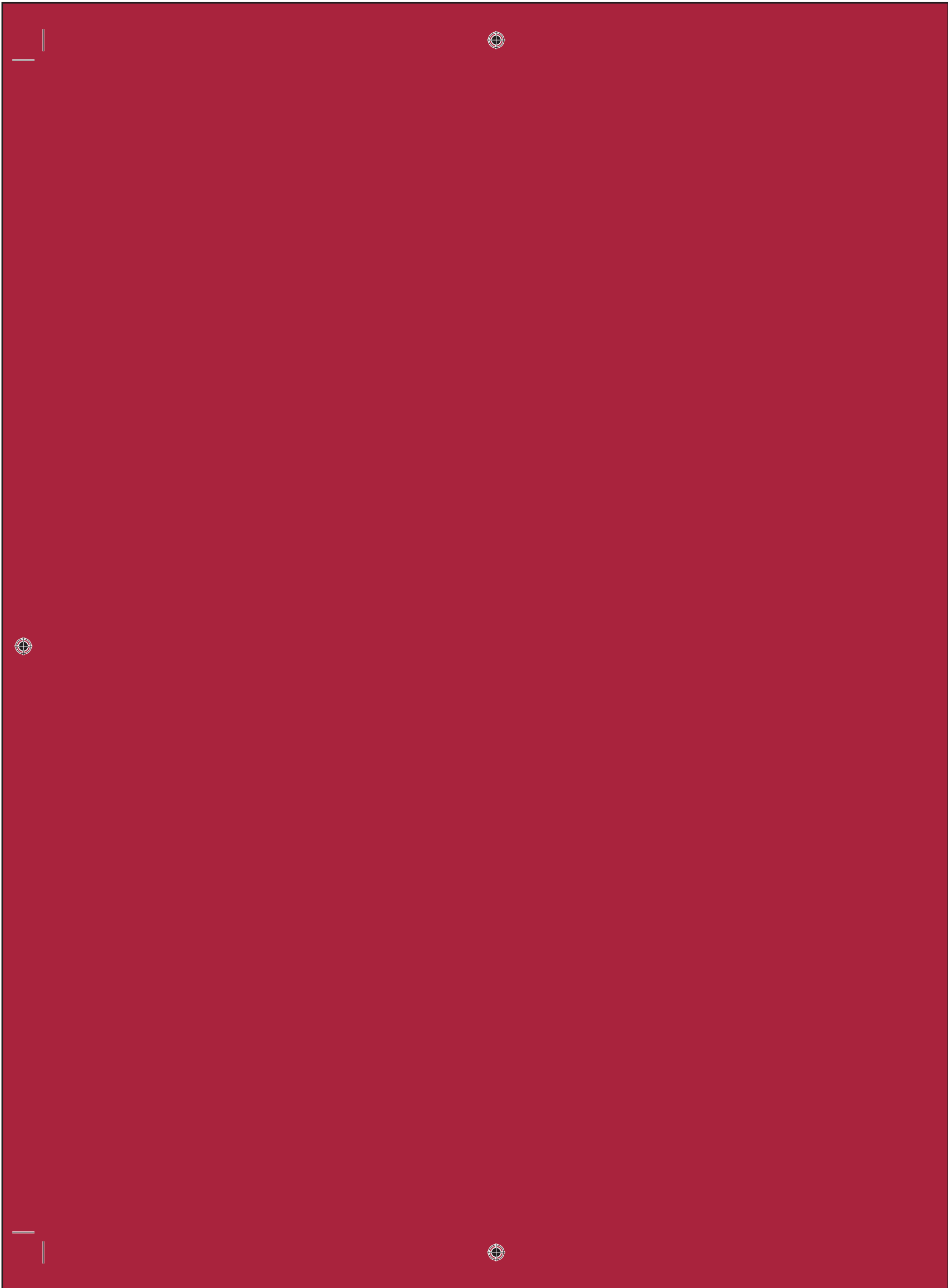


Welding



WELDOX[®]
STRUCTURAL STEEL PLATE

HARDOX[®]
WEAR PLATE



A photograph of a middle-aged man, likely a welder, smiling broadly. He is wearing a blue and red work jacket over a white t-shirt with the letters 'DI' visible. He is also wearing a black welding helmet with a clear visor, safety glasses, and brown leather work gloves. The background shows a workshop environment with large windows and industrial equipment.

Welding of WELDOX® and HARDOX®

The extreme performance of WELDOX structural steel plate and HARDOX wear plate is combined with exceptional weldability. Any conventional welding method can be used for welding these steels to any type of weldable steel.

This brochure is aimed at simplifying, improving and boosting the efficiency of the welding process. It offers good advice on preheat and interpass temperatures, heat input, welding consumables, shielding gas and a great deal more. The aim is to enable every user to gain full benefit of the unique properties of WELDOX and HARDOX.



Important parameters in welding

Clean the joint to remove foreign matter such as moisture and oil residue before welding. In addition to good welding hygiene, the following items are important:

- Preheat and interpass temperature
- Heat input
- Welding consumables
- Shielding gas
- Weld sequence and gap size in the joint

Preheat and interpass temperatures

The right preheat and interpass temperature is important in order to avoid hydrogen cracking. Our recommendations are given in the table on the next page.

Influence of alloying elements on the choice of preheat and interpass temperatures

A unique combination of alloying elements optimizes the mechanical properties of WELDOX and HARDOX. This combination governs the preheat and interpass temperature of the steel during welding, and can be used to calculate the carbon equivalent value. The carbon equivalent value is usually expressed as CEV or CET in accordance with the equations below.

The alloying elements are specified in the inspection certificate of the plate and are stated in percent by weight in these formulas. A higher carbon equivalent usually requires a higher preheat and interpass temperature. Typical values of carbon equivalents are given in our product data sheets.

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

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

Hydrogen cracking

Due to their low carbon equivalents, WELDOX and HARDOX are better able to resist hydrogen cracking than many other high strength steels. The risk of hydrogen cracking will be minimized if our recommendations are followed.

Two rules for avoiding hydrogen cracking:

- **Minimize the hydrogen content in and around the prepared joint**
 - Use the right preheat and interpass temperature
 - Use welding consumables with a low hydrogen content
 - Keep impurities out of the weld area
- **Minimize the stresses in the weld joint**
 - Do not use welding consumables of a higher strength than is necessary
 - Arrange the weld sequence so that the residual stresses are minimized
 - Set the gap in the joint to a maximum of 1/8"

The contents of this brochure represent general suggestions. SSAB Oxelösund AB accepts no responsibility for their suitability in individual cases. The user is therefore responsible to make the necessary adaptations to the conditions in each individual case.



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Preheat and interpass temperatures for WELDOX and HARDOX

The lowest preheat and interpass temperature during welding is shown in the chart below. Unless otherwise stated, these values are applicable for welding with unalloyed and low alloyed welding consumables.

- When plates of different thicknesses, but of the same steel grade are welded together, the thickest plate determines the required preheat and interpass temperature.
- When different steel types are welded together, the plate requiring the highest preheat temperature determines the required preheat and interpass temperature.

Note: The table is applicable to single plate thickness when welding with a heat input of 43 kJ/inch. Further information on single plate thickness can be found in TechSupport #61 at www.ssabox.com.

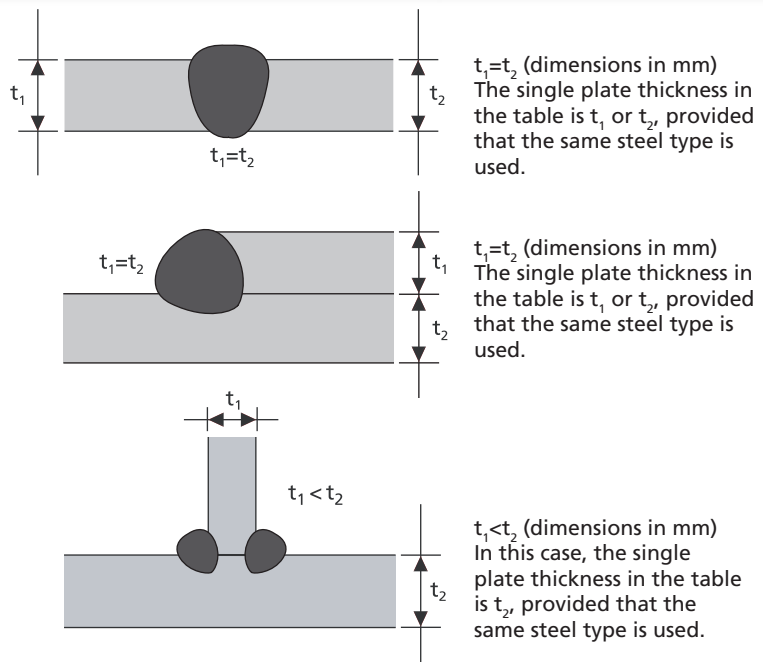
Minimum recommended preheat and interpass temperatures for different single plate thicknesses (inch)

	1/8	3/8	3/4	1 1/4	1 5/8	2	2 3/8	2 3/4	3 1/8	3 1/2	4 3/4	5 1/8
WELDOX 700	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	175°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F
WELDOX 900*	Room temperature (approx. 70°F)	175°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F
WELDOX 960*	175°F	175°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F
WELDOX 1030*	175°F	175°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F
WELDOX 1100*	Room temperature (approx. 70°F)	175°F	275°F	275°F	275°F	275°F	275°F	275°F	275°F	275°F	275°F	275°F
WELDOX 1300*	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F
HARDOX HiTuf	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	225°F	275°F	275°F	275°F	275°F	275°F	275°F
HARDOX 400	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	175°F	175°F	225°F	225°F	350°F	350°F	350°F	350°F	400°F	400°F
HARDOX 450	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	275°F	275°F	275°F	300°F	300°F	300°F	300°F	300°F	300°F	300°F
HARDOX 500	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	350°F	350°F	350°F	400°F	400°F	400°F	400°F	400°F	400°F	400°F
HARDOX 550	275°F	275°F	350°F	350°F	400°F	400°F	400°F	400°F	400°F	400°F	400°F	400°F
HARDOX 600	300°F	300°F	350°F	350°F	400°F	400°F	400°F	400°F	400°F	400°F	400°F	400°F
HARDOX 600 Stainless steel consumables	Room temperature (approx. 70°F)	Room temperature (approx. 70°F)	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F	225°F

■ Room temperature (approx. 70°F)
 ■ Outside the size range
 ■ Only stainless steel consumables
 Preheat and interpass temperature at least 225°F

Maximum recommended interpass temperature

WELDOX 700**	600°F
WELDOX 900**	600°F
WELDOX 960**	600°F
WELDOX 1030	400°F
WELDOX 1100	400°F
WELDOX 1300	400°F
HARDOX HiTuf**	600°F
HARDOX 400	450°F
HARDOX 450	450°F
HARDOX 500	450°F
HARDOX 550	450°F
HARDOX 600	450°F



* The consumable determines the preheating temperature if its carbon equivalent is higher than that of the plate.

** Interpass temperatures of up to approx. 750°F can be used in certain cases for WELDOX 700-960 and for HARDOX HiTuf. In such cases, use WeldCalc.

If the ambient humidity is high or the temperature is below 40°F, the lowest recommended preheat temperatures given on the previous page should be increased by 80°F. This also applies to firmly clamped weld joints and if the heat input is 25 kJ/inch.

The lowest recommended preheat and interpass temperatures in the chart on the previous page are not affected at heat inputs higher than 43 kJ/inch.

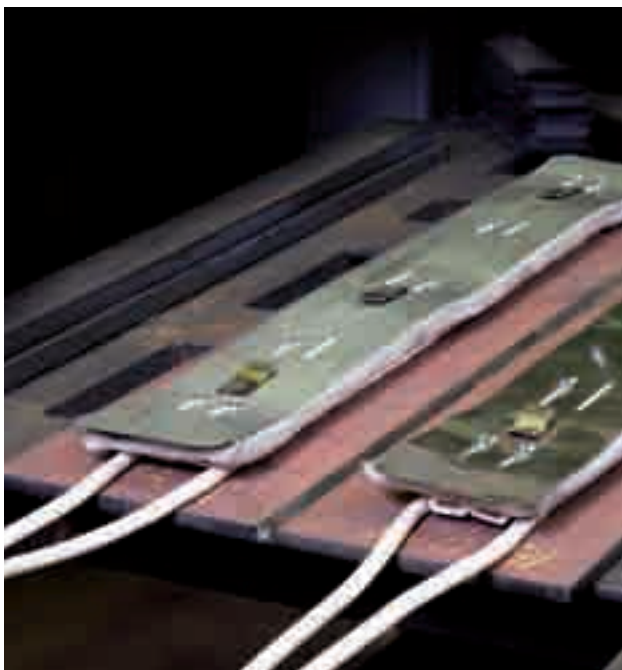
The information is based on the assumption that the welded joint is allowed to cool in air.

Note that these recommendations also apply to tack welds and root runs. Each of the tack welds should be at least 2" long. The distance between tack welds can be varied as required.

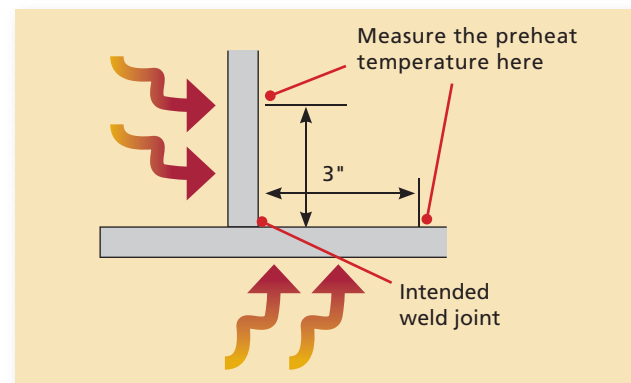
Attaining and measuring the preheat and interpass temperature

The required preheat and interpass temperature can be achieved in several ways. Electric preheater elements around the prepared joint are often best, since they

provide uniform heating of the area. The temperature should be monitored by using, for example, a contact thermometer.



Using preheater elements



Measure the temperature of the thickest plate in the joint. If the plate is 1" thick, measure the temperature 2 minutes after heating. If the plate is 1/2" thick, measure the temperature after 1 minute, etc. The interpass temperature can be measured in the weld metal or in the immediately adjacent parent metal.

Heat input

Welding with the recommended heat input results in good mechanical properties in the heat affected zone (HAZ).

The heat supplied by the welding process affects the mechanical properties of the welded joint. This is described by the heat input (Q) that can be calculated using the formula below.

$$Q = \frac{k \times U \times I \times 60}{v \times 1000}$$

Q = Heat input [kJ/inch]

U = Voltage [V]

I = Current [A]

v = Welding speed [inch/min]

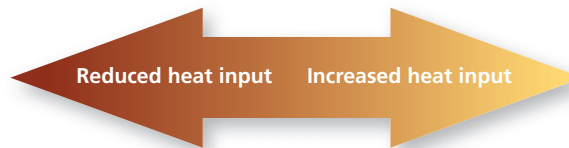
k = Thermal efficiency

Different methods of welding have varying thermal efficiency (k). See the table below for approximate values of this property.

Thermal efficiency	k
SMAW	0.8
All types of GMAW and FCAW	0.8
SAW	1.0
GTAW	0.6

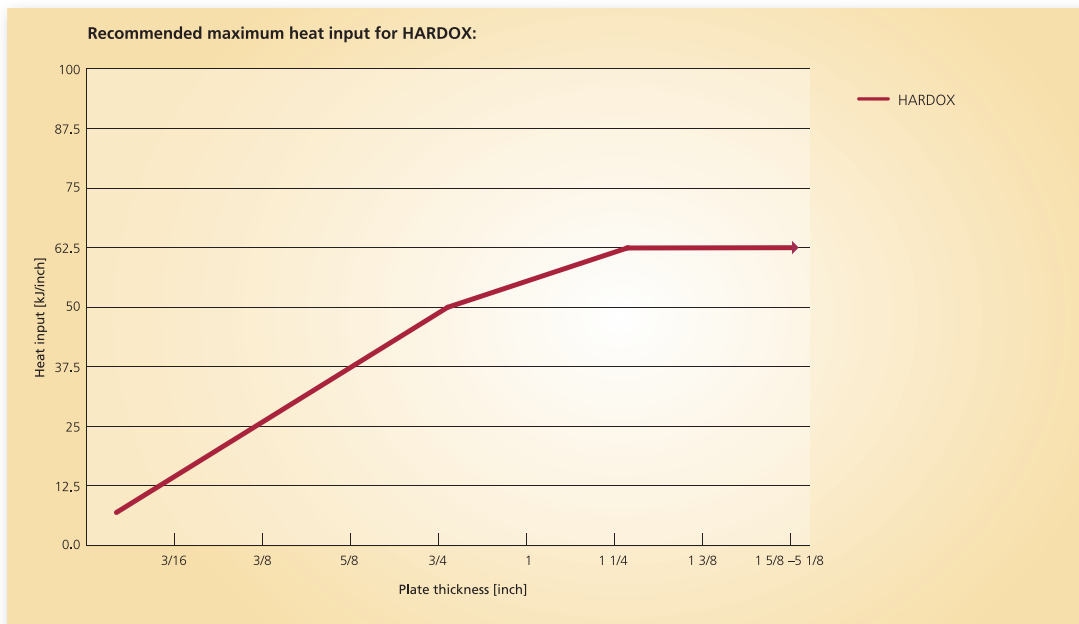
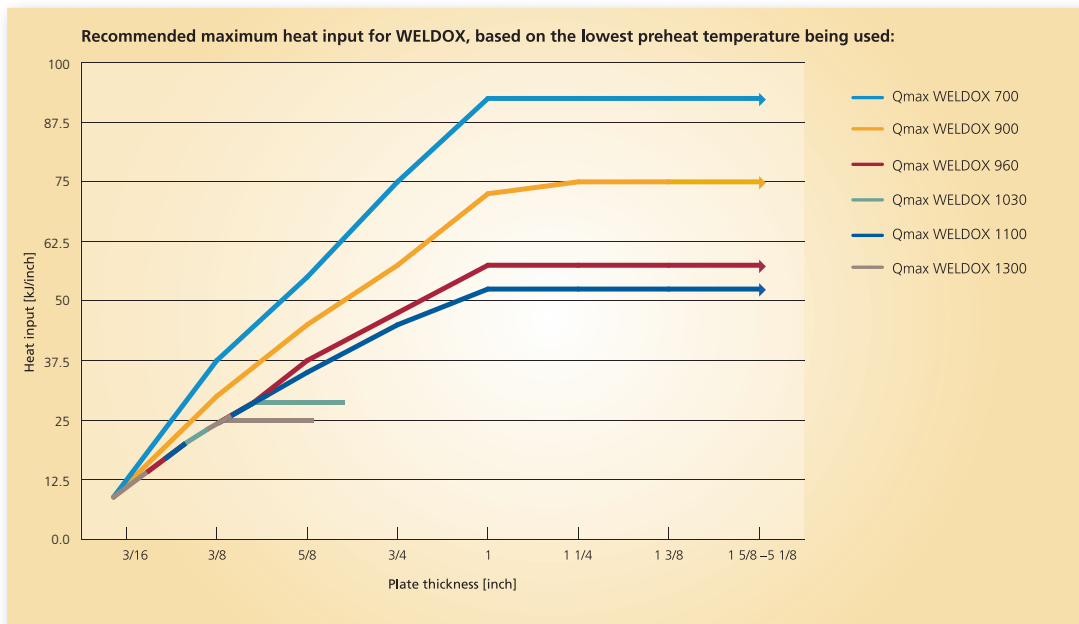
Effects of heat input on a weld joint

- Better toughness
- Increased strength
- Reduced deformation
- Lower residual stresses
- Narrower HAZ



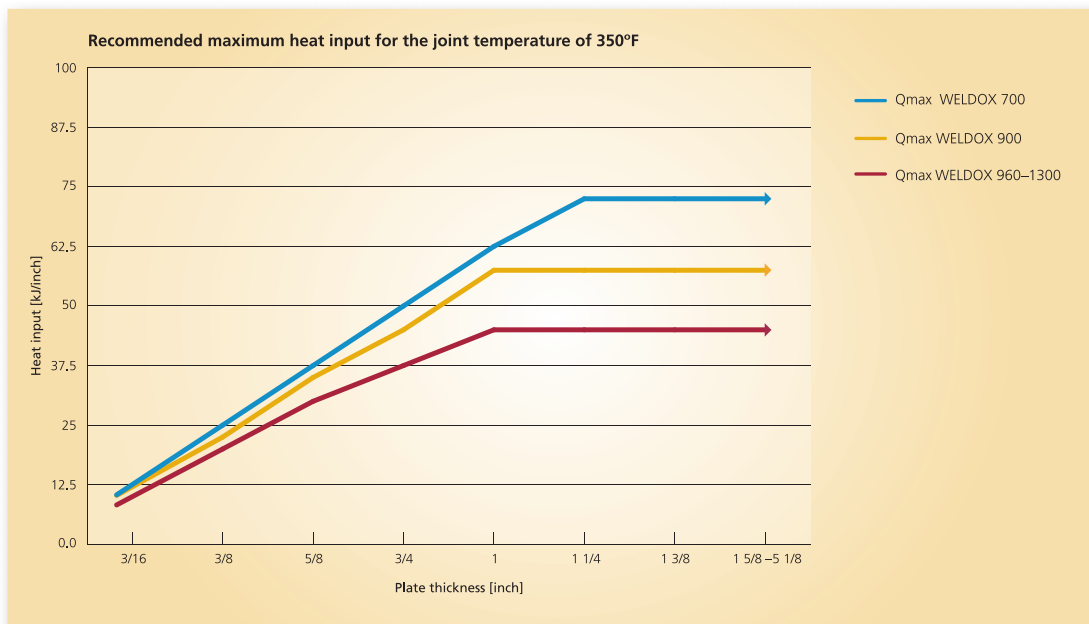
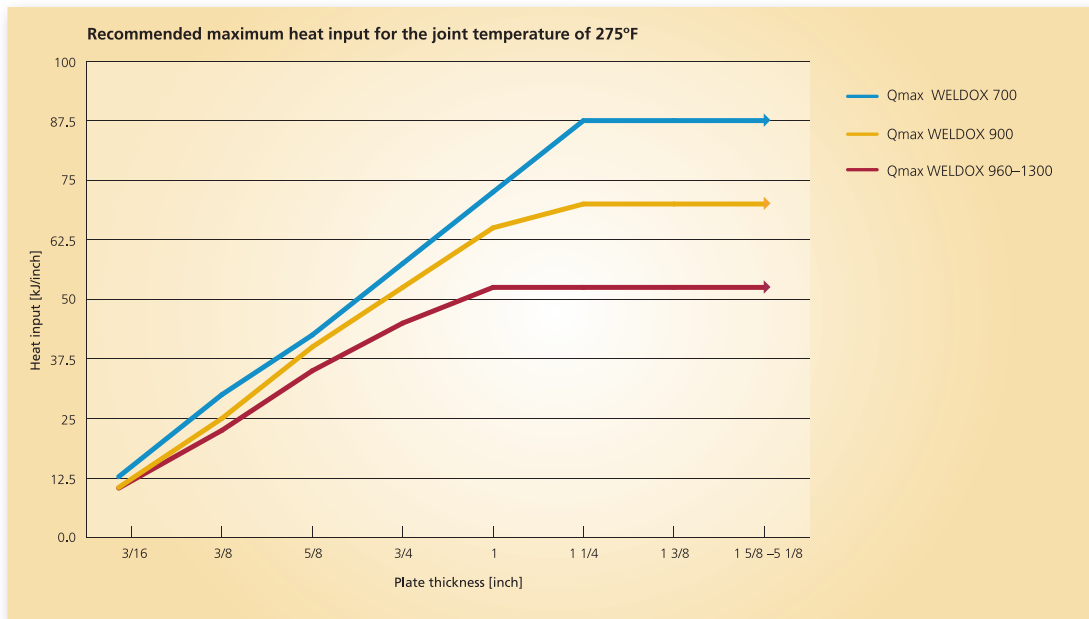
- Higher productivity for conventional welding methods

Our recommendations for WELDOX structural steels are based on typical values for toughness in the HAZ being at least 20 Ft Lbs at -40°F. The demands on toughness in the weld joints in HARDOX wear plate are often lower. The recommendations for HARDOX should therefore be regarded as approximate values.



Welding at higher elevated temperatures

Higher elevated temperatures that may occur, for instance in multipass weld joints, affect the recommended heat input. The figure below shows the recommended heat inputs for joint temperatures of 275°F and 350°F.



The WeldCalc computer program can be used for preheat and interpass temperatures above 350°F. WeldCalc has been developed at SSAB Oxelösund by our world leading experts on the welding of heavy plate. The program can be ordered free of charge at www.ssabox.com.

Welding consumables



Unalloyed, low alloyed and stainless steel consumables can be used for the welding of WELDOX and HARDOX.

Strengths of unalloyed and low alloyed welding consumables

The strength of the welding consumables should be selected in accordance with the figure on the next page. Using low-strength consumables can offer several benefits, such as higher toughness of the weld metal, higher resistance to hydrogen cracking and lower residual stresses in the weld joint. In multipass joints in WELDOX 700 – 1300, it is particularly beneficial to weld with consumables of different strengths. Tack welds and the first passes are welded with low strength consumables and then high strength consumables are

used for the remainder of the passes. This technique can increase both the toughness and the resistance to hydrogen cracking. The carbon equivalent value of consumables with a yield strength >100 ksi (700 MPa) may be higher than that of the plates. When there are different recommended preheat temperatures for the joint materials and the consumables, then the highest value should be used. HARDOX should be welded with low strength consumables as shown in the figure on the following page.

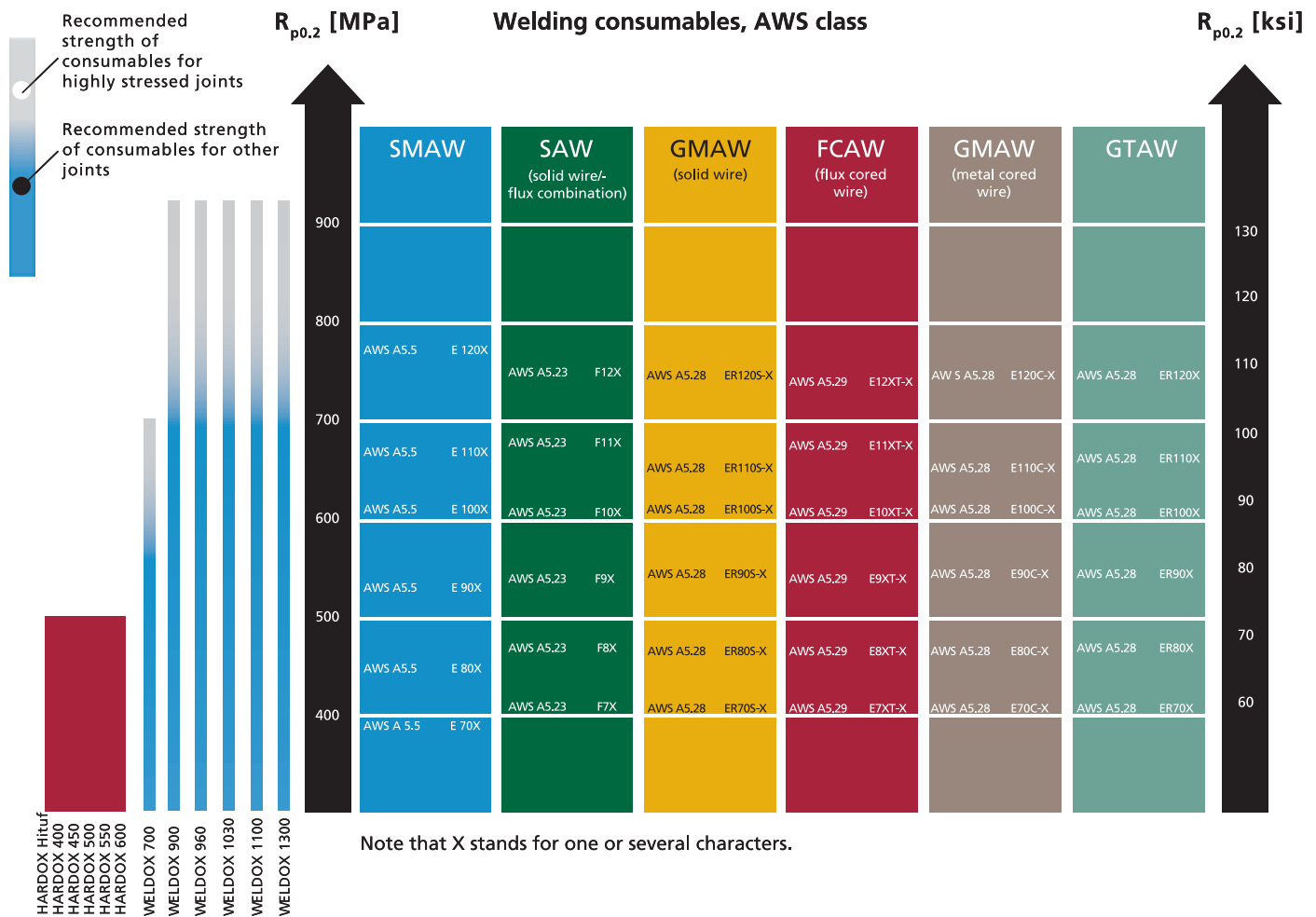
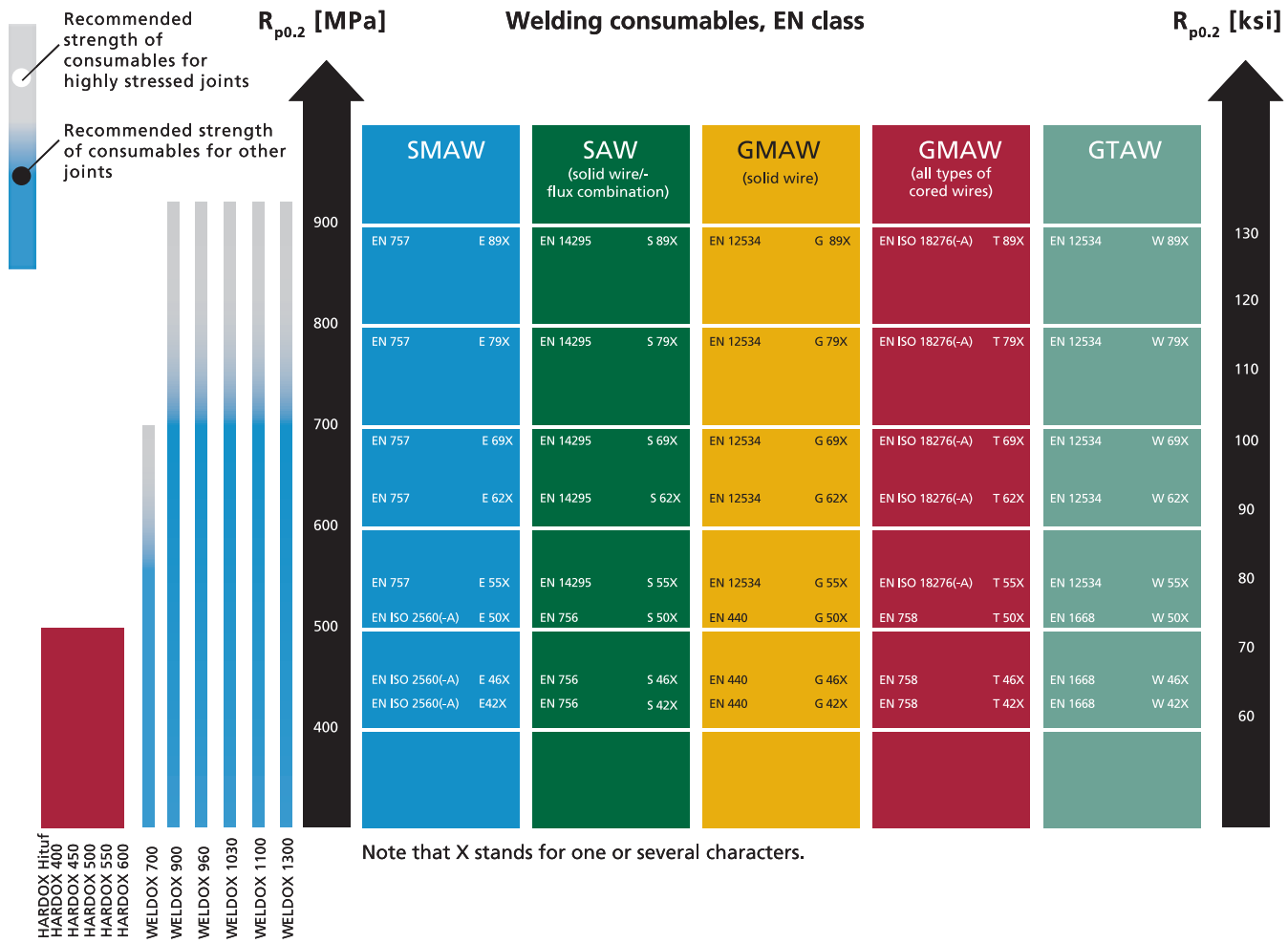


-  welding consumables with higher strength
-  welding consumables with lower strength

Hydrogen content of unalloyed and low alloyed 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 wires used in GMAW and GTAW welding can produce these low hydrogen contents in the weld metal. The hydrogen content for other types of welding consumables can best be obtained from the respective manufacturer.

Examples of consumables are given at www.ssabox.com in the publication TechSupport #60. If consumables are stored in accordance with the manufacturer's recommendations, the hydrogen content will be maintained at the intended level. This applies, above all, to coated consumables and fluxes.



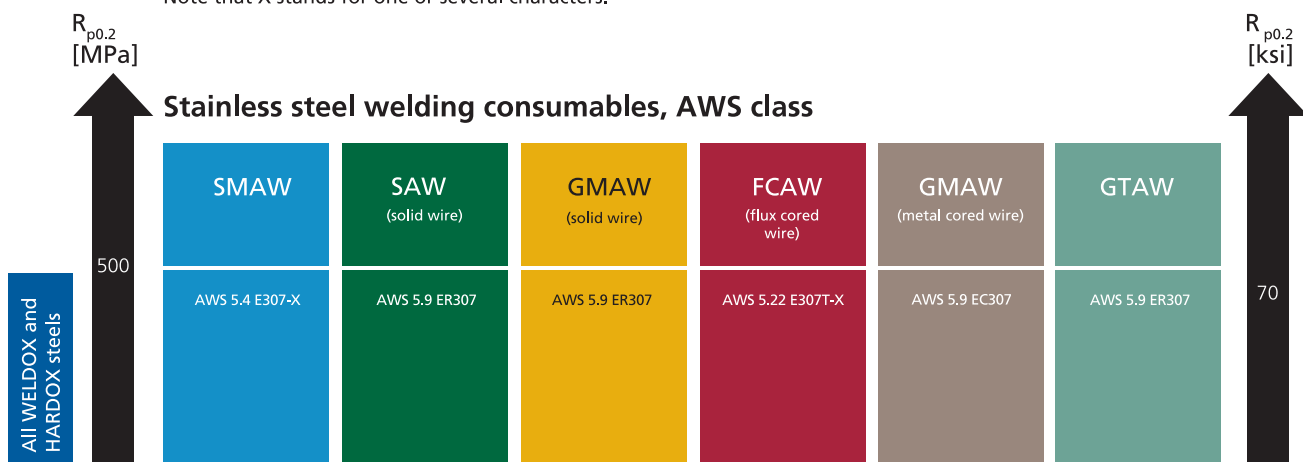
Stainless steel welding consumables

Consumables of austenitic stainless steels can be used for the welding of all our products. They allow welding at room temperature (70°F) without preheating, excluding HARDOX 600, as shown in the chart. We recommend giving first preference to consumables in accordance with AWS 307 and second preference to those in accordance with AWS 309. 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. Suggestions for various stainless steel consumables are given at www.ssabox.com in the publication TechSupport #60.



Note that X stands for one or several characters.



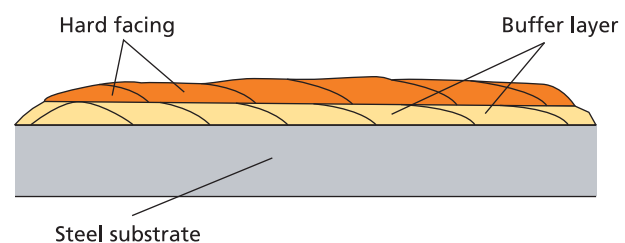
Note that X stands for one or several characters.

Hard facing

Hard facing with special consumables increases the wear resistance of welded joints. Both the instructions for the consumables used and the ordinary recommendations for WELDOX and HARDOX should be followed.

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

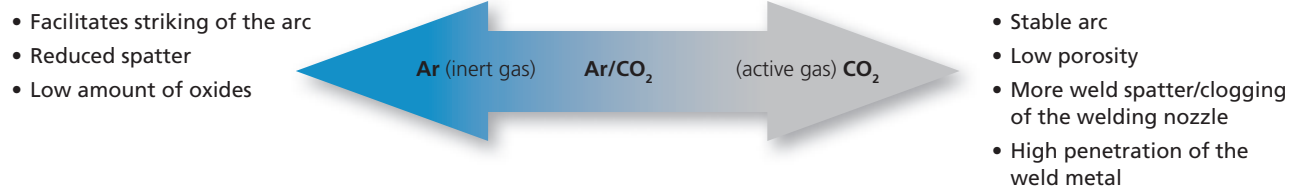
for WELDOX and HARDOX steels. Stainless steel consumables in accordance with AWS 307 and AWS 309 should preferably be used for the buffer layer.



Shielding gas

The choice and mixture of shielding gases is dependent on the welding situation and AR and CO₂ are the most commonly used.

Effects of various shielding gas mixtures



Examples of shielding gas mixtures are given below.

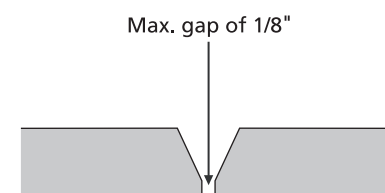
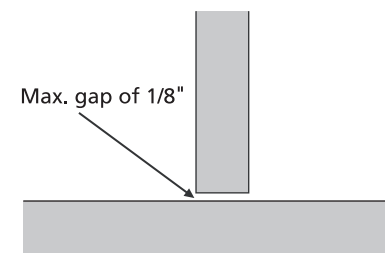
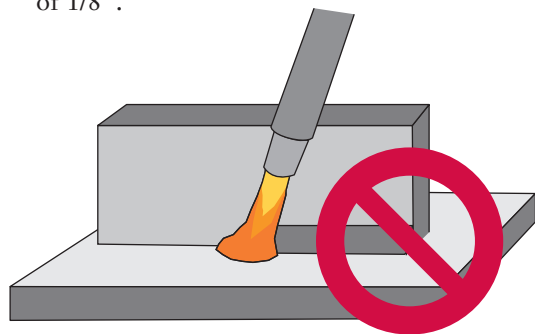
Welding method	Arc type	Shielding gas (weight %)
GMAW, solid wire GMAW, metal cored wire	Short arc	Ar + 15-25 % CO ₂
GMAW, solid wire GMAW, metal cored wire	Spray arc	Ar + 8-25 % CO ₂
FCAW	Short arc	Ar + 15-25 % CO ₂ , or pure CO ₂
FCAW	Spray arc	Ar + 8-25 % CO ₂
All types of GMAW and FCAW	All arc types	Ar + 15-25 CO ₂
GTAW		Pure Ar

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 nozzle measured in mm.

Weld sequences and gap size

To avoid hydrogen cracks in the welded joint:

- The starting and stopping sequences should not be located in a corner. If possible, the starting and stopping procedures should be at least 2 – 4 inches from a corner.
- The gap in the weld joint should be a maximum of 1/8".



Welding on the WELDOX and HARDOX primer



Welding can be carried out directly on the excellent WELDOX and HARDOX primer, due to its low zinc content.

The primer can easily be brushed or ground away in the area around the joint. Removing the primer prior to welding can be beneficial, as it can minimize the porosity in the weld and can facilitate welding in positions other than the horizontal.

If the primer is left on the weld preparation, the porosity of the weld metal will be slightly increased. The GMAW welding process with flux cored wire and the SMAW welding process offer the lowest porosity.

As in all welding operations good ventilation must be maintained, then the primer will not have a harmful effect on the welder and his surroundings.

For further information, download TechSupport #25 from www.ssabox.com.

For best possible results, the primer can be removed.

Post weld heat treatment

HARDOX HiTuf and WELDOX 700-960 can be stress relieved by post weld heat treatment, although this is seldom necessary. Other WELDOX and 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 Oxelösund. This can be ordered at www.ssabox.com.



SSAB Oxelösund – a subsidiary of SSAB Swedish Steel Group – is the world's leading manufacturer of quenched and tempered heavy plate, marketed under the well known brand names of HARDOX® Wear Plate, WELDOX® Structural Steel Plate, ARMOX® Protection Plate and TOOLOX® Prehardened Tool & Machine Steel. The steels are characterized by the combination of high strength and toughness, derived from the clean steel composition and a unique production process.

SSAB Oxelösund focuses exclusively on developing quenched and tempered steels. With a strong local presence in more than 45 countries we provide our customers with high quality steel as well as commercial and technical support.

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