

Welding of Hardox





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The unique performance of Hardox wear plate is combined with exceptional weldability. Any conventional welding methods can be used for welding these steels to any type of weldable steel.

This brochure aims to simplify, improve and boost the efficiency of welding processes. It offers advice on i.e. preheat and interpass temperatures, heat input, welding consumable, etc. It enables every user to gain full benefit of the unique properties of Hardox.

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Hardox

Hardox is the brand name for wear resistant steels from SSAB. Hardox wear plates are widely used in every climate, terrain and environment. Users all over the world put their trust in Hardox when fighting wear. Hardox boosts performance and maximizes the uptime of applications like excavators, front wheel loaders, tipper bodies, mining trucks, conveyors, chutes, containers, crushers, fragmentizers, mixers, sieves, demolition tools, and barges. For workshops, it shortens lead times and cuts production costs.

Table 1. Mechanical properties Hardox

Mechanical Properties					
Steel grade	Hardness [HBW] Min - max	Yield strength ¹ (MPa)	Elongation A ₅ ¹ (%)	Impact toughness CVL ¹ t=20 mm	Thickness (mm)
Hardox HiTuf	310 - 370	850	14	95J -40 °C	40 - 160
Hardox 400	370 - 430	1000	10	45J -40 °C	3 - 130
Hardox 450	425 - 475	1300	3 ²		0.7 - 2.10
Hardox 450	425 - 475	1100 - 1300	10	50J -40 °C	3 - 130
Hardox 500	450 - 540	1250		35J -40 °C	4 - 80
Hardox 550	525 - 575			30J -40 °C	10 - 50
Hardox 600	570 - 640			20J -40 °C	8 - 51
Hardox Extreme	57 - 63 ³			<15J -40 °C	8 - 20

1. Typical values

2. A₈₀

3. HRC

Table 2. Chemical Composition

Chemical Composition (ladle analysis)									
Steel grade	C Max %	Si Max %	Mn Max %	P Max %	S Max %	Cr Max %	Ni Max %	Mo Max %	B Max %
Hardox HiTuf	0.20	0.60	1.60	0.020	0.020	0.70	2.0	0.70	0.005
Hardox 400 ¹	0.15	0.70	1.60	0.025	0.010	0.50	0.25	0.25	0.004
Hardox 450 ²	0.18	0.25	1.30	0.015	0.004	0.10	0.10	0.04	0.003
Hardox 450	0.26	0.70	1.60	0.025	0.010	1.40	1.50	0.60	0.005
Hardox 500	0.30	0.70	1.60	0.020	0.010	1.50	1.50	0.60	0.005
Hardox 550	0.37	0.50	1.30	0.020	0.010	1.40	1.40	0.60	0.004
Hardox 600	0.47	0.70	1.00	0.015	0.010	1.20	2.50	0.70	0.005
Hardox Extreme	0.47	0.50	1.0	0.015	0.020	1.20	2.50	0.80	0.005

1. Max. for 20 mm plate thickness

2. 0.7 - 2.10 mm plate thickness

Important parameters affecting the welding result

Clean the weld area to remove moisture, oil, corrosion or any impurities prior to welding. In addition to good welding hygiene, the following aspects are important:

- ▶ Choice of welding consumables
- ▶ Preheat and interpass temperatures
- ▶ Heat input
- ▶ Weld sequence and size of root gap in the joint

Welding consumables

STRENGTH OF UNALLOYED AND LOW-ALLOYED WELDING CONSUMABLES

Unalloyed and low alloyed consumables with maximum yield strength of 500 MPa is generally recommended for Hardox. Consumables of higher strength (R_e max. 900 MPa) may be used for Hardox 400 and 450 in the thickness range 0.7 – 6.0 mm. Low alloyed consumables result in higher hardness of the weld metal and thus reduced wear rate of the weld metal. If the wear properties of the weld metal are essential, the top cap of the joint could be welded with consumables used for hardfacing, see chapter “hard facing”. In addition, recommended consumables for Hardox steels and their designations according to AWS and EN classifications could be found in Table 3.

Table 3: Recommended consumables for Hardox steels

Welding method	AWS classification	EN classification
MAG, solid wire	AWS A5.18 ER70X-X AWS A5.28 ER80X-X	EN ISO 14341-A- G 38xxxxxx EN ISO 14341-A- G 42xxxxxx
MAG, metal cored wire	AWS A5.18 E7XC-X AWS A5.28 E8XC-X	EN ISO 17632-A- T 42xxxxH5 EN ISO 17632-A- T 46xxxxH5
MAG, flux cored wire	AWS A5.29 E7XT-X AWS A5.29 E8XT-X	EN ISO 17632 -A- T 42xxxxH5 EN ISO 17632 -A- T 46xxxxH5
MMA	AWS A5.5 E70X AWS A5.5 E80X	EN ISO 2560-A- E 42xxxxH5 EN ISO 2560-A- E 46xxxxH5
SAW	AWS A5.23 F7X AWS A5.23 F7X	EN ISO 14171-A- S 42xxxx EN ISO 14171-A- S 46xxxx
TIG	AWS A5.18 ER70X AWS A5.28 ER80X	EN ISO 636-A- W 42xx EN ISO 636-A- W 46xx

Note: X stands for one or more characters

Requirements on hydrogen content of welding consumables

The hydrogen content should be lower than or equal to 5 ml of hydrogen per 100 g of weld metal when welding with unalloyed or low-alloyed welding consumables.

Solid wire used in MAG and TIG welding can produce these low hydrogen contents in weld metal. Hydrogen content for other types of welding consumables should be obtained from the respective manufacturers.

If consumables are stored in accordance with the manufacturer's recommendations, the hydrogen content will be maintained to meet requirement stated above. This also applies, to all coated consumables and fluxes.

Stainless steel welding consumables

Consumables of austenitic stainless steels can be used for the welding of all Hardox products, as shown in Table 4. They allow welding at room temperature (+ 5 - 20 °C) without preheating, excluding Hardox 600 and Hardox Extreme.

SSAB recommend giving first preference to consumables in accordance with AWS 307 and second preference to those in accordance with AWS 309. These types of consumables have yield strength up to approximately 500 MPa in all weld metal.

The AWS 307 type can withstand hot cracking better than AWS 309. It should be noted that manufacturers seldom specify the hydrogen content of stainless steel consumables, since hydrogen does not affect the performance as much as it does in unalloyed and low-alloyed consumables.

Table 4: Recommended stainless steel consumables for Hardox steels

Welding method	AWS classification	EN classification
MAG, solid wire	AWS 5.9 ER307	First preference: EN ISO 14343-A: B 18 8 Mn/ EN ISO 14343-B: SS307 Second preference: EN ISO 14343-A: B 23 12 X/ EN ISO 14343-B: SS309X
MAG, metal cored wire	AWS 5.9 EC307	First preference: EN ISO 17633-A: T 18 8 Mn/ EN ISO 17633-B: TS307 Second preference: EN ISO 17633-A: T 23 12 X/ EN ISO 17633-B: TS309X
MAG, flux cored wire	AWS 5.22 E307T-X	First preference: EN ISO 17633-A: T 18 8 Mn/ EN ISO 17633-B: TS307 Second preference: EN ISO 17633-A: T 23 12 X/ EN ISO 17633-B: TS309X
MMA	AWS 5.4 E307-X	First preference: EN 1600: E 18 8 Mn Second preference: EN 1600: E 19 12 X
SAW	AWS 5.9 ER307	First preference: EN ISO 14343-A: B 18 8 Mn/ EN ISO 14343-B: SS307 Second preference: EN ISO 14343-A: S 23 12 X/ EN ISO 14343-B: SS309X
TIG	AWS 5.9 ER307	First preference: EN ISO 14343-A: W 18 8 Mn/ EN ISO 14343-B: SS307 Second preference: EN ISO 14343-A: W 23 12 X/ EN ISO 14343-B: SS309X

Note: X stands for one or more characters

Shielding gas

Shielding gases for Hardox steels are generally the same as usually selected for unalloyed- and low alloy steel.

Shielding gases used for MAG-welding of Hardox steels usually contains a mixture of Argon (Ar) and carbon dioxide (CO₂). Small amount of oxygen (O₂) is sometimes used together with Ar and CO₂ in order to stabilize the arc and reduce the amount of spatter. A shielding gas mixture of about 18 – 20 CO₂ in Argon is recommended to use for manual welding which facilitates good penetration in the material with reasonable amount of spatter. If automatic or robot welding is used, a shielding gas containing 8 – 10 CO₂ in Argon could be used in order to optimize the weld result with regards to the productivity and spatter level. Effects of various shielding gas mixtures can be seen in Figure 1. Recommendations for shielding gas in different welding methods can be found in Table 3. Shielding gas mixtures mentioned in table 5 are general mixtures that can be used for both short- and sprayarc welding.

Figure 1: Shielding gas mixtures and their effect on the welding operation

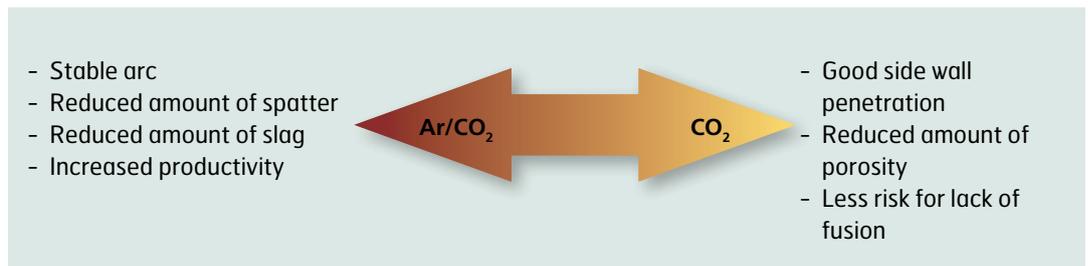


Table 5: Examples of shielding gas mixtures and recommendations

Welding method	Arc type	Position	Shielding gas
MAG, solid wire	Short Arc	All positions	18 – 25% CO ₂ in Ar
MAG, cored wire	Short Arc	All positions	18 – 25% CO ₂ in Ar
MAG, solid wire	Spray Arc	Horizontal (PA, PB, PC)	15 – 20% CO ₂ in Ar
MAG, FCAW	Spray Arc	All positions	15 – 20% CO ₂ in Ar
MAG, MCAW	Spray Arc	Horizontal (PA, PB, PC)	15 – 20% CO ₂ in Ar
Robotic and automated MAG	Spray Arc	Horizontal (PA, PB, PC)	8 – 18 % CO ₂ in Ar
TIG		All positions	100% Ar

Note: Gas mixtures including three components, i.e. O₂, CO₂, in Ar is sometimes used in order to optimize the weld properties.

In all welding methods based on shielding gas, the flow of shielding gas is dependent on the welding situation. A general guideline is that the shielding gas flow in l / min should be set to the same value as the inside diameter of the gas nozzle measured in mm.

Heat input

Heat input (Q) is the amount of energy applied to the base material per length unit. Heat input is calculated according to the formula below:

$$Q = \frac{k \cdot U \cdot I \cdot 60}{v \cdot 1000} \text{ kJ/mm}$$

Q = Heat input (kJ/mm)

k = Arc efficiency (dimension less)

U = Voltage

I = Current

v = Travel speed (mm/min)

Various welding processes have different thermal efficiency. Table 4 describes approximate values for different weld methods.

Table 6: Thermal efficiency of different weld methods

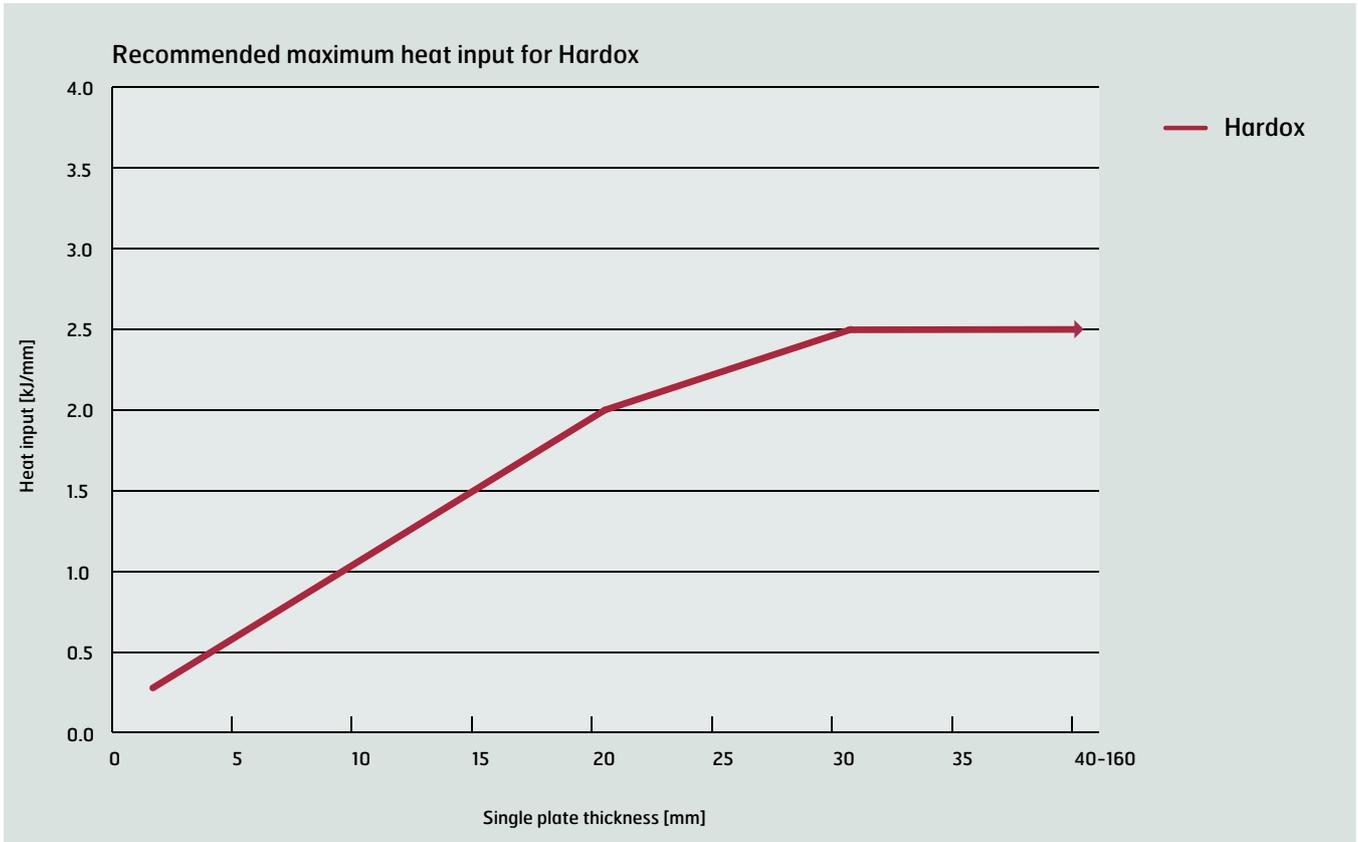
Weld method	Thermal efficiency (k)
MAG	0.8
MMA	0.8
SAW	1.0
TIG	0.6

Excessive heat input increases the width of the Heat Affected Zone (HAZ) which in turn impairs the mechanical properties as well as the wear resistance of the HAZ. Welding with low heat input provides benefits like:

- ▶ Increased wear resistance of the HAZ
- ▶ Decreased deformation (single pass welded joints)
- ▶ Increased toughness of the joint
- ▶ Increased strength of the joint

Very low heat input might however have a negative effect on the impact toughness ($t_{8/5}$ values below 3 seconds). Figure 2 indicates recommended maximum heat input (Q) for Hardox.

Figure 2: Recommended maximum heat inputs for Hardox steels



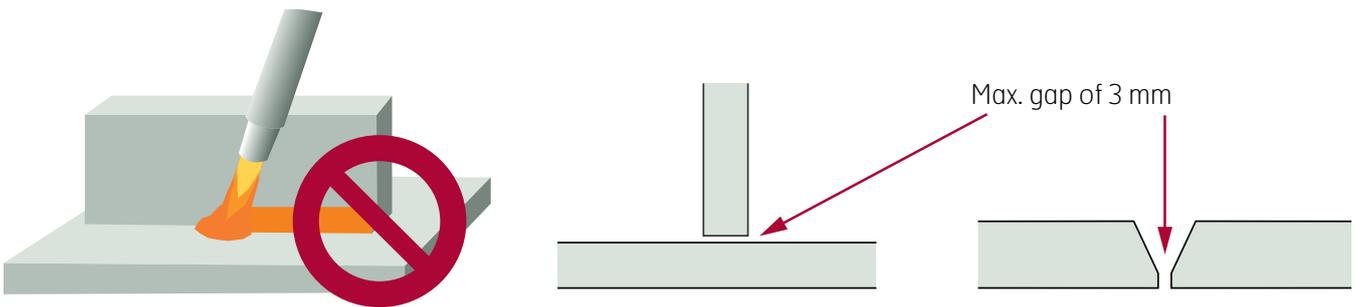
Cooling time $t_{8/5}$

Cooling time ($t_{8/5}$) is the time which takes for the weld to cool from 800 °C to 500 °C and it is the key role to dominate final microstructure in the weld. Recommended cooling times are often supplied for structural steels in order to optimize the weld process for a certain requirement e.g., to fulfill the minimum impact toughness requirement. Recommended maximum cooling times for the different Hardox grades are presented by SSAB software - "WeldCalc".

Welding sequence and root opening size

Before tack welding operation, it is important to maintain root opening between base plates not exceeding 3 mm, see figure 3. It is aimed for as uniform gap size along the joint as possible. In addition, it should avoid weld start and weld stops in highly stressed areas. If possible, the start and stop procedures should be at least 5–10 cm from a corner, see Figure 3. When welding to the edge of plates, sacrificing plates would be beneficial.

Figure 3: Avoid start and stops in highly stressed areas like e.g. corners. Gap size should not exceed 3 mm.



Preheat and interpass temperatures

It is essential to follow recommended minimum preheat temperature as well as the procedure for how to obtain and measure the temperature in and around the joint in order to avoid hydrogen cracking.

INFLUENCE OF ALLOYING ELEMENTS ON THE SELECTIONS OF PREHEAT AND INTERPASS TEMPERATURES

A unique combination of alloying elements optimizes the mechanical properties of Hardox. This combination governs preheat and interpass temperatures of Hardox steel during welding, and can be used to calculate the carbon equivalent. Carbon equivalent is usually expressed as CEV or CET in accordance with the formulas below.

$$CEV = C + \frac{Mn}{6} + \frac{(Mo+Cr+V)}{5} + \frac{(Ni+Cu)}{15} \quad (\%)$$

$$CET = C + \frac{(Mn + Mo)}{10} + \frac{(Cr+Cu)}{20} + \frac{Ni}{40} \quad (\%)$$

The alloying elements are specified in the mill certificate of the plate and are stated in weight percentage in these two formulas. A higher carbon equivalent usually requires a higher preheat and interpass temperatures. Typical carbon equivalent for Hardox are given in SSAB product data sheets.

Hydrogen cracking

Due to relatively low carbon equivalent, Hardox resist hydrogen cracking better than many other wear resistance steels.

THE RISK OF HYDROGEN CRACKING WILL BE MINIMIZED IF THE RECOMMENDATIONS BELOW ARE FOLLOWED:

- ▶ Preheat the weld area to recommended minimum temperature
- ▶ Measure preheat temperature according to SSAB recommendation
- ▶ Use processes and consumables that supplies a maximum hydrogen content of 5ml/100g weld metal
- ▶ Keep the joint clear from impurities, like rust, grease, oil, frost, etc.
- ▶ Use only weld consumables classifications recommended by SSAB
- ▶ Apply a proper welding sequence in order to minimize residual stresses
- ▶ Avoid root opening size exceeding 3 mm, see figure 3

Preheat and interpass temperatures for Hardox

Minimum recommended preheat and maximum interpass temperatures during welding are given in table 7 and 8. Unless otherwise stated, these values are applicable for welding with unalloyed and low-alloyed welding consumables.

- ▶ When plates of different thicknesses, but of same steel grade are welded together, the thicker plate determines the required preheat and interpass temperatures, see figure 4.
- ▶ When different steel types are welded together, the plate requiring the highest preheat temperature determines the required preheat and interpass temperatures.
- ▶ Table 7 is applicable for heat inputs of 1.7 kJ/mm or higher. If heat inputs of 1.0 – 1.69 kJ/mm are used, it is recommended to increase 25°C above the recommended preheat temperature.
- ▶ If lower heat input than 1.0 kJ/mm is applied, it is recommended to use SSAB software “WeldCalc” in order to calculate the recommended minimum preheating temperature.
- ▶ If the ambient humidity is high or the temperature is below +5 °C, the lowest recommended preheat temperatures given in table 7 should be increased by 25 °C.
- ▶ For double V-butt welds in thicknesses above 30 mm it is recommended to move the root run some distance from the centerline of the plate.

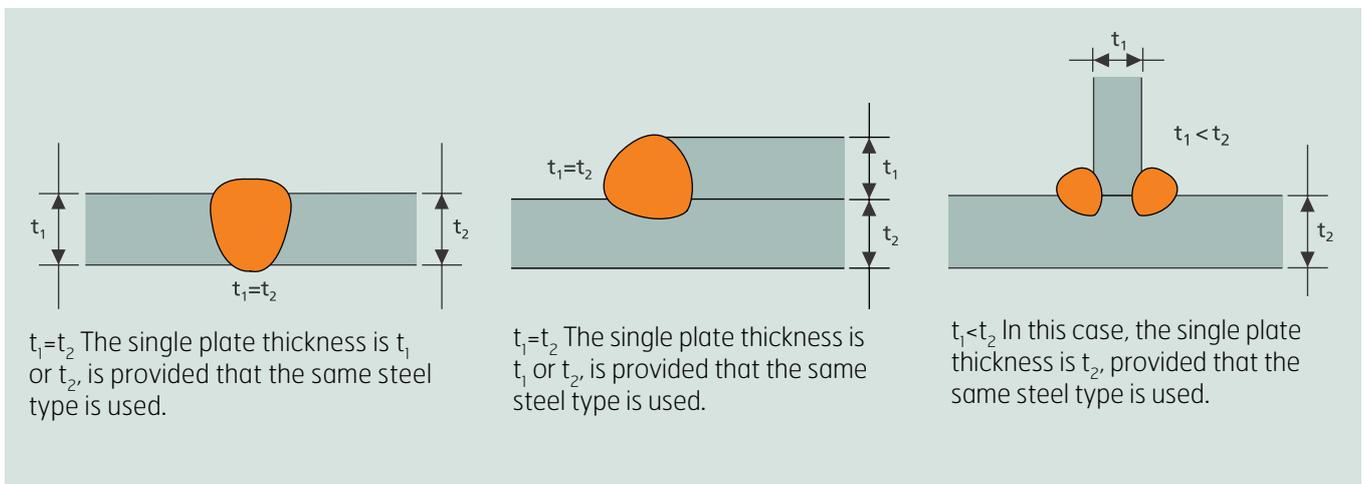
Table 7: Recommended preheating temperatures. The single plate thickness in millimeter is shown on the x-axis.

Minimum recommended preheat and interpass temperatures for different single plate thicknesses (mm)

	0	10	20	30	40	50	60	70	80	90	120	130	160
Hardox HiTuf						100°C					125°C		
Hardox 400				75°C		100°C	175°C				200°C		
Hardox 450				125°C				150°C					
Hardox 500			175°C			200°C							
Hardox 550	125°C		175°C		200°C								
Hardox 600	150°C		175°C										
Hardox 600 Stainless steel consumables				100°C									
Hardox Extreme Stainless steel consumables				100°C									

■ Room temperature (approx. 20°C)
 Outside the size range
 ■ Only stainless steel consumables
 Preheat and interpass temperature at least 100°C

Figure 4: Schematic drawing showing “single plate thickness”



Interpass temperature

Interpass temperature shown in table 8 is the maximum recommended temperature in the joint (on top of the weld metal) or immediately adjacent to the joint (start position) just before start of next weld pass.

Table 8: Maximum recommended interpass temperature/preheating temperature

Hardox HiTuf**	300°C
Hardox 400	225°C
Hardox 450	225°C
Hardox 500	225°C
Hardox 550	225°C
Hardox 600	225°C
Hardox Extreme	100°C

** Interpass temperatures of up to approx. 400°C can be used in certain cases for Hardox HiTuf. In such cases, use WeldCalc.

The minimum recommended preheat and maximum interpass temperatures shown in table 7 and table 8 are not affected at heat inputs higher than 1.7 kJ / mm. The information is based on the assumption that the welded joint is allowed to cool in air. Note that these recommendations also apply to tack welds and root runs. Each of the tack welds should be at least 50 mm long. The distance between tack welds can be varied as required

Attaining and measure the preheat temperature

Required preheat temperature can be achieved in several ways. Electric preheater elements (Figure 5) around the prepared joint are often best, since uniform heating of the area can be obtained. The temperature should be monitored by using, for example, a contact thermometer.

It is recommended to measure the recommended preheating temperature on the opposite side of the heating operation, see Figure 6.

Figure 5: Example of electrical heating mats

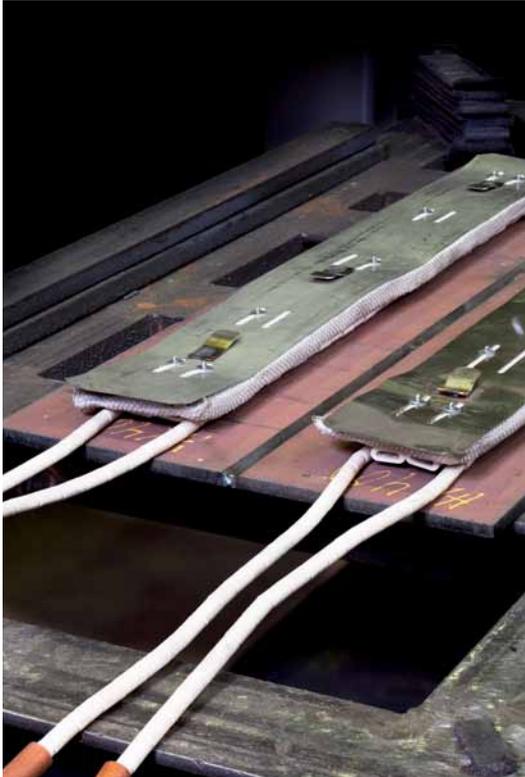
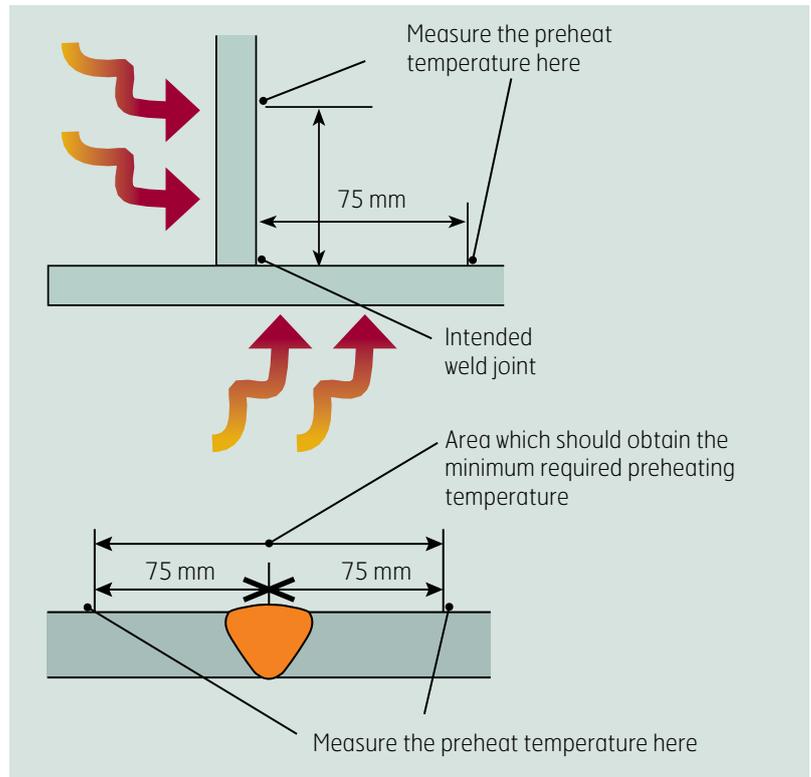


Figure 6: Recommended preheating operation



A waiting time of minimum 2 min/25 mm thickness should be conducted before measuring the preheating temperature. The minimum preheating temperature should be obtained in an area of 75 + 75 mm around the intended weld joint, see Figure 6.

Hard facing

If the weld joint is located in an area with the expectation of high wear, hardfacing with special consumables can be employed in order to increase wear resistance of weld metal. Both the instructions for joining and hardfacing for Hardox should be followed. Some electrodes for hardfacing require very high preheat temperature, it may exceed maximum recommended interpass temperature for Hardox steel. It is worth noted that using preheat temperature above the maximum recommended Interpass temperature for Hardox steel may reduce the hardness of the base plate and result into detariation of wear resistance of the preheated area.

Minimum and maximum preheat temperatures are the same as for conventional types of welding, see table 5. The definition of single plate thickness for hard surfacing situations is according to figure 7

Figure 7: Definition of single plate thickness

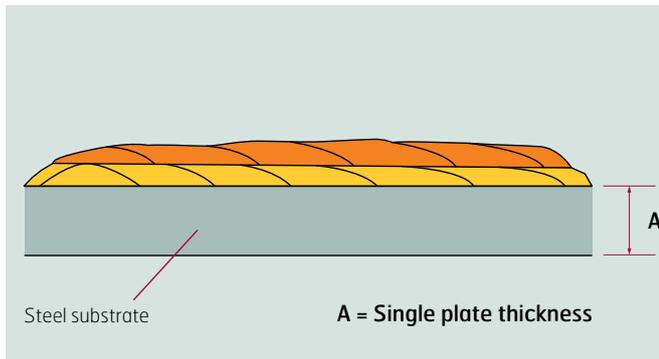
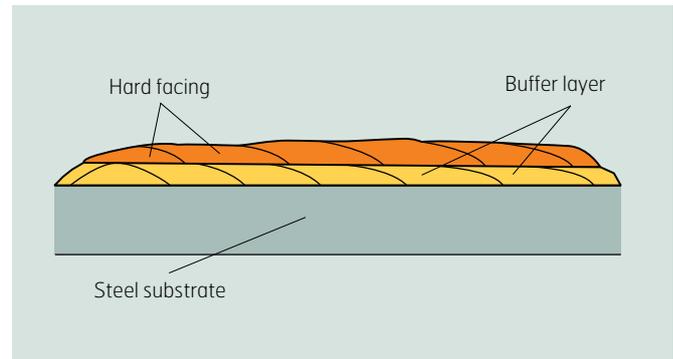


Figure 8: Example of welding sequence using electrodes for buffer layer and hard facing



It is beneficial to weld a buffer layer with extra high toughness between the ordinary welded joint or plate and the hard facing. The choice of consumables for the buffer layer should follow the welding recommendations for Hardox steels. Stainless steel consumables in accordance with AWS 307 and AWS 309 should preferably be used for the buffer layer, see Figure 8.

Recommendations in order to minimize distortion

The amount of distortion during/after welding is related to the base plate thickness and welding procedure. Distortion becomes more obvious in thinner gauges while heavy deformation or even burn thru can cause problem and compromise the whole structure.

IN ORDER TO MINIMIZE THE AMOUNT OF DISTORTION DURING WELDING, THE FOLLOWING RECOMMENDATIONS COULD BE APPLIED:

- ▶ Weld with heat input as low as possible (single pass welded joints)
- ▶ Minimize the cross sectional area, see figure 9
- ▶ Prebend, clamp or angle the parts before welding in order to compensate for the deformation, see figure 10
- ▶ Avoid irregular root opening
- ▶ Use symmetrical welds, see figure 9
- ▶ Minimize reinforcements and optimize the throat thickness of the fillet welds
- ▶ Weld from rigid areas to loose ends
- ▶ Decrease spacing between the tack welds
- ▶ Use back step welding technique, see figure 11-12

Figure 9: Cross section of the weld and how it influences the angle deviation

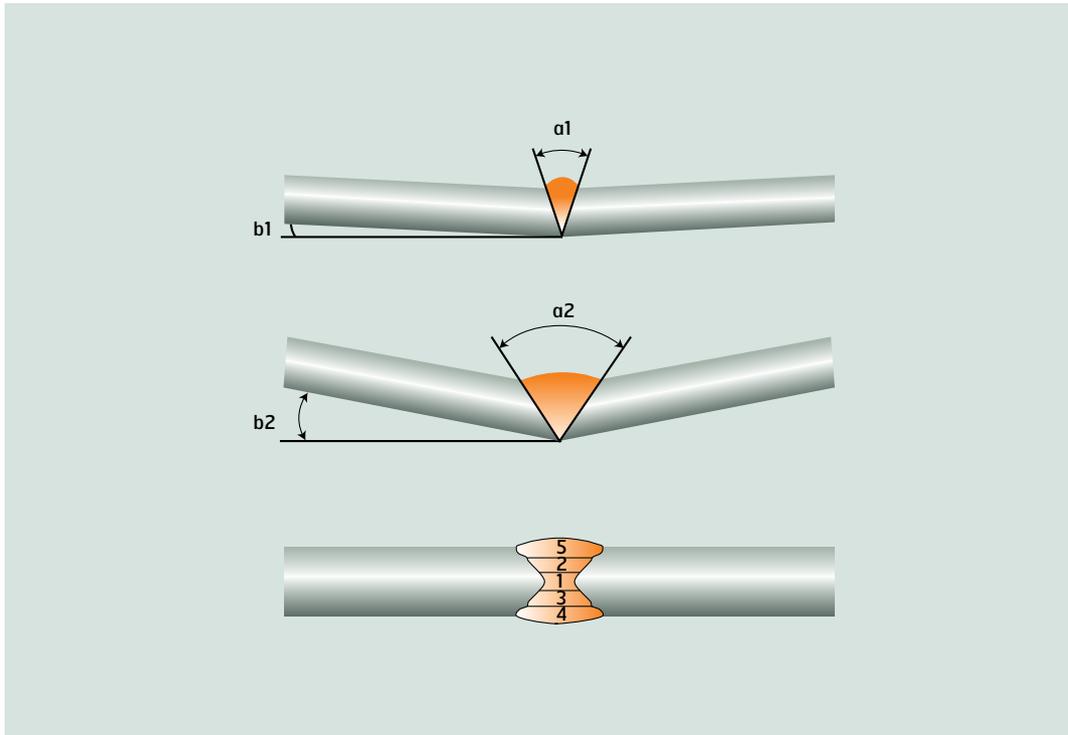


Figure 10: Presetting of a fillet joint and a single-V butt joint.

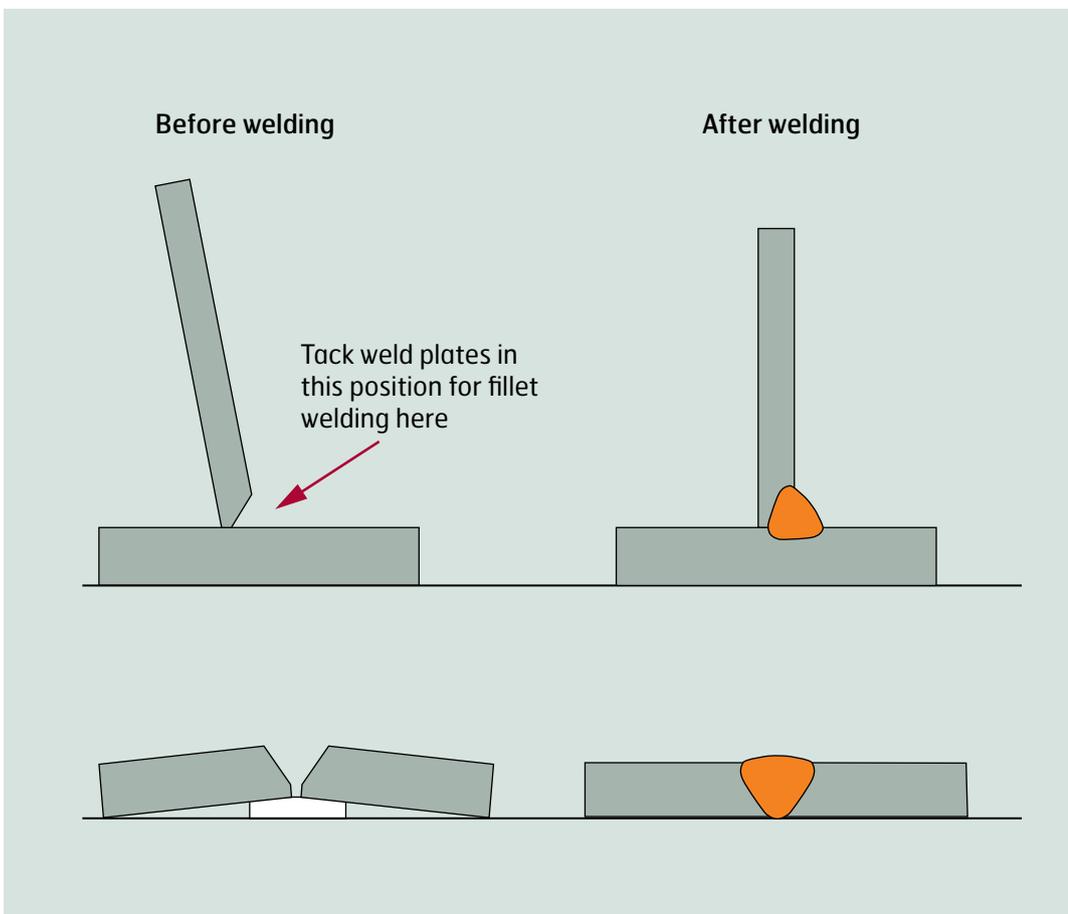


Figure 11: Use a symmetrical weld sequence

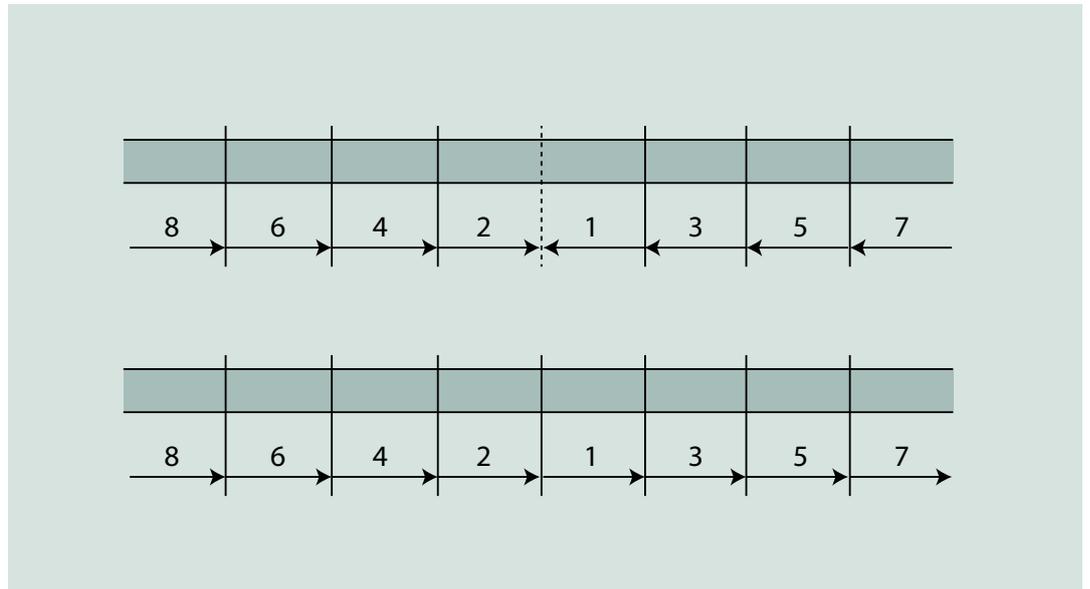
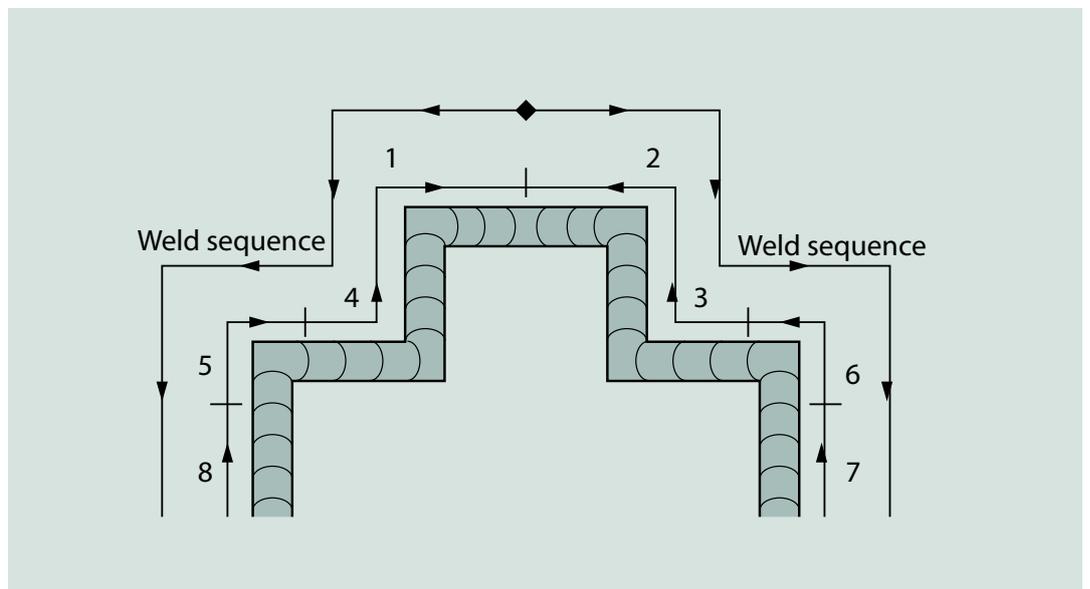


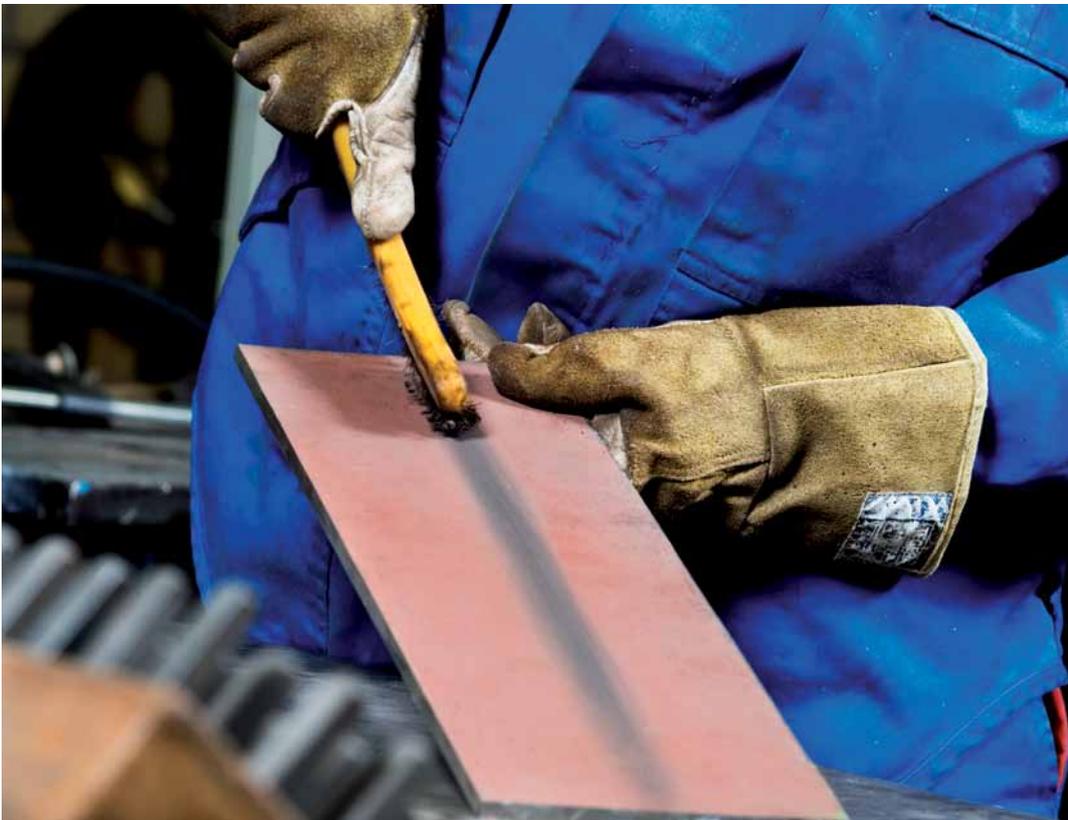
Figure 12: Example of back step welding technique



Welding on Hardox primer

Welding can be carried out directly on Hardox primer due to its low zinc content. The primer can be easily brushed or ground away in the area around the joint, see Figure 13. Removing primer prior to welding can be beneficial, as it can minimize the porosity in weld, and can facilitate out-of-position welding. If primer is remained on weld surface, sub-surface and surface porosity of the weld may be slightly increased. FCAW with basic flux offer the lowest porosity. It is important that good ventilation must be maintained in all welding processes, then primer would not have a harmful effect on welder and surroundings. For further information, download the file of "TechSupport #25" from www.ssab.com website.

Figure 13: The primer is easy to brush away if necessary



Post weld heat treatment

Hardox HiTuf can be stress relieved by post weld heat treatment, although this is seldom necessary. Other Hardox steels should not use this method for stress relieving, since this may impair the mechanical properties. For further information, see the Welding Handbook from SSAB. This can be ordered at www.ssab.com.

SSAB is a global leader in value added, high strength steel. SSAB offers products developed in close cooperation with its customers to create a stronger, lighter and more sustainable world.

SSAB has employees in over 45 countries and operates production facilities in Sweden and the US. SSAB is listed on the NASDAQ OMX Nordic Exchange, Stockholm. www.ssab.com

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