# TECHSUPPORT #16
# Thermal Cutting of Hardox and Strenx

## Cutting of Hardox and Strenx

Hardox® Wear Plate and Strenx™ Performance Steel are extremely clean steels. This together with their low alloying content makes them very easy to cut. Hardox and Strenx can be cut by all thermal cutting methods, including oxy-fuel cutting, plasma cutting as well as laser cutting. Of course, it is also possible to use cold cutting processes.

The recommendations in Tech Support #16 mainly concern the thermal cutting processes and are divided into three sub-chapters, i.e. oxy-fuel cutting, plasma cutting and laser cutting.

The cold cutting methods, shearing and punching, are limited to the softer Hardox grades (400 and 450) and all Strenx grades in moderate thicknesses. Abrasive Water Jet (AWJ) cutting is a cold cutting method that enables all Hardox and Strenx grades to be cut independent of thickness.

**FIGURE 1.** From top left, Oxy-fuel cutting, Plasma cutting, Laser cutting, AWJ cutting.

Thermal cutting of Hardox and Strenx is as simple as cutting regular mild steel. Regarding the actual cutting process, is often even simpler to cut Hardox and Strenx compared with mild steel due to the cleanness of the steel. However while cutting thick plates of Hardox some attention is needed due to the risk of cut edge cracking. Since Strenx and Hardox belong to the family quenched and tempered steels, they also respond to thermal cutting differently than e.g. mild steel. QT steels are susceptible to softening due to thermal cutting and some QT-steels are susceptible to cut edge cracking. By following the recommendations and guidelines given below, both Hardox and Strenx can be thermally cut with conventional equipment. Further information can be found in the Welding Handbook published by SSAB.

## Cut edge cracking

Cut edge cracking is a phenomenon that is closely related to hydrogen cracking in welds and occurs when thermal cutting methods are used. If cut edge cracks should occur, they will become visible between 48 hours and up to several weeks after the cutting. So, cut edge cracking can be regarded as delayed cracking. The risk of cut edge cracking increases with the steel hardness and plate thickness. How to reduce the risk of cut edge cracking is described below.

Cut edge cracking is closely related to the hydrogen content and residual stresses in the steel plate. It is therefore of interest to reduce the hydrogen content as well as the residual stresses, which can be done in different ways:

1. Preheating the plate
2. Post heating
3. Reduced cutting speed
4. Combination of preheating, post heating and reduced cutting speed together with a prolonged cooling process of HAZ

### Preheating

One method to avoid hydrogen cracking when cutting is to preheat the material and cut it while the material is warm. Preheating can preferably be used prior to oxy-fuel cutting and plasma cutting with oxygen as plasma gas.

Regarding all type of laser cutting and plasma cutting with nitrogen, preheating is not recommended due to its negative effect of the cut edge quality.

Depending on the situation, either part of the plate or the entire plate can be heated. The way to do this can be:

- Heating furnace
- Preheating torches
- Electrical mats

Heating in furnaces is the best way to preheat due to that it results in an even temperature of the entire plate. Preheating torches can also be applied for preheating of Hardox and Strenx plates see **figure 3**. It is of importance that the torches are in motion so that the temperature of the plate does not exceed maximum preheating temperature. Further, the preheating temperature is measured on the opposit side of where the preheating is applied.

Electrical mats is a slow preheating method, so to preheat to 150-200 °C a good practice is to preheat overnight and begin the cutting operation the next morning.

### Post heating

Post heating is a reliable method in order to avoid cut edge cracking. This can either be done in a furnace or with torches. The easiest method is to use torches since they are widely spread in industry, furnaces are not so common. It is important that the post heating process takes place as soon as possible after the part has been cut out. The maximum time is 30 minutes between start of cutting and start of post heating procedure. It is of importance not to heat the material too much.

Using furnaces the temperature should not exceed the maximum allowable temperature listed in **table 2** and the plate has to stay in the furnace until it reaches this temperature. Depending on the thickness of the plate the time will vary, but as a general rule of thumb the time of post heating should be at least 5 minutes for every mm of plate thickness (i.e. 50 minutes for a 10 mm thick plate).

Using torches, **figure 4**, it is of importance to not overheat. The temperature of the cut edge shall not exceed 700 °C. Normally post heat treatment using torches is done manually and in this case it is of importance to know how to control the temperature. This is done by looking at the color of the cut edge just behind the torch, it should just start to glow (very dark red). If the color is bright sherry or dark orange the temperature is too high and the post heating will not be successful and has to be redone. If the post heating is done in strong light (outside in the sun) it is harder to determine the temperature, so if possible perform the post heating indoors.

## Reduced cutting speed

When cutting speed is reduced, the material heats up around the cut front and the heat affected zone will be wider. This affects the residual stresses in such a way that the risk of cut edge cracking is reduced. One should though bear in mind that reduced cutting speed is not as reliable as preheating or post heating and should only be used as a substitute if, for instance, the workshop does not have appropriate pre/post heating equipment.

If reduced cutting speed is used it is important that the cutting speed doesn't exceeds the one listed in in this document, otherwise the risk for cutting cracks won't be reduced at all.

## Slow cooling

Regardless of whether or not preheating of the cut parts are employed, a slow cooling rate will reduce the risk of cut edge cracking. Slow cooling can be achieved if the parts are stacked together while still warm from the cutting process, and are covered with an insulating blanket. Allow the parts to cool slowly down to room temperature.

## Stress raisers

Sharp corners will act as stress raisers and since hydrogen cracking is closely related to residual stresses, sharp corners will increase the risk for cut edge cracking. This is true for all cutting methods both thermal and cold cutting methods like AWJ cutting. If the following actions are considered the risk for cracks will decrease:

1. If possible avoid sharp "inward facing" corners
2. If possible use smooth geometries
3. When sharp corners can't be avoided, make a circular loops around "outward facing" corners.
4. If the cutting operation is to be stopped (I.e. overnight) make a clean cut to remove stress raisers

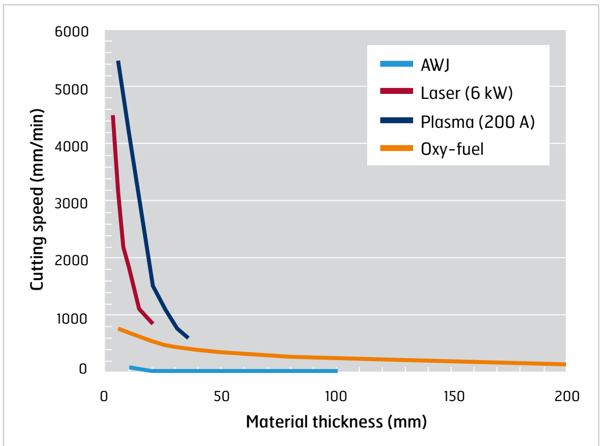


**FIGURE 2.** Cutting speed as a function of material thickness for different cutting processes

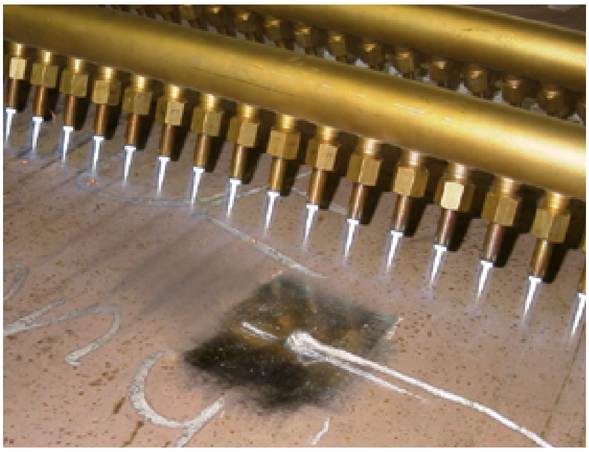

**FIGURE 3.** Preheating lances.

**FIGURE 4.** Manually post heating.

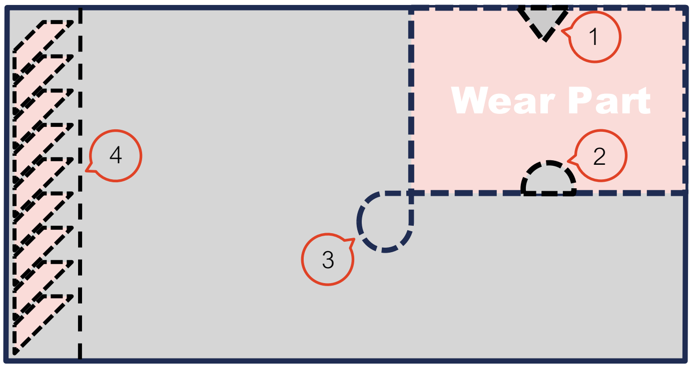


**FIGURE 5.** Avoid sharp inward facing corners.

# Oxy-fuel Cutting

Hardox and Strenx are easily cut by the oxy-fuel cutting process. Oxy-fuel cutting has almost no limitations when it comes to material thickness, i.e. material thicknesses up to 1000 mm can be cut. Although it is possible to cut relatively thin materials, the main thickness is above 20 mm. Generally features for oxy-fuel cutting can be seen in **table 1**. A common misunderstanding is that you need higher cutting oxygen pressure to cut hard steels. Since Oxy-fuel cutting is a thermal process the hardness of the steel has no influence on the cutting performance. Both Hardox and Strenx have a low alloying concept which together with the cleanness of the steel makes them easy to cut.

## Hardox

### Preheating

The preheat recommendations for oxyfuel cutting can be seen in **table 2**.

### Post heating

As mentioned in the cut edge cracking section, it is preferable to use post heating of the cut edge in order to minimize the risk of cut edge cracking. In the case of post heat treatment in a furnace, use the temperatures (maximum) given in **table 2**. Let the plate/part stay in the furnace until the core temperature has reached the accurate temperature (**table 2**).

If the post heating is done with a torch, make sure that the temperature does not exceed 700 °C. In practice this means that the cut edge just behind the torch should start to glow with a very dark red color (blood red or very dark sherry), see schematic **figure 6**.

It is also important that the post heat treatment takes place as soon as possible after finished cutting operation. Maximum 30 minutes between the start of the cutting operation and the start of the post heating operation.

### Reduced cutting speed

When cutting speed is reduced, the material heats up around the cut front and the heat affected zone will be wider. This affects the residual stresses in such a way that the risk of cut edge cracking is reduced. One should though bear in mind that reduced cutting speed is not as reliable as preheating or post heating and should only be used as a substitute if, for instance, the workshop does not have appropriate pre/post heating equipment.

If reduced cutting speed is the only available measure to counteract the risk for cutting cracks, the cutting speeds should not exceed the maximal cutting speeds listed in **table 3**. Don't use a too big nozzle (i.e. use a 25-50 mm nozzle instead of a 50-100 mm nozzle for a 50 mm thick plate).

In order to get a good cut edge quality the cutting oxygen pressure needs to be reduced. How much the cutting pressure needs to be reduced depends on type and size of the nozzle. Always do a test cut where the cutting oxygen pressure is adjusted until a good cut edge quality is obtained.

Make sure that the plate is as warm as possible prior to cutting. During winter store the plate inside the workshop some time prior to cutting.

## Strenx

Most Strenx grades in moderate thicknesses have a high enough resistance to hydrogen cracks that it is unnecessary to take additional steps, such as preheating, to avoid cut edge cracking. However when cutting Strenx 700-960 in thicknesses above 80 mm and Strenx 1100 in thicknesses above 30 mm the risk for cut edge cracking increases. The risk for cut edge cracking can be reduced by either preheating the plate, use post heating or apply slow cutting.

Suitable preheating temperatures for Strenx 700-960 is 150°C. For Strenx 1100 just below 150°C.

If preheating is applied the preheat temperatures should not exceed the ones mentioned in **table 4**.

Regarding post heat treatment of Strenx, see post heat treatment of Hardox above.

For slow low cutting use the same parameters for Strenx 700-960 as Hardox HiTuf and for Strenx 1100 use the same parameters as for Hardox 450.

| Cutting method | Kerf width | HAZ | Dim. tolerances |
|---|---|---|---|
| Oxy-fuel cutting | 2-5 mm | 4-10 mm | ± 2.0 mm |

**TABLE 1.** General features for oxy-fuel cutting.

| Material | Max preheating temp. (°C) |
|---|---|
| Strenx 700 | 300 |
| Strenx 900 | 300 |
| Strenx 960 | 300 |
| Strenx 1100 | 150 |
| Strenx 1300 | 150 |

**TABLE 4.** Recommended maximum preheat levels.

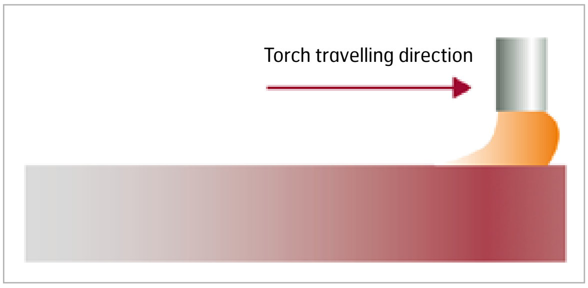


**FIGURE 6.** Color of the cut edge behind the post heating torch.

| Grade | Plate thickness | Minimum preheating temp. (°C) | Maximum preheating temp. (°C) |
|---|---|---|---|
| Hardox HiTemp | 5 – 51 mm | No preheating | 500 |
| Hardox HiTuf | < 90 mm<br>≥ 90 mm | No preheating<br>100 | 300 |
| Hardox 400 | < 45 mm<br>45 – 59.9 mm<br>60 – 80 mm<br>> 80 mm | No preheating<br>100<br>150<br>175 | 225 |
| Hardox 450 | < 40 mm<br>40 – 49.9 mm<br>50 – 69.9 mm<br>≥ 70 mm | No preheating<br>100<br>150<br>175 | 225 |
| Hardox 500 | < 25 mm<br>25 – 49.9 mm<br>50 – 59.9 mm<br>≥ 60 mm | No preheating<br>100<br>150<br>175 | 225 |
| Hardox 550 | < 20 mm<br>20 – 51 mm<br>> 51 mm | No preheating<br>150<br>170 | 200 |
| Hardox 600 | < 12 mm<br>12 – 65 mm | No preheating<br>175 | 180 |
| Hardox Extreme* | 8 – 19 mm | 100 | 100 |

**TABLE 2.** Preheat temperatures for oxy-fuel cutting of the Hardox grades.

*SSAB recommends AWJ cutting. If only oxy-fuel cutting is available follow the recommendations in table 2.

**TABLE 3** shows maximal cutting speed (mm/min) for oxy-fuel cutting without preheating. Slow cutting is by its own, not a sufficient method to counteract cutting cracks for Hardox extreme. If the only available method is oxy-fuel cutting use preheating together with post heating with a torch.

| Max plate thickness | Hardox HiTemp | Hardox HiTuf | Hardox 400 | Hardox 450 | Hardox 500 | Hardox 550 | Hardox 600 | Hardox Extreme |
|---|---|---|---|---|---|---|---|---|
| 12 mm | no restriction | no restriction | no restriction | no restriction | no restriction | no restriction | no restriction | ** |
| 15 mm | no restriction | no restriction | no restriction | no restriction | no restriction | no restriction | 300 | ** |
| 20 mm | no restriction | no restriction | no restriction | no restriction | no restriction | no restriction | 200 | ** |
| 25 mm | no restriction | no restriction | no restriction | no restriction | 300 | 270 | 180 | |
| 30 mm | no restriction | no restriction | no restriction | no restriction | 250 | 230 | 150 | |
| 35 mm | no restriction | no restriction | no restriction | no restriction | 230 | 190 | 140 | |
| 40 mm | no restriction | no restriction | no restriction | 230 | 200 | 160 | 130 | |
| 45 mm | no restriction | 230 | 230 | 200 | 170 | 140 | 120 | |
| 50 mm | no restriction | 210 | 210 | 180 | 150 | 130 | 110 | |
| 60 mm | | 200 | 200 | 170 | 140 | * | * | |
| 70 mm | | 190 | 190 | 160 | 135 | * | * | |
| 80 mm | | 180 | 180 | 150 | 130 | | | |
| >80 mm | | * | * | * | * | | | |

*Only preheating is applicable. **SSAB recommends AWJ cutting.

# Plasma Cutting

Hardox and Strenx are easily cut by the plasma cutting process. Plasma cutting has a limitation when it comes to material thickness and the main thickness to be cut is below 50 mm (plasma cutting machine dependent). Generally features for plasma cutting can be seen in **table 5**.

**Figure 7** shows cutting speed as a function of material thickness and available power for plasma cutting.

## Hardox and Strenx

There is no difference in plasma cutting Hardox and Strenx compared to ordinary mild steel, i.e. use the same process parameters. Preheating or post heating to enhance hydrogen migration from HAZ is not required during plasma cutting of most Hardox and Strenx grades. Hardox 600 and Hardox Extreme have to be either preheated or post heat treated in order to avoid cut edge cracking, see recommendations for oxy-fuel cutting.

| Cutting method | Kerf width | HAZ | Dim. tolerances |
|---|---|---|---|
| Plasma cutting | 2-6.5 mm | 2-5 mm | ± 1.0 mm |

**TABLE 5.** General features for plasma cutting.

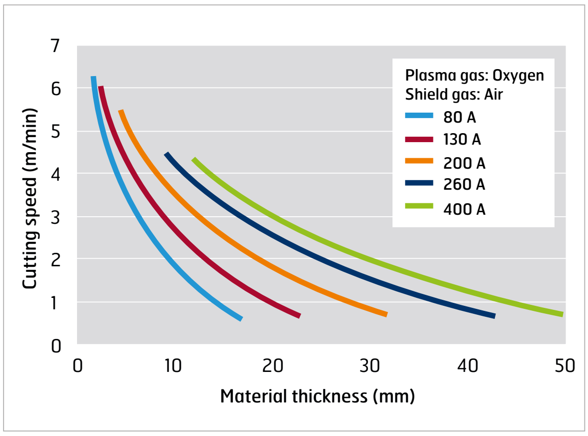


**FIGURE 7.** Shows general cutting speeds for different plasma power sources.

# Laser Cutting

Laser cutting of Hardox and Strenx can easily be done by using the normal processing parameters for the given material thickness. The maximum thickness is approximately 25 mm depending on the laser cutting equipment. Most common is to cut thicknesses below 15 mm. Generally features for laser cutting can be seen in **table 6**.

Laser cutting is faster than oxy-fuel cutting and gives higher cut edge quality than plasma cutting. **Figure 8** shows cutting speed as a function of material thickness and laser power.

Due to the relatively thin thicknesses and small thermal impact, preheating to enhance hydrogen migration from HAZ is not required during laser cutting of Hardox and Strenx grades. Preheating is instead detrimental to the cut edge quality.

## Hardox and Strenx

It is no difference to laser cut Hardox and Strenx compared to ordinary mild steel, i.e. use the same process parameters. The primer reduces the cutting speed, but this can be solved by first vaporize the primer and then cut the contour with full speed.

| Cutting method | Kerf width | HAZ | Dim. tolerances |
|---|---|---|---|
| Laser cutting | < 1 mm | 0.2-2 mm | ± 0.2 mm |

**TABLE 6.** General features for laser cutting.

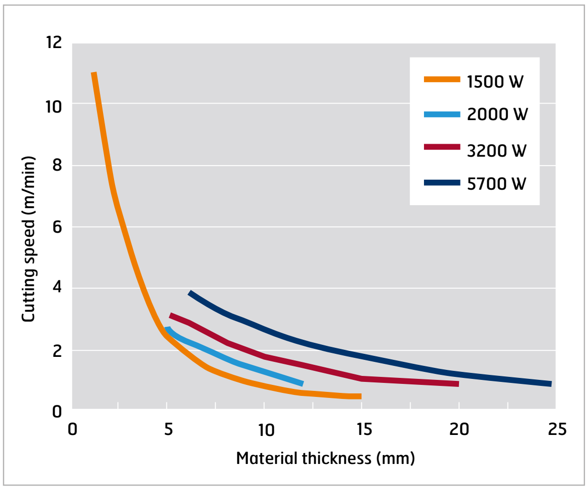


**FIGURE 8.** Laser cutting speeds.

## Hardness properties in HAZ

The properties of HAZ depend on:

- Whether or not the steel was tempered during manufacturing, and if so, how it was carried out
- The chemical composition of the steel
- The impact of the thermal treatment from the cutting process

The width of HAZ increases with increasing thermal impact from the cutting process. For instance, cutting with the same power and reduce the cutting speed leads to a wider HAZ. Different thermal cutting processes have different thermal impact, resulting in wider or narrower HAZ. Oxy-fuel cutting has the highest thermal impact followed by plasma cutting and laser cutting. **Figure 9** shows a schematic figure of HAZ for Strenx 1100 – Strenx 1300 and Hardox 400 – Hardox Extreme.

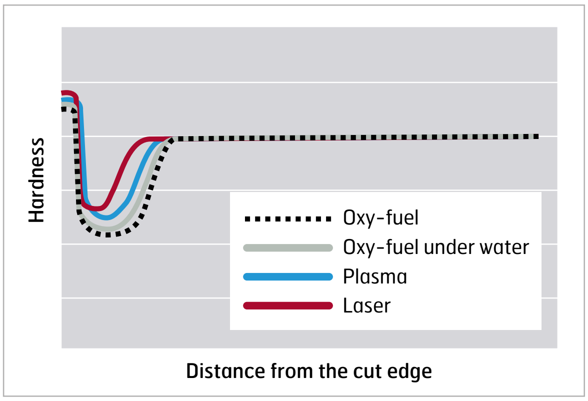


**FIGURE 9.** Hardness profiles in HAZ after thermal cutting of Hardox and Strenx with different cutting methods.

## Plate handling

While storing Hardox 550, Hardox 600 and Hardox Extreme, make sure the plates are not subjected to 3 point bending. Three point bending can occur if the plates are stacked with dunnage between the layers and the dunnage is not properly placed. Always make sure that the dunnage in each layer is placed on top of the dunnage in the layer below.

Never return a plate to the stock with any sharp corners left, these corners will act as stress raisers and may cause delayed cracking in the plate. Always make a clean cut to remove such sharp corners before the plate is returned to stock. This is true for all cutting methods both thermal and cold cutting methods like AWJ cutting. Hardox 550, Hardox 600 and Hardox Extreme are especially sensitive to this.

**FIGURE 11.** Properly stacked plates.

# Reducing the risk of softening

The resistance of the steel to softening depends on its chemistry, microstructure and the way in which it has been processed. The smaller the part that is thermally cut, the greater the risk of the whole component being softened. If the temperature of the steel gets too high, the hardness of the steel will be reduced, according to **figure 11**. Check maximum allowable temperature in **table 3 and 4**.

## Cutting method

When small parts are cut, the heat supplied by the cutting torch and by preheating will be accumulated in the workpiece. The smaller the size of the cut part the greater the risk of softening. When oxy-fuel is used for cutting 30 mm or thicker plate, the rule of thumb is that there is risk of loss of hardness of the entire component if the distance between two cuts is less than 200 mm. The best way of eliminating the risk of softening is to use cold cutting methods, such as abrasive water jet cutting. If thermal cutting must be performed, laser or plasma cutting is preferable to oxy-fuel cutting. This is because oxy-fuel cutting supplies more heat and thus raises the temperature of the workpiece.

## Submerged cutting

An effective way of limiting and reducing tempering of the plate is to water-cool the plate and the cut surface during the cutting operation. This can be done either by submerging the plate in water (**figure 12**) or by spraying water on the piece during and after cutting. Submerged cutting can be done both in plasma cutting and in oxy-fuel cutting.

Some advantages offered by submerged cutting are:

- Prevents loss of hardness of the whole component
- Reduced distortion of the cut part
- Parts are cooled directly after cutting
- No fumes or dust
- Reduced noise level

Since preheating is not applicable for submerged cutting, the only available measures to counteract the risk for hydrogen cracking are post heating and reduced cutting speed. When small parts are cut by oxy-fuel from thick Hardox plate, there is risk of softening as well as cut edge cracking. This is best avoided by submerged cutting at low cutting speeds or with a post heat treatment of the cut parts. The post heating can be done either with a torch or in a furnace.

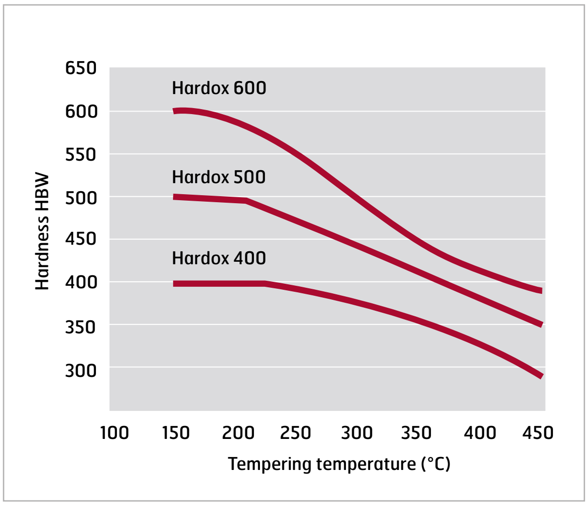


**FIGURE 11.** Surface hardness vs. tempering temperature.

**FIGURE 12.** Submerged cutting.

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