act as a stable thermal barrier between the hot work material (chip) and the tool face, protecting the tool from the heat.

Both these effects imply in turn, that for the same heat generation as in the uncoated case, the cutting speed can be increased without exceeding the tempering temperature. Usually the cutting speed can be increased 2-3 times for the same tool life.

In addition the coatings are extremely wear resistant when sliding against other materials.

Coating types

There are a wide variety of PVD coatings on the market. The most popular are nitride based combinations of the elements Ti, Al, Cr and C. Also, more advanced multilayered coatings can be found as well as coatings customised to combine wear resistance with a very low friction against most steels.

When choosing a PVD coating it is important to remember that a broad range of standard tools are not subjected to the most extreme working conditions, for example dry machining or high speed machining. Accordingly these tools will not require high-performance coatings. Instead more traditional and reliable coatings such as TiN or TiAlN can be used with excellent results. However, if the application is severe, utilisation of the best coatings on the market can, provided they are applied optimally, give exceptionally good, predictable results and an extended number of details produced.

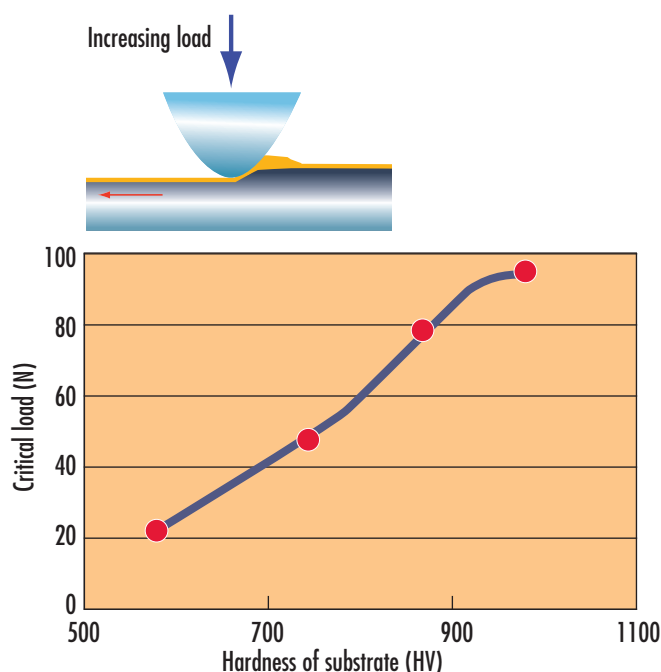| Coating material	Micro hardness (HV 0.05)	Coefficient of friction	Residual stress (GPa)	Oxidation onset temperature (°C)	Typical application
TiN	2200	0.4	-2.5	600	General purpose coating, injection moulding of plastic material
TiCN	3000	0.4	-3.5	500	For tools subjected to high mechanical load, e.g. milling and forming of steels
TiAlN	3000	0.4	-3.5	800-900	Today's best general purpose coating
CrN	2200	0.4	-2.0	750	For cu-machining and injection moulding of plastic materials
WC/C	1000	0.2	-1.0	300	A low friction coating for machine elements
DLC	Various DLC processes are available on the market. DLC coatings typically are used for precision components such as automotive parts like tappets and injection parts. DLC coating can posses hardness values from 1000 HV to 5000 HV and the friction against steels is normally 0.1-0.2				
TiAlSiN	3600	0.4	not known	1100	High performance coating for dry machining or high speed machining of steels
AlCrN	3200	0.35	-3	1100	High performance coating for dry machining or high speed machining of steels
Multilayers	Various multilayer processes are available on the market. Typically a multilayer is combined of existing coatings, e.g. TiN + TiAlN. Normally it is claimed that multilayer coatings add toughness to the coating				

Today's most common PVD coatings and their most important properties and application area.

How to optimise the performance of coated tools?

Substrate material – material carrying the coating

In addition to coating adhesion, the hardness at working temperature of the substrate material carrying the PVD coating is the most important parameter. The rule is that the higher the hardness of the substrate the better the load carrying capacity and hence support to the coating. The surfaces have to be extremely smooth if a new harder HSS grade or even if a harder coating is to be utilised in your application, in order to maintain toughness.

The high carbide content in HSS is beneficial not only in terms of hardness but also to increase the wear resistance of the tool. This can be of importance where PVD begins to wear locally, as the higher the wear resistance of the exposed HSS material, the longer it will take before total failure

will occur. In addition, MC carbides also promote coating adhesion since they are very hard and have a crystalline structure similar to that of most PVD coatings.

The surface carrying the coating

A unique feature of PVD coatings is the compressive residual stress accumulated in the coating after deposition. For some coatings this can be as high as 5 GPa. Because of it, the coating can easily flake from sharp edges and around porosity and other surface defects. Porosity in the coating can, for example be found when the coating is deposited on a non-optimised substrate, i.e. a substrate which contains a large number of inclusions, e.g. oxides. In the worst case, a huge concentrate of oxides present on the surface of the substrate can suppress surface deposition entirely or in part.
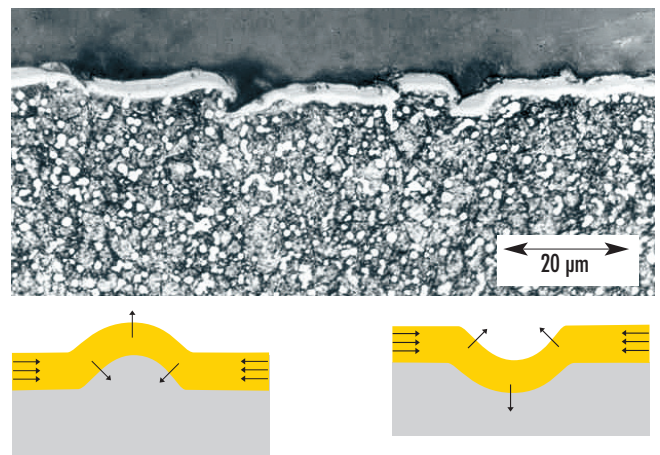

The diagram above shows how the substrate hardness influences the coating adhesion. A diamond is pressed against a coated surface with increasing load. The load at which the coating breaks is recorded. The critical load also depends on other factors, like: type of coating, surface roughness, direction, and many other parameters.

To put a coating on top of a rough tool surface is not a good idea. First of all, the roughness is not improved by the coating, as the coating is as thin as a few μm. Secondly, the coating may fall off at the peaks and in the valleys of the rough surface, owing to high compressive stresses in the coating. These unprotected areas will show accelerated wear and in addition provide starting points for fracture initiation. Thus, the combination of high performance tool materials, such as ASP grades, and modern high performance PVD coatings requires also high quality surface preparation.

Surface preparation

To achieve all the benefits possible from a PVD coating on a HSS material, a number of parameters must be checked prior to coating of the part. Firstly, all surfaces must be free from oil and/or grease. This is normally no problem as the PVD coating companies have processes, which take care of it. It is however a good practice to clean the tools directly after grinding as dried in dirt is difficult to remove later on.

Burrs on cutting edges must be removed before coating deposition. Any remaining burr, however slight, is detrimental. The presence of even a very small burr will lower the strength of the cutting edge, leading to micro chipping and consequently coating removal. The rule of thumb is to aim for a zero burr height and if possible also apply a small rounding of the cutting edge, in order to strengthen the edge. The size of the rounding depends on the application, but typically a 5 to 20 µm rounding will give a significant improvement.

The smoother the surface of the HSS, the better the PVD coating will work as the load is better distributed on the surface. In order to obtain optimal surfaces, it is a good idea to first grind close to the aimed surface roughness and then use an appropriate technique of edge preparation (see previous chapter).

It is important to remember that the function of the coating depends not only on surface roughness but also the quality of the surface. For example, if the grinder has burned the surface and the depth of the remaining damaged zone exceeds one micron, a weakening of the interface will take place. The same argument can be used for spark eroded surfaces.

Since PVD coatings work best if they are applied on clean surfaces of high performance materials, it is easy to understand that defects like inclusions of e.g. oxides, burning as a consequence of excessive grinding or process residues from polishing will have a negative impact on coating adhesion. Some of these defects can be removed by micro blasting prior to deposition of the PVD coating. For polished surfaces, where micro blasting can not be used, the polishing procedure must be optimised so that no residues are left in the surface. For soldered materials it is important to choose a soldering material that does not contain metals with high vapour pressure, e.g. cadmium, lead or zinc.
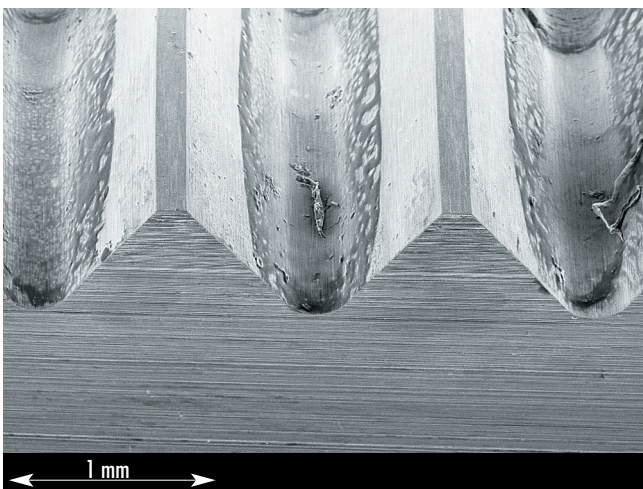
This tap has not been cleaned before the deburring operation. The dirt remains after the treatment.
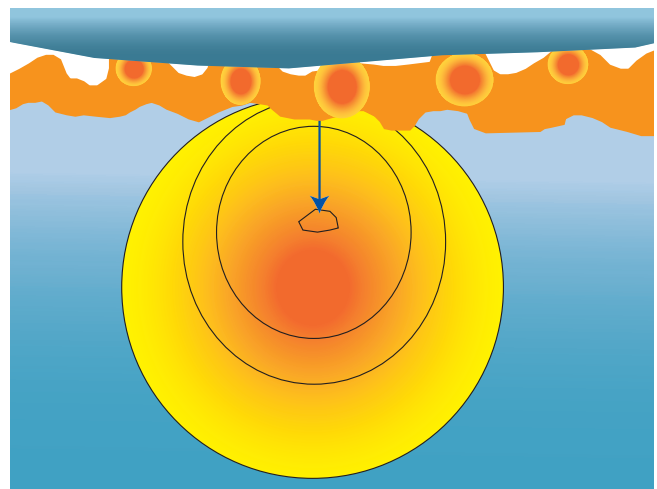
An uneven surface will locally give high loads on and underneath the surface. This will lead to chipping of the substrate or the coating.

Preparation of PVD coated surfaces

Many of today's PVD coatings are deposited using techniques, which generate relatively rough surfaces. The main reason for this is that the techniques produce small droplets, which are entrapped in the coating, which normally increase the surface roughness. It is important to note that the protruding droplets are as hard as the rest of the coating and must therefore be removed in order to avoid that they act as a metal file in the application. Hence a so-called post treatment, i.e. a smoothening process of the coating, is often done by the coating companies to remove the droplets. Such post treatment is today available at most coating companies but is normally not offered as a standard solution.

Manufacturing for best performance (deburring, surface topography, surface roughness)

There are some principles to follow for the successful utilisation of PVD coated tools.
In case of cutting and punching tools:

- **Always aim for zero burr height at all cutting edges and an edge radius of 5 – 20 microns.**

- **Aim to achieve a surface roughness (R_a-value) below 0.2 µm, preferably 0.1 µm.**

- **No damaged material should remain just under the surface, i.e. there should be "ideal" HSS material all the way up to the surface.**

- **Always protect PVD coated HSS from corrosion using for example environmentally friendly lubricants.**

- **All PVD coated HSS tools should be handled with care, as edges are very sensitive to chipping.**

- **In the case of forming tools larger edge radius are acceptable, although surface roughness (R_a-value) should be 0,1 µm or better.**
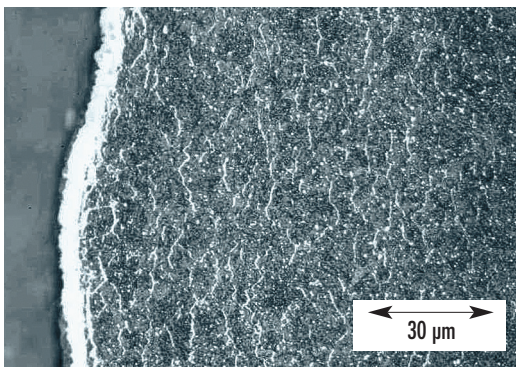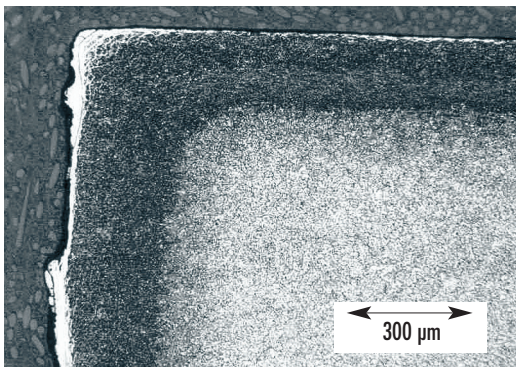
Nitriding

Nitriding is used for the production of case hardened surface layers. The hardened surface layer is effective in reducing wear, both abrasive wear owing to the high hardness of the nitrided layer, and also adhesive wear owing to the high chemical stability of the nitrided layer. A nitrided layer can also improve the corrosion resistance of a tool. However, on the negative side, the nitrided layer is very brittle and provides an ideal site for crack initiation and therefore a reduction in the tool edge strength. The brittleness of the nitrided surface is due to nitride films found in grain boundaries of the HSS material and/or the outermost layer of pure nitride - the so-called 'white layer'. Very often, surface cracks are found in the nitrided layer and this is particularly true for tools for which the 'white layer' has not been removed. Thus, for high speed steel it is recommended that the nitrided layer is no thicker than a few micrometers.

Tool parts can be nitrided by various processes such as gaseous mixtures, salt baths, plasmas etc. The characteristics of these methods are quite different; for instance, the temperature at the tool surface may vary from 400 to 600 °C. Generally, longer times and higher temperatures generate a thicker nitrided layer and hence higher wear resistance. However, high temperature can also yield over-tempering, and hence softening, of the tool surface. Therefore, tools made of HSS with thick nitrided layers have significantly reduced mechanical properties and surface cracks, micro chipping and fractures are often observed in such tools.

Peening

Peening is one of the final operations in production of, for instance, drills and is carried out in order to reduce residual stresses and to straighten the tool. However, it is important that the peening strokes are not too hard as it may introduce surface cracks and marks which will lower the strength of the tool.

Marking

Prior to final sale, the finished tool is often marked in some way. If the marking is made mechanically, e.g. stamping, the marks may easily act as initiation points for fracture. Preferable, the marking should be made in a way which minimises the destructive influence on the surface, such as laser marking, or be placed at a part of the tool which is under low mechanical stresses.


Pictures of a nitrided zone. In the high magnification picture on the bottom the nitride films in the grain boundaries are seen as white lines. These nitride films make the material extremely brittle and hence lower the strength of the tool considerably.
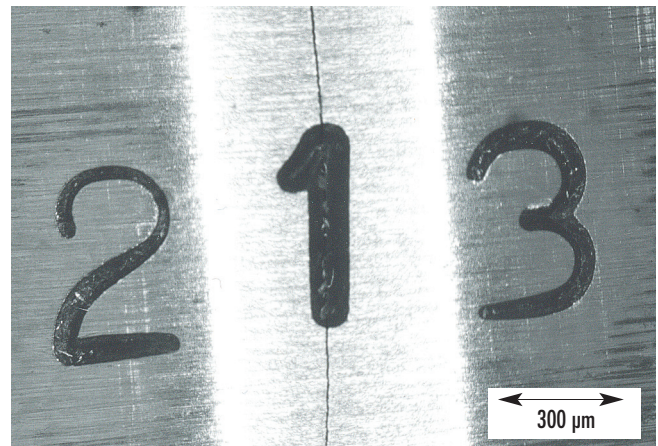
In this case the marking has been carried out by stamping and placed at a part of the tool which is under high mechanical load. The mark has acted as an initiation point for fracture and lowered the total strength of the tool.
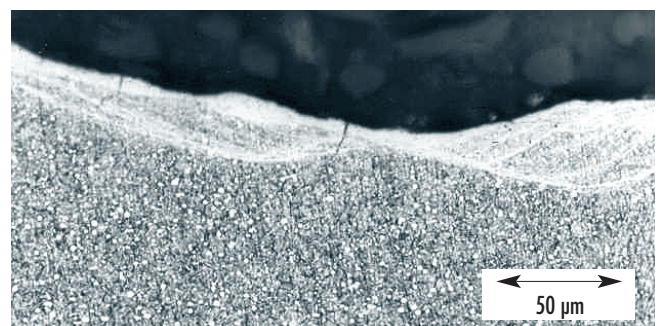
Section of a tool that has been peened. In this case the peening has been too hard and cracks at the surface of the tool can be observed. These cracks will act as fracture initiation sites and lower the strength of the tool.

Trouble shooting

Technique	Problem	Possible cause	Solution
Heat treatment	Decarburisation	Salt bath heat treatment	Add regeneration agent to the salt bath prior to heat treatment.
	Carburisation	Grease or oil at surface in vacuum heat treatment	Cleaning of the tool prior to heat treatment
		Non dissolved regeneration agent in salt bath	All regeneration agent must be dissolved before the tools are put into the salt bath
	Oxidation	Oxidising media (salt or air)	Change to vacuum heat treatment
EDM	Thick white layer, surface cracks	Melting of the surface owing to high energy in spark discharges	Reduced energy will give a thinner white layer. Remove white layer by, for instance, grinding or electro-chemical polishing.
Grinding*	Residual stresses	Too high load and / or temperature at the surface	Decreased stock removal rate Larger grit size of wheel More open dressing Softer wheel
	Burrs	Too high load Dull wheel	Lower stock removal rate Sharper (dressed) wheel
	Burning	Too high temperature at the surface	Improved cooling
	Poor surface finish	Too coarse wheel Too soft wheel Too low wheel speed	Finer dressing Smaller grit size Use harder wheel Decrease metal removing rate Increase wheel speed
	Loss of form	Too soft wheel Too low wheel speed	Harder wheel Decrease metal removal rate increase wheel speed
Coating	Coating fall off during use of tool	Poor surface roughness Dirty surface (oxidation)	Improved grinding, see above. Use of surface preparation technique such as blasting, polishing, electrochemical polishing in order to reduce surface roughness and remove oxide layer.
Nitriding	Micro-chipping or fracture of tool during use	Insufficient strength owing to thick brittle nitrided layer	Decreased thickness of nitrided zone
Marking	Fracture initiated at marking	Marking acts as fracture initiation point	Place the marking at a position where the stresses are lower. Use a less destructive technique, such as laser marking

* See also the educational brochure about grinding produced by Erasteel

ERASTEEL