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HOT-ROLLED STEEL PLATES, SHEETS AND COILS

Thermal cutting and flame straightening

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In this data sheet, we have collected information on the thermal cutting and flame straightening of hot-rolled steel products: In this data sheet, we have collected information on the thermal cutting and flame straightening of hot-rolled steel products:

- flame cutting
- plasma cutting
- laser cutting
- flame straightening.

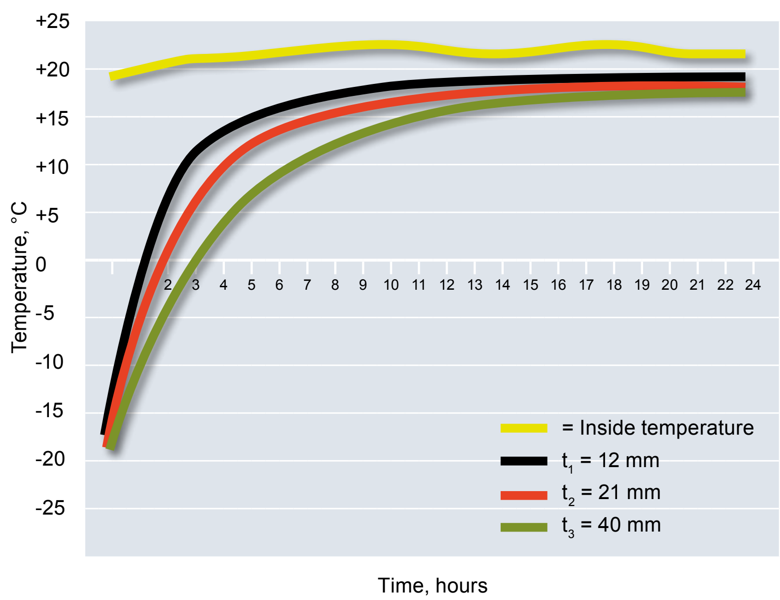
Thermal cutting

Thermal cutting of hot-rolled steel sheets and plates is a typical engineering workshop procedure to cut plates into shape and prepare welding grooves. Processes include flame, plasma and laser cutting.

Regardless of the strength of the steel, successful thermal cutting requires that the plate is allowed to warm up throughout to room temperature +20°C before cutting. Figure 1 shows the time required, when the plate is taken from a cold storage inside to the factory hall. The test is carried out using three different plate thicknesses.

Figure 1.
The warm-up time of cold (-20°C) steel plates

The test was carried out at Ruukki Raahe works, February 2011, inside a factory hall, whose temperature varies +20°C - +22°C. The plate sizes are: 12 x 1000 x 2000, 21 x 1000 x 1600 and 40 x 1000 x 2000 mm.



The results of warm-up test -20°C to +17°C are summarized as follows:

- about 8 hours for a plate thickness of 12 mm
- about 12 hours for a plate thickness of 21 mm
- about 17 hours for a plate thickness of 40 mm.

The surface as well as the centre part of the plate are getting warm at the same speed during this kind of a slow transition. If thick and large plates are stacked, the warming-up takes a considerably longer time. As a rule of thumb, the warm-up time -20°C to +20°C for a normal plate size (width 2 meter and length 6 meter) is about 24 hours. It is highly recommended to take the cold plates into the workshop a day before starting of plate processing.

Usually, no special measures are needed in thermal cutting of steels up to 500 MPa yield strength class. As the strength and hardness of steel increases, preheating becomes necessary, for example in flame cutting. Table 1 shows special features for the thermal cutting of the different steel grades. All steels manufactured by Ruukki are suitable for thermal cutting.

Table 1.
Special features in thermal cutting of hot-rolled steel grades

	Thermal cutting
Multisteel and Multisteel N	Suitable for flame, plasma and laser cutting.
Ruukki Laser 250 C/355 MC/420 MC	Excellently suitable for laser cutting in particular.
Optim 500/550/600/650/700 MC and Optim 700 MC Plus	A narrow softened zone will form at the cut edge.
Optim 500 ML	Suitable for flame, plasma and laser cutting.
Optim 900/960/1100 QC and Optim 960 W	A narrow softened zone will form at the cut edge.
COR-TEN® B	Thermal cutting similar to other S355 strength class steels. For thermal cutting of plate thicknesses over 15 mm, observe working temperature recommendations for welding.

In flame cutting, similar microstructure zones are formed on the surface of the steel as in a welded joint. Carbonisation (increased carbon content) of the surface contributes to the hardening of a flame cut surface. Carbonisation is due to the selective burning of the steel, and as the iron oxide layer formed on the cut surface prevents the formation of carbon monoxide, the carbon content in the molten layer increases. In structural steels, the depth of the carbonised layer is less than 0.1 mm. The width of the heat affected zone normally is less than 5 mm.

In flame cutting, the thickness of the steel plate has an effect on the heating and cooling rates of the material and thus, on the hardness and grain size of the flame cut surface. The maximum hardness of the surface increases with the increase in thickness of the workpiece. However, the maximum hardness is determined primarily by the carbon content of the steel.

Excessive hardening can be avoided through preheating. Preheating decreases the hardness of the flame cut edge and improves its deformation capability. It also makes the machining of the plate edge easier and speeds up the flame cutting procedure. The need for preheating depends on the plate thickness, steel hardenability (chemical composition) as well as cutting process (gas) and cutting speed.

General rule for the need for preheating T °C:

$$T = 500 \sqrt{C_{ekv} - 0.45}\text{, when plate thickness } t = 5 – 100 \text{ mm}$$
$$T = 500 \sqrt{C_{ekv} \cdot (1 + 0,0002\, t) - 0.45}\text{, when plate thickness } t > 100 \text{ mm)}$$
$$C_{ekv} = C + 0.155 (Cr + Mo) + 0.14 (Mn + V) + 0.115\, Si + 0.045 (Ni + Cu)$$

The hardening of the surface due to flame cutting increases the strength of the surface, but the strengthened area is very narrow.

When compaired to flame cutting higher cutting speeds can be used in all plasma cutting processes, leading to narrower heat affected zones but usually higher hardening on the cut surface.

As far as fatigue strength is concerned, a flame cut edge is no weaker than, for example, a honed edge. For optimum fatigue strength, the cut surface should be as smooth as possible.

High-quality laser cut plate edges possess a good fatigue strength, close to that of a hot-rolled surface. This is due to the heat treatment effects of the cutting process, which cause a hard ferritic-martensitic-bainitic microstructure on the cut edge. A hard microstructure, combined with possible compressive stresses, improves the fatigue strength. The small surface roughness of a laser cut edge has a crucial effect on the good fatigue strength.

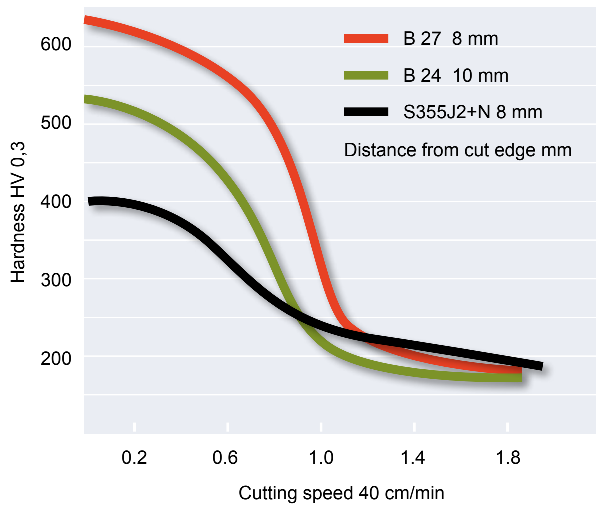
A good-quality mechanically cut edge has fatigue strength properties almost comparable to a hot-rolled surface.

Hardenable Boron steels

The high hardenability of boron steels should be taken into account when they are thermally cut in the hot-rolled condition. The hardness and depth of the hardened layer in the flame cut surface are dependent on the cutting method and heat input during the cutting. The hardening depth in flame cutting is less than 1 mm with plate thicknesses less than 30 mm.

Figure 2 shows the hardening of a flame cut edge of B 24 and B 27 steels, together with a structural steel in the S355 strength class, when oxy-propane cutting is used. Cutting speed is 40 cm/min. When the cutting speed is lowered to 20 cm/min, the maximum hardness of boron steels is reduced to 400 HV.

Figure 2.
Hardening of flame cut edge in oxy-propane cutting



The hardening depth in plasma cutting is shallower than in flame cutting (with water plasma approximately 0.5 mm), but the hardness of the surface becomes higher than in flame cutting.

Excessive hardening of the cut surface affects the bendability of the plate in the hot-rolled condition.
Excessive hardening in flame cutting can be avoided by sufficient preheating (150 – 200°C).

In hardened boron steels, an area softer than the base metal, approximately 2 mm in depth, is formed beneath the flame cut surface. Preheating is recommended before flame cutting hardened boron steels, especially with thicker plates. Hardened boron steel plates must not be thermally cut when they are cold.

• Flame straightening

Flame straightening is used for returning a worked steel object to its original form if the object deviates from the desired shape after working. The heating may affect only the surface of the object or penetrate deeper, up to the entire depth of the object. The heating depth should be selected based on the intended amount of straightening.

The straightening flame must be sharp, local and short in duration. In addition to the sharpness of the flame, its accurate pointing increases the straightening effect. Beware of using an unnecessary hot flame. The surface of the steel will overheat and become upset without improving the straightening effect. Straightening with excess heat may also deteriorate the properties of the steel.

European structural steels are defined in the standard EN 10025-1, -2, -3, -4, -5 and -6. High strength cold formable steels are presented in the standard EN 10149-1, -2 and -3. All these standard steels may be flame straightened under certain conditions. The peak temperature must remain below the limit given in Table 2. This ensures that the properties of the steel remain unchanged even after flame straightening.

Table 2. Flame straightening. Hot-rolled steels, maximum recommended temperatures [1)]

Delivery condition of steel		Max. recommended flame straightening temperatures		
		Short-term surface heating	Short-term full thickness heating	Long-term full thickness heating
Normalised Normalised rolled	N N	≤ 900°C	≤ 700°C	≤ 650°C
Thermomechanically rolled up to strength class S460	TM	≤ 900°C	≤ 700°C	≤ 650°C
Thermomechanically rolled S500 – S700	TM	≤ 900°C	≤ 600°C	≤ 550°C
Quenched and tempered	QT	Tempering temperature used in manufacture of quenched and tempered steel lowered by 20°C. Maximum temperature usually ≤ 550°C.		

[1)] CEN technical report CEN/TR 10347:2006 "Guidance for forming of structural steels in processing".

Normalised steels may usually be flame straightened at higher temperatures than extra high strength, thermomechanically rolled or quenched and tempered steels. Traditional hot-rolled (rolling condition) steels behave as normalised or normalised rolled steels in flame straightening. When heat treated, the strength of normalised, normalised rolled and hot-rolled steels is retained best as the strength is exclusively a result of alloying.

The basic strength of **thermomechanically rolled steel** comes from alloying, but additional strength is achieved through the rolling technique and cooling after rolling. The effect of alloying on the strength of TM steels is reduced when the strength class of the steel increases.

The production process of **quenched and tempered steel** includes annealing in austenitising temperature, followed by quenching (Q) and finally tempering (T). When quenched and tempered steel is tempered for added toughness, it is annealed in the so-called tempering temperature, which is lower than the austenitising temperature.

Hardened steels are manufactured in the same way as quenched and tempered steels. The final production stage of hardened steels is quenching, or hardening, from which the designation is derived. Thus, hardened steel is not actually tempered, which accounts for its different properties from quenched and tempered steel. Special care should be taken when flame straightening hardened steels. The maximum recommended temperature is 450°C. Jack straightening or presses are alternative straightening methods. Thinner plate structures may also be straightened by combined jack straightening and hammering. Combined jack straightening and flame straightening is not recommended as it may lead to damage to the structure being straightened.

Raex steels may be flame straightened provided that the mechanical properties of these steels, created through heat treatments, are taken into account.

Post-welding heat treatments are not permitted on Raex steels. A longer exposure to temperatures higher than 250°C impairs the properties required of the steel.

In flame straightening, the temperature of the so-called hot spot may not exceed 450°C to avoid local tempering and deterioration of hardness. Special care must be taken in flame straightening in case the structure is intended for applications subjected to varying, fatiguing loads. Examples are the vanes of fan blowers.

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