Hardening Guide

The way to the perfect knife steel

This Hardening Guide contains all a knife manufacturer needs regarding the heat treatment of Sandviks knife steel. We describe, for example, what happens in the material during the hardening process itself, we compare different steel grades and suitable applications, and we provide detailed instructions for the hardening temperature that produces the very best results. For obvious reasons, the technical level in this guide is fairly high, but we have assumed that you already are an expert in your field. To be on the safe side, we have written a brief technical glossary that explains the most important concepts.

Technical glossary

Alloying elements

In addition to iron, a stainless steel consists principally of carbon and chromium. It may also contain small quantities of vanadium, molybdenum, nitrogen and other elements.

Austenite

When iron is heated to above 910°C, its internal structure changes to austenite. One
of the characteristics of austenite is that it is non-magnetic, soft and ductile.

- **Retained austenite**

After quenching and transformation from austenite to martensite, it is beneficial to retain a small amount of austenite for increased toughness. This is called retained austenite (RA).

**Carbides**

Carbides are hard, ceramic-type particles, which means that they are wear resistant, but at the same time brittle and difficult to grind.

- **Primary carbides**

These are formed during the primary production stage and are large, being up to 40 microns in diameter. They are very stable, which means that they do not dissolve into the matrix during heat treatment.

- **Secondary carbides**

The secondary carbide structure is formed during hot rolling/forging and annealing of the steel. These carbides are small, the average size is about 0.5 microns in diameter. The small carbides contribute to good wear resistance, but without compromising sharpness and regrindability.

**Composition**

The chemical composition is the balance of iron, carbon and other alloying elements comprising the steel. The composition should be well balanced, not over-alloyed and accurate. The specification tolerances must be tight in order to secure a consistently high quality of the finished knife.

**Diffusion**

When the material is heated in the hardening process, the secondary carbides are dissolved and enable the carbon and chromium alloying elements to disperse (diffuse) in the matrix. This enables the hardness to increase and the corrosion
resistance to improve during the quenching phase.

**Deep-freezing**

Deep-freezing to -20°C to -150°C can be started after hardening, when the material has been quenched to room temperature, in order to increase the hardness. In the hardening recommendations in this guide, Sandvik presents only -20°C and -70°C as possible deep-freezing temperatures.

**Ductility**

The ability to allow for changes in shape without fracture.

**Edge performance**

Edge performance comprises three elements: Sharpness, edge stability and wear resistance.

**Edge stability**

This is the ability of the knife edge to withstand edge rolling and edge micro-chipping. Rolled edges and micro-chipped edges are the most common reason for regrinding.

- **Edge rolling**

Edge rolling occurs when an edge rolls or folds as a result of being subjected to high forces. Typical behavior for softer steels, since hardness will counteract this behavior.

- **Edge chipping or micro-chipping**

In this process, small carbide particles break away from the edge. This usually occurs in brittle steels with large carbides (coarse grades) or extremely high carbide density (powder metallurgical steels).

**Hardening**

Hardening is a way of making the steel harder. By first heating the steel to between
1050 and 1090°C and then quenching it, the material will become much harder by the microstructure being transformed into hard and wear resistant martensite.

- **Batch hardening**

Simultaneous hardening of batches of products, usually in a vacuum furnace.

- **Piece hardening**

Hardening of individual products in a fairly small furnace or a belt furnace.

- **Hardening program**

Preselected hardening program that is appropriate to Sandvik knife steels and their intended applications. carefully predetermined times and temperatures for heating, quenching and tempering.

- **Under-hardening**

If the steel is heated to an insufficiently high temperature or for too short a time, an insufficient amount of carbides will be dissolved. This will result in low hardness and inadequate corrosion resistance.

- **Over-hardening**

If the hardening temperature is too high or if the heating time is too long, almost all carbides will be dissolved. This will result in low hardness and brittleness of the material.

**Martensite**

A steel becomes martensitic when its austenitic structure is rapidly quenched. Martensitic stainless knife steels become stainless only after heat treatment, when the steel structure is transformed to martensitic. Sandvik makes only martensitic stainless knife steels.

**Micron**

Equal to one thousandth of a millimeter.
**Microstructure**

The microstructure of steels is what distinguishes Sandvik fine-grained steels with a maximum carbide size of 2 microns (average of 0.5 microns) from other knife steels such as 440, D2, etc. that have large primary carbides with a diameter of up to 40 microns.

**Pitting corrosion**

Corrosion of stainless steels often takes place in the form of a process known as pitting corrosion. Corrosion starts in places where the protective chromium oxide on the material surface is worst, i.e. in a weak spot, and then penetrates into the grain boundaries.

**Purity**

Non-metallic inclusions will always be a weak point in the steel. They are the starting point for corrosion and the crack initiation point that reduces toughness. Sandvik chromium steels have been used for decades in the health care industry around the world, because of their high purity in terms of non-metallic inclusions. Click here for more information.

**Quenching**

Quenching is the rapid cooling from hardening (austenitizing) temperature to room temperature. When a sufficient quantity of carbides has been dissolved during heating, the material must be cooled quickly to room temperature. The purpose of quenching is to retain the carbon and chromium in the matrix, to ensure maximum hardness and corrosion resistance.

**Rockwell C hardness (HRC)**

Method used for measuring the hardness of steel. The method consists of impressing a diamond tip into the steel with a force of 150 kg. The depth of the impression is then measured by means of a laser. Sandvik knife steels have a hardness range of 54-63 HRC, depending on grade and heat treatment.
**Tempering**

Hardened steels are tempered at 175-350°C for about 2 hours in order to relieve the brittleness caused by hardening. Higher tempering temperatures yield a somewhat tougher material, whereas a lower tempering temperature produces a harder but somewhat more brittle material.

--- **Temper embrittlement**

Tempering temperatures above 350°C should be avoided, since this would increase the risk of the material becoming more brittle and its corrosion resistance being impaired.

**Toughness**

Resistance of the steel to cracking.

**Sensitizing**

If a steel is quenched too slowly, carbides will have time to precipitate at the grain boundaries, which will lead to a brittle material with poor corrosion resistance. The phenomenon is known as sensitizing.

**Steel matrix**

The steel that bonds the carbides together is called the steel matrix. The chemical composition of the steel matrix is what determines the hardness and corrosion resistance of the steel.

**Wear resistance**

A measure of how long the edge retains its sharpness.
The steel making process

Most steels are recycled today, and the Sandvik steel mill is designed to use recycled steels. In the mill, the molten steel is cast into billets. Sandvik uses a continuous casting process that produces a very uniform composition and chemical structure of the steel. The steel is hot rolled or forged at high temperature and ends up as hot rolled coils. This material is annealed and pickled in order to clean the strip and also to condition the microstructure. The steel is then cold rolled down to the appropriate thickness and is annealed again in order to soften the steel and make it suitable for fine blanking. The last steps are slitting to the desired width, packing and shipping.

Steel matrix

The steel that bonds the carbides together is called the steel matrix. The steel matrix is what determines the hardness and corrosion resistance of the steel.

The hardness of the matrix typically increases with increasing carbon content, but there is also a limit here. If too much carbon is dissolved in the matrix, the transformation to martensite in the heat treatment process will become very difficult, and too much soft residual austenite will thereby be left after heat treatment. This “retained austenite” can be transformed further by deep-freezing the steel to sub-zero temperatures before tempering. Carbon is the main driver for hardness, but the nitrogen present in some steels is also a hardness driver.

The corrosion resistance of the matrix increases with increasing chromium content.
The magic content for “stainless” is 10.5% chromium dissolved in the matrix. Remember that there will always be chromium bound to the carbon in the carbides. So even if a steel specification says 13 % chromium, the content in the matrix may still be less than 10.5% and the steel will then not be stainless in normal use. Proper heat treatment is ultimately what sets the chromium content in the matrix and thereby the final corrosion resistance.

The steel matrix consists of two metallic phases, i.e. martensite and retained austenite. The retained austenite recommended by Sandvik should be in the range of 5-15% for a knife. Depending on the application and grade, the balance will then be martensite. Martensite is hard and brittle, while retained austenite is tough and ductile. Successful heat treatment will optimize the hardness, corrosion resistance and toughness of the steel.

**Steel production pictures**

The pictures below show the production procedure from scrap to finished knife steel. All of the pictures have been taken in the modern Sandvik production unit in Sandviken, Sweden.
Sandvik 12C27

– The well-rounded knife

12C27 is Sandvik’s most well-rounded knife steel. With excellent edge performance allowing razor sharpness, high hardness, exceptional toughness and good corrosion resistance.

Sandvik 12C27 is our main knife steel for hand-held knives, high-end ice skate blades and ice drills. Continuous improvement over a period of 45 years has evolved Sandvik 12C27 into the high performing steel grade it is today. The composition is tighter, the purity level is much higher and the fine carbide microstructure of today is far from how the 12C27 of the sixties looked.

With a hardness range of 54-61 HRC, high toughness, scary sharpness and good corrosion resistance, Sandvik 12C27 is the recommended for hunting knives, pocket knives, camping knives, high-end chefs knives and tactical knives.

Like most of Sandviks knife steels this grade is fine-blankable enabling efficient production.

**Chemical Composition**

<table>
<thead>
<tr>
<th>Grade</th>
<th>Carbon [C] %</th>
<th>Chromium [Cr] %</th>
<th>Molybdenum [Mo] %</th>
<th>Silicon [Si] %</th>
<th>Manganese [Mn] %</th>
</tr>
</thead>
<tbody>
<tr>
<td>12C27</td>
<td>.60</td>
<td>13.5</td>
<td>-</td>
<td>.40</td>
<td>.40</td>
</tr>
</tbody>
</table>
Difference between carbon steel and stainless steel

Sandvik produces martensitic stainless knife steels. The steel becomes stainless only after heat treatment, when the steel structure has become martensitic.

There are also austenitic stainless steel grades, but these are different in composition and structure and are rarely used in edge applications, since the edge properties are inferior to those of martensitic stainless steel grades. (From here on we will refer to martensitic stainless steels as simply “stainless”.)

So what is the difference between a carbon steel and a stainless steel? There are two main differences. The first difference is that stainless steels have much higher corrosion resistance, due to the protective chromium oxide layer that covers the steel surface after heat treatment. The second difference relates to the alloying elements that form “carbides”. These carbide particles provide the steel with significant wear resistance. The carbides are bonded together by the steel matrix.

Different type of knife steels

A knife steel with large primary carbides is generally very difficult to regrind, since the carbides crumble out of the edge and cause a "saw edge" instead of a razor-sharp edge. So Sandvik mainly produces fine-grained knife steels with extremely high edge sharpness properties.

The pictures below show the microstructures of the three classes of stainless steel on the market. From left to right:

1. Coarse carbide tool steel grades
2. Medium carbide powder metallurgic grades
3. Fine grain knife steels
### Combination of Knife Steel Properties

<table>
<thead>
<tr>
<th>Steel Type</th>
<th>Example of Grades</th>
<th>Sharpness</th>
<th>Edge Stability</th>
<th>Wear Resistance</th>
<th>Toughness</th>
<th>Corrosion Resistance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse Carbide Steels</td>
<td>440A, 440C, D2, 9Cr18MoV, 19C27</td>
<td>Poor</td>
<td>Poor</td>
<td>Excellent</td>
<td>Poor</td>
<td>Very Good</td>
</tr>
<tr>
<td>Powder Metallurgical Grades</td>
<td>PM Steels for knife applications</td>
<td>Very Good</td>
<td>Average</td>
<td>Excellent</td>
<td>Average</td>
<td>Very Good</td>
</tr>
<tr>
<td>Fine Grain Knife Steels</td>
<td>13C27, 12C27, 12C27M, 7C27Mo2</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Very Good</td>
<td>Excellent</td>
<td>Very Good</td>
</tr>
<tr>
<td>Carbon Steels</td>
<td>1095, 1075</td>
<td>Excellent</td>
<td>Excellent</td>
<td>Poor</td>
<td>Excellent</td>
<td>Insignificant</td>
</tr>
</tbody>
</table>

Table: Combination of knife steel properties for different classes of steel. Note that corrosion resistance is destructive for the cutting edge. So the lack of sufficient corrosion resistance is also affecting knife performance and not only the esthetics of the blade.

1. **Coarse carbide tool steel grades**

   Example of grades: 440A, 440C, D2, Sandvik 19C27.

   Coarse tool steel grades have a large amount of primary carbides. The carbides are the white spots in the picture and they are about 50 000 times bigger than the small secondary carbides in the picture to the right that represents Sandvik 12C27. These large carbides contribute to the wear resistance of the steel but, at the same time, they also reduce the toughness and the sharpness potential of the blade. The large carbides make the knife very difficult to sharpen and tend to fall out of the cutting edge. As a result, blades made of this steel become micro-serrated.

   These steels are developed for stamping tools and various wear parts. Stamping tools usually have 90-degree edges, for which a primary carbide grade is well suited.

   These steels are suitable for knives for which the wear resistance demands are very high and on which very wide edge angles are acceptable, but on which the sharpness and toughness demands are low. This steel type is not at all compatible with keen knife-edge geometries.
Sandvik 19C27 is a grade of this type and is recommended for industrial applications, such as for cutting fibers and paper.

2. **Medium-size carbide powder-metallurgical grades**

Examples of grades: Any high-alloy powder metallurgical grade for knife applications.

These grades have a much finer structure than the coarse carbide steels, but the carbides are still about 200 times larger than the small carbides in the microstructure of Sandvik 12C27. The structure is homogenous and has a high carbide density. This makes these grades highly wear resistant and the medium-size carbides give satisfactory edge properties. Due to their high fraction of hard and brittle carbides, these grades are difficult to sharpen and have low toughness. Especially if used on keen edge geometries, these grades have a tendency to chip in the edge, which is known as micro-chipping.

These grades are good for knives on which the wear resistance demands are very high, and on which average demands are made on edge performance, such as edge toughness, regrindability, edge stability and keen edge geometries.

3. **Fine-grained knife steels**

Examples of grades: 13C26, 12C27, 12C27M, 7C27Mo2

The Sandvik philosophy is to develop fine carbide steels for world-class edge performance. The fine structure allows for razor sharpness and keen edges. These steels perform well in all edge geometries, since they are not restricted by large primary carbides. The structure makes the steel easy to sharpen and gives the blade exceptional toughness. Due to their microstructure, these steels are also suitable for stamping and fine blanking. Efficient production methods have always been of focal interest in the Sandvik way of doing business.

These grades are used for knives, razors and electric shavers.

The combination of high hardness and a fine carbide structure ensures exceptional edge performance. The high hardness
provides good edge stability, the high toughness prevents micro-chipping, and the small carbides with an average size of 0.5 microns allow for unparalleled sharpness. A sharp edge should have a radius of 1-2 microns, which is easy to achieve with the small carbides in the Sandvik steels.

4. **Carbon steels**

Examples of grades: 1075, 1095

Carbon steels also have carbides, but of a different type. These carbides, known as cementite, consist of iron and carbon, Fe3C (three iron atoms bonded to each carbon atom). Blades made of carbon steels are easy to sharpen, achieve high hardness and have excellent toughness. But they have poor wear resistance and corrode easily.

Carbon steels were entirely dominant for knives until the introduction of stainless steels, and they are still used in applications in which high demands are made on toughness and regrindability, such as for large fixed-blade knives for outdoor applications.

**Furnace type**

Knife steel can be hardened in roughly three different ways, depending on the equipment:

- Piece hardening in a small furnace or hardening in a belt furnace. These two procedures are equivalent in terms of times and temperatures, and share the same hardening program.
- Batch hardening of larger batches, e.g. in a vacuum furnace.

Regardless of the method used, the purpose is the same: to harden the material in order to increase the hardness and improve the corrosion resistance.

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Thickness</th>
<th>Time in furnace</th>
</tr>
</thead>
<tbody>
<tr>
<td>mm</td>
<td>inches</td>
<td>minutes</td>
</tr>
<tr>
<td>2.50</td>
<td>0.100</td>
<td>5</td>
</tr>
<tr>
<td>3.00</td>
<td>0.118</td>
<td>6</td>
</tr>
<tr>
<td>3.25</td>
<td>0.128</td>
<td>7</td>
</tr>
<tr>
<td>3.50</td>
<td>0.138</td>
<td>8</td>
</tr>
<tr>
<td>3.75</td>
<td>0.148</td>
<td>10</td>
</tr>
<tr>
<td>4.00</td>
<td>0.157</td>
<td>12</td>
</tr>
</tbody>
</table>
material thickness. The table below shows the approximate soaking times in the furnace as a function of the material thickness.

When the blade has been soaked in the furnace for the time specified above, it is removed and immediately quenched, preferably in oil intended for quenching.

In belt furnaces, the material is either placed together on a long belt, or the knife blades are placed on a mesh belt that transports them through the furnace. The most critical operation for hardening in belt furnaces is quenching, which should be given extra attention for optimal performance.

**Hardening of larger batches**

When larger batches are hardened, rate of temperature increase will be much slower, and the material should therefore be given a chance to achieve uniform temperature by soaking it at 850°C during the heating process. The material should also be given a longer soaking time when hardening, and the temperature should be lowered slightly to compensate for the longer soaking time as shown in the figure below.
Quenching is equally critical in this type of hardening, and it is very important for the furnace equipment used to have a very high cooling capacity in order to meet the requirement for lowering the temperature to 600°C within 2 minutes.

**Hardening in various furnace types**

**Piece furnace**

Hardening in a smaller furnace normally takes place to a temperature of 1080°C.

**Belt furnace**

In a belt furnace, the material is normally placed together on a mesh belt that transports the material through the furnace.
The purpose of hardening and tempering

Hardening is a way of making the knife material harder. By first heating the steel to between 1050 and 1090°C and then quickly cooling (quenching) it, the material will become much harder, but also more brittle.

To reduce the brittleness, the material is tempered, usually by heating it to 175 - 350°C for 2 hours, which results in a hardness of 53 - 63 HRC and a good relationship between sharpness retention, grindability and toughness.

Tempering should be carried out within a reasonable time after hardening - preferably within an hour or so. But bear in mind that the blade should be allowed to cool to room temperature before tempering is started. The transformation to martensite will otherwise be interrupted and the hardening results may be impaired.

A higher tempering temperature will yield a somewhat softer material with higher toughness, whereas a lower tempering temperature will produce a harder and somewhat more brittle material, as shown by the figure below.

A camping knife or a survival knife, for example, may be tempered at 350°C so that it will be able to withstand rough handling without breaking. On the other hand, if the knife is expected to keep a sharp edge, it can instead be tempered at 175°C for maximum hardness.
Tempering temperatures below 175°C should be used only in exceptional cases, when extreme demands are made on high hardness, since very low tempering temperatures will result in a very brittle material. Similarly, tempering temperatures above 350°C should be avoided, since this could give rise to tempering embrittlement and impaired corrosion resistance.

Note that if the finished knife is later exposed to temperatures above the tempering temperature (e.g. during grinding), the properties of the knife will be impaired.

Correctly performed hardening will result in a good relationship between hardness, toughness and corrosion resistance of the finished knife blade.
The hardening procedure

It is now time to describe how hardening is carried out in practice, what distinguishes the various furnace types, and what should be borne in mind in the various furnace types and processes.

In addition, we describe the importance of quenching the material as quickly as possible from the hardening temperature, and how hardness is affected by different tempering temperatures. The required hardness can be achieved by varying the tempering temperature within the range we specify.
Hardening programs

The hardening programs are carefully matched to the various Sandvik steel grades. Choose the furnace type to suit either individual pieces or an entire batch. Then enter the steel grade. The programs are then started by heating a blade from room temperature to the required hardening temperature (A = austenitizing) of between 1050 and 1090°C, depending on the steel grade. The material is then quenched (Q = quench) to room temperature in the space of less than 2 minutes, possibly followed by deep-freezing (DF = deep-freezing) to between -20 and -70°C. This is followed by the tempering process (T = tempering), during which the material is heated to 175 - 350°C, depending on the required hardness.

Deep-freezing

Deep-freezing is used if cooling to room temperature does not produce sufficient hardness, and involves cooling the knife blades down from -20°C to -150°C before they are tempered. In this guide Sandvik provides hardening program with -20°C or -70°C, respectively.

The simplest way of deep-freezing the knife blades is to place them in a freezer or immerse them in dry ice. The knife blade is then left to “thaw” to room temperature, and is then tempered in the usual way.

Deep-freezing increases the hardness by 1 – 3 HRC, but reduces the toughness slightly. For most applications, hardness between 57 and 58 HRC provides a good balance between edge stability, toughness and grindability.
Effect of deep-freezing on Sandvik 12C27, on which the hardness increases by about 2 HRC.
What happens inside the material?

During the heating process at the beginning of hardening, the hard carbides are dissolved and enable the carbon and chromium alloying elements to disperse (diffuse). This enables both the hardness and the corrosion resistance to be improved during the quenching phase.

When a sufficient amount of carbides has dissolved, this condition must be retained by cooling the steel very rapidly (known as quenching). During the quenching process, the structure of the steel is transformed from austenite to martensite with carbides, and the hardness increases in this transformation.

Part of the austenite in the steel at high temperature is not transformed but is retained in the material in the form of retained austenite. Retained austenite is a soft and tough component in the steel of the finished knife blade.

After quenching, the material must be tempered in order to reduce the internal stresses, at the same time increasing the toughness of the steel.

Has the hardening been correctly done?

It is obviously difficult to check the hardening results without destroying the knife blade. The only test that can be done relatively simply is to assess the hardness of the steel, but this only provides an indication of how the material has been hardened. It is therefore extremely important to follow the hardening instructions as regards the times and temperatures of the various operations. But to make certain
that the material also has the correct structure, toughness, adequate corrosion resistance and an appropriate quantity of retained austenite, a knife blade should be sent to the test laboratory at regular intervals for testing.

If the straightness or flatness of the knife blades is found to need adjustment after quenching, this is best done before the material is tempered, at least before it has had time to cool to room temperature.

Re-hardening is not recommended, since it seldom produces good results. But if this is necessary for any reason, it is advisable to lower the hardening temperature by about 10°C below normal. However, larger batches can be hardened as usual.

Optimum hardening produces an unstructured matrix of tempered martensite with very small, uniformly distributed carbides, and a certain amount of residual austenite. The content of retained austenite should be between 5 and 15 % (see the picture below).
We have arranged some pictures illustrating how hardening, quenching and tempering are carried out, examples of different furnace types and a collage of the path from scrap to steel. This is aimed at assisting you in your work of converting good knife steel to the best possible knife blade.

**Pitting corrosion**

Pitting corrosion 1  
Pitting corrosion 2  
Pitting corrosion edge 1  
Pitting corrosion edge 2  
Pitting corrosion edge 3  
Pitting corrosion edge 4 (1500x)
Edge performance

Cross section chipped edge

Cross section edge rolling

Edge chipping 1 (200x)

Edge chipping 2 (200x)

Edge chipping (400x)

Edge chipping (750x)

Edge rolling

Knife edge 12C27 (1400x)

Knife edge 440C (1400x)

Microstructure

12C27 before and after hardening

Grain boundary carbide web due to slow quench (500x)

Powder steel grade 1.05%C 14%Cr 4%Mo
Other pictures

Laser cutting of blades