STRENX™
PERFORMANCE STEEL

WELDING OF STRENX

SSAB

WELDING OF STRENX

The extreme performance of Strenx™ high strength steel is combined with exceptional weldability. Any conventional welding method can be used for welding Strenx to other types of weldable steels.

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

In the brochure references are made to:

- Our TechSupports documents which give further information regarding a certain topic. Each TechSupport addresses a given area such as measures for avoidance of discontinuities and examples of suitable brand names for consumables.

- Our software WeldCalc™ allows users to optimize their welding performance based on the specific conditions and requirements of their welded structure.

TechSupports can be found and downloaded on our home page www.ssab.com/download-center. A user licence for WeldCalc™ can be obtained through registration on the same home page. Both TechSupports and a user licence for WeldCalc™ are free of charge.

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 is important:

- Preheat and interpass temperatures in order to avoid hydrogen cracking
- Heat input
- Welding consumables
- Shielding gas
- Weld sequence and gap size in the joint

METHODS FOR JOINT PREPARATION

All conventional methods for joint preparation can be used with these steels. The most common methods are machining and thermal cutting. Preparation of plate thicknesses up to approximately 10 mm can also be made with shearing and punching.

For plate thicknesses up to approximately 4 mm the requirements on the edges are not very strict for conventional arc welding. For lap joints and fillet joints of all plate thicknesses the demands on the edges are often moderate. Milling and thermal cutting (gas, plasma or laser cutting) are the most common methods used for joint preparation. Joint preparation in Strenx is as easy to perform as in mild steels.

During thermal cutting a thin oxide film may form on the joint surface. It is recommended to remove this film before welding. If plasma cutting is used for joint preparation, it is recommended that oxygen is used as the plasma gas. Nitrogen may cause porosity in the weld metal. If nitrogen is used, grinding the cut surfaces by a minimum approximate value of 0.2 mm before welding is recommended. For thin plates ordinary shearing can be used as joint preparation.

HEAT INPUT

Welding with the recommended heat input results in good mechanical properties in the joint.

The heat input (Q) from welding depends of the current, voltage and travel speed. Q describes the delivered energy/length of the joint. Its value affects the mechanical properties of the welded joint. During welding there is a loss of energy in the arc. The thermal efficiency factor (k) is the ratio of heat input transferred to the joint. Different methods of welding have varying thermal efficiency. See the table below for approximate values of k.

The heat input can be calculated using the formula below

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

Q= Heat input [kJ/mm]
U= Voltage [V]
I= Current [A]
v= Welding speed [mm/min]
k= Thermal efficiency [dimensionless]

Thermal efficiency	k [dimensionless]
MMA	0.8
MAG, all types	0.8
SAW	1.0
TIG	0.6

General effects of heat input on a welded joint

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

- Higher productivity for conventional welding methods

AVOIDING HYDROGEN CRACKING

Due to low carbon equivalents, Strenx has very high resistance to hydrogen cracking. The risk of hydrogen cracking will be minimized if our recommendations are followed.

Two rules for avoiding hydrogen cracking:

1. 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

2. Minimize the stresses in the welded joint

- Do not use welding consumables of a higher strength than necessary
- Arrange the weld sequence so that the residual stresses are minimized
- Set the gap within the joint to a maximum of 3 mm

MINIMUM PREHEAT AND INTERPASS TEMPERATURES

All Strenx grades can be welded without risk of formation of hydrogen cracks if our recommendations are followed. When no preheating is recommended it is under the condition that the ambient air and joint temperature is at least +5°C. If the air temperature is below +5°C preheating of the joint to min. +60°C is requested.

Multi pass joints have the same preheating requirements as the first weld pass.

Strenx MC, Plus and CR grades

Minimum preheat/interpass temperatures are not required at any plate thickness.

Strenx 700 to Strenx 1300

These grades are available with larger plate thicknesses than MC, Plus and CR grades. Their strength levels in combination with larger plate thicknesses means that preheating is necessary for certain plate thicknesses and steel grades.

Our recommendations are illustrated on page 8.

How alloying elements influence preheat and interpass temperatures

A unique combination of alloying elements optimizes the mechanical properties of Strenx.

The combination governs the minimum preheat temperature of the steel during welding, and can be used to calculate its carbon equivalent value.

The carbon equivalent value is usually expressed as CEV or CET in accordance with the equations below.

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

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

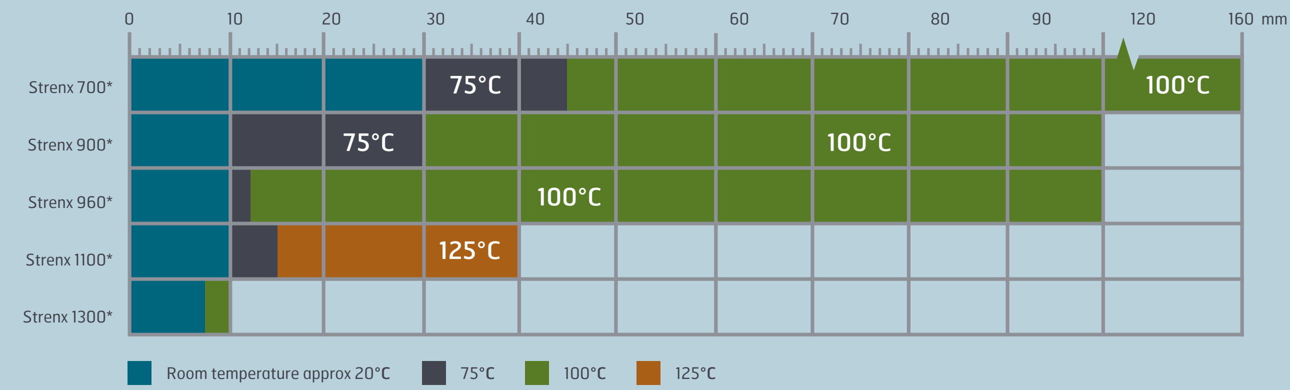
The alloying elements are specified in the inspection certificate of the plate and are stated in percent by weight in these formulas. A higher carbon equivalent usually requires a higher preheat and interpass temperature of the joint. Typical values of carbon equivalents are given in our product data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

PREHEAT AND INTERPASS TEMPERATURES FOR STRENX 700 TO STRENX 1300

The lowest preheat temperature during welding is shown in the chart. Unless otherwise stated, these values are applicable for welding with unalloyed and low-alloyed welding consumables. For single plate thicknesses not represented in the chart, please contact SSAB for further assistance.

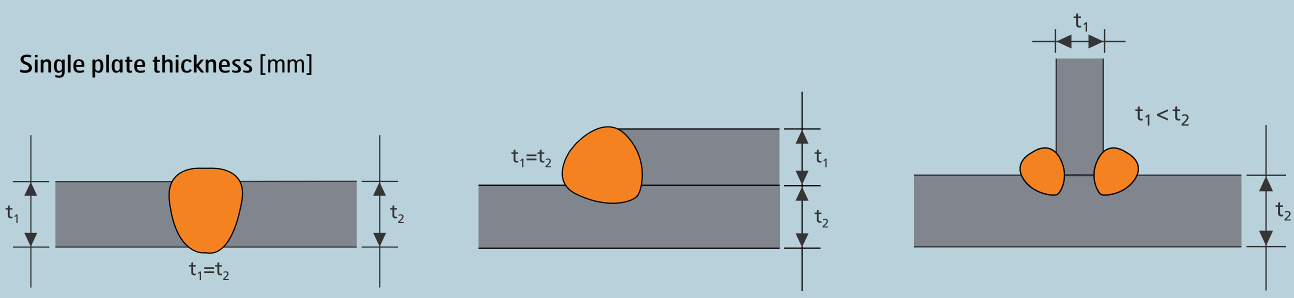
- When plates of different thicknesses, but of the same steel grade are welded together, the thickest plate determines the required minimum preheat temperature.
- When different steel types are welded together, the plate requiring the highest minimum preheat temperature determines the lowest possible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

Minimum preheat and interpass temperatures [°C]



*The table is applicable to single plate thickness when welding with a heat input of 1,7 kJ/mm or more.
For plate thicknesses not represented in the diagram, contact SSAB for further information.

Single plate thickness [mm]



$t_1 = t_2$ (dimensions in mm) The single plate thickness in the table is t_1 or t_2, provided that the same steel type is used.

$t_1 = t_2$ (dimensions in mm) The single plate thickness in the table is t_1 or t_2, provided that the same steel type is used.

$t_1 < t_2$ (dimensions in mm) In this case, the single plate thickness in the table is t_2, provided that the same steel type is used.

Increase the minimum preheat temperature by 25°C in relation to preheat table above for each of the following cases:

1. If the ambient humidity is high or the surrounding air temperature is below +5°C
2. Firmly clamped joints
3. For heat inputs in the range of 1.0-1.6 kJ/mm

The lowest recommended preheat and interpass temperatures in the chart on page 8 are not affected at heat inputs higher than 1.7 kJ/mm. For heat input below 1.0 kJ/mm on page 8 the minimum preheat temperature can be calculated with WeldCalc™.

The information is based on the assumption that the welded joint is allowed to cool in air. These recommendations also apply to tack welds and root runs below 1.0 KJ/mm. Each of the tack welds should preferably be at least 50 mm long. Comment: For plate thicknesses up to 8 mm shorter tack lengths may be used.

Maximum preheat temperatures are to be allowed in order to attain favourable properties throughout the welded structure. See page 14 for further information. The distance between tack welds can be varied as required. Contact SSAB for further information in the following cases if :

- More than one of the cases 1-3 on page 8 are present at the same time
- Tack weld length below 50 mm is requested

Preheat/interpass temperatures due to consumable properties

When welding with consumables with yield strengths ($R_{p0.2}$) up to 700 MPa the consumable properties typically don't influence the minimum preheat temperature of the joint.

Using preheater elements

The reason is that the carbon equivalent, CET, of the parent metal typically exceeds that of the weld metal by at least 0,03 units of percentage. For consumables with yield strengths of 700 MPa and higher, the CET value for the consumable verses the CET value for Strenx is normally so high that the minimum preheating temperature of both the steel and the consumable are to be considered.

In this situation, the highest minimum preheat temperature of either the joint plates or the consumable should be used. The software WeldCalc™ can simplify these calculations.

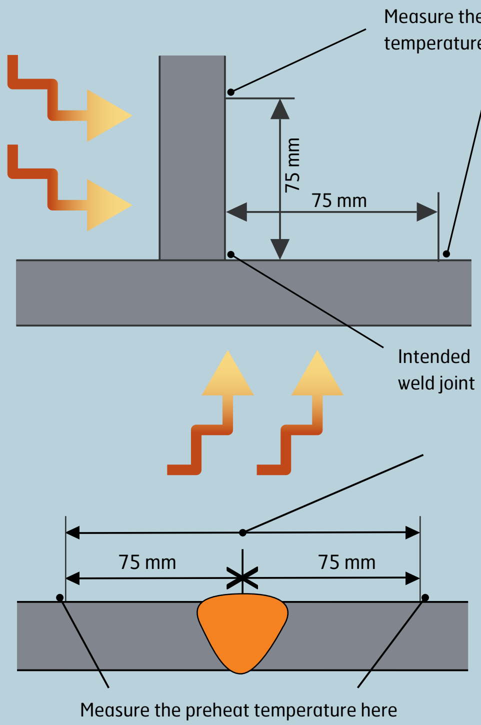
As for all types of low alloyed consumables the maximum hydrogen content is set to 5 ml/100 g of weld metal.

Attaining and measuring the preheat and interpass temperatures

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.

Single plate thickness

Measure the temperature of the thickest plate in the joint. 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.



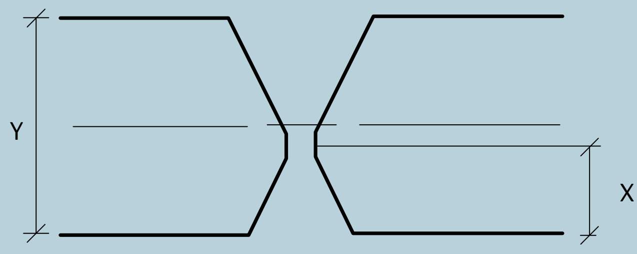
JOINING THICKER PLATES

When welding plates thicker than 25 mm, asymmetrical joints are recommended.

This will give additional resistance to hydrogen cracks. The reason is that the center part of thicker plates may, to some extent, contain chemical elements that can support formation of hydrogen cracks. Joints with plate thicknesses up to 25 mm can be either symmetrical or asymmetrical.

Joints with plate thicknesses above 25 mm

Asymmetrical joint: The center of the joint is preferably taken approximately 5 mm from the center of the plate thickness

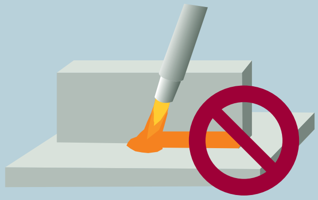


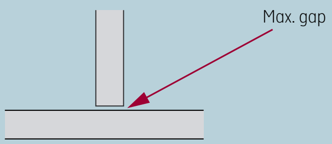
Y: Plate thickness X: (Plate thickness/2)-5 mm

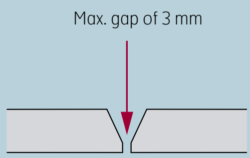
Weld sequences and gap size

To avoid hydrogen cracks in the joint

- The starting and stopping sequences should not be located in a corner. If possible, the starting and stopping procedures should be at least 50–100 mm from a corner.
- The gap in the weld joint should be a maximum of 3 mm.







MECHANICAL PROPERTIES IN WELDS

Strenx CR grades

The heat input is set low enough in order to avoid burning through the material and in order to keep distortions in the joint at low levels. With suitable settings the heat input will provide good mechanical properties in the joint.

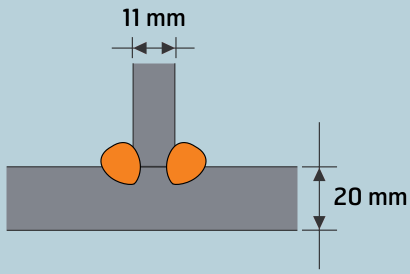
Each welding situation is more or less unique. As a consequence, SSAB does not state requirements for maximum heat input. The strength of the joint will to some extent be lower compared to the properties of the unaffected parent metal. In general low heat input supports high strength in the joint. More precise values are found in TechSupport 60.

Strenx 100, Strenx 110, Strenx 700 to Strenx 1300, Strenx MC and Strenx Plus grades

Our recommendations for Strenx high strength steel are based on typical values for toughness in the HAZ being at least 27J at -40°C. In addition, low heat input supports high static strengths in the joint. For single plate thicknesses not represented in the chart, please contact SSAB for further assistance.

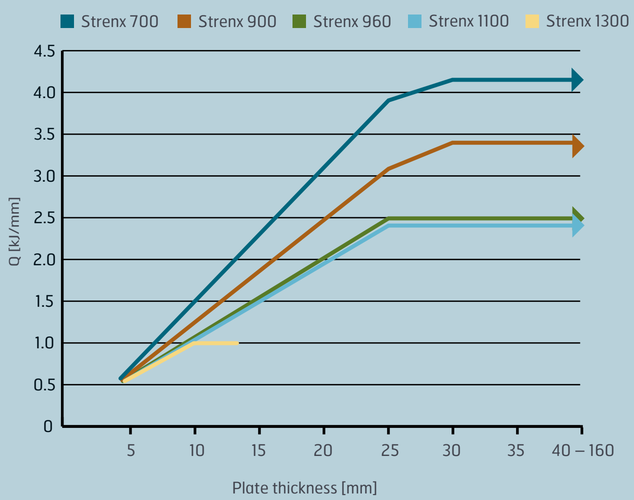
Plate and sheet thickness

When a joint with different plate thicknesses is welded, the recommended heat input is based on the thinnest plate in the joint.



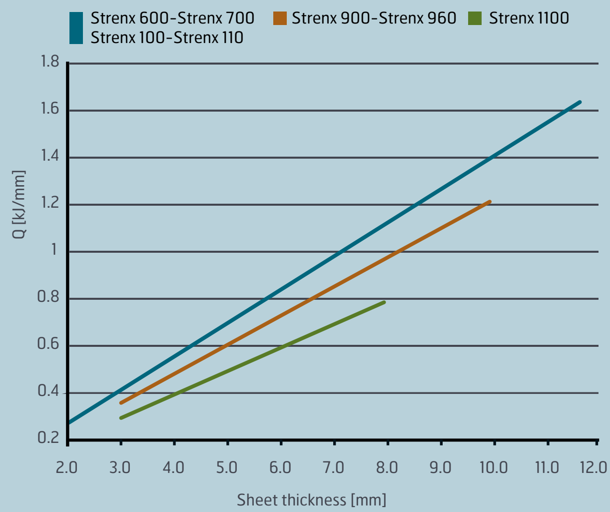
In this case, the permissible heat input is based on the 11 mm plate thickness.

Recommended maximum heat input based on the lowest preheat temperature being used



Recommended maximum heat input based on the lowest preheat temperature being used

MC and Plus grades and XF

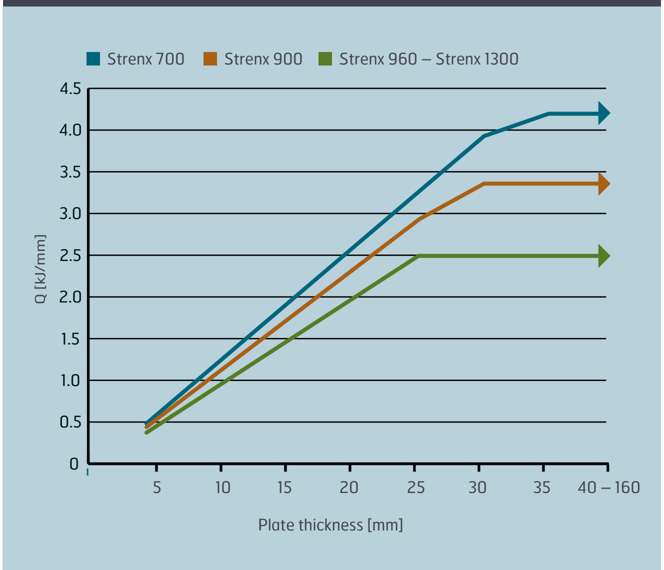


Welding at higher elevated preheat interpass temperatures

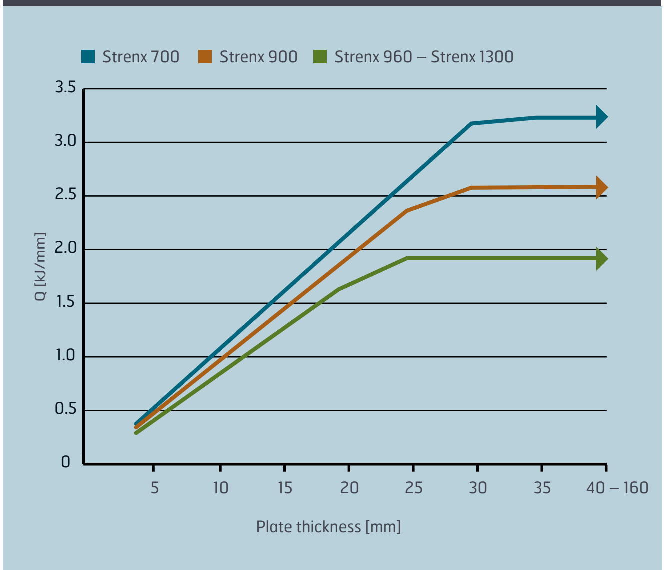
Higher elevated temperatures that may occur, for instance in multipass weld joints, affect the recommended heat input.

The figures below show the recommended heat input for joint temperatures of 100°C and 175°C.

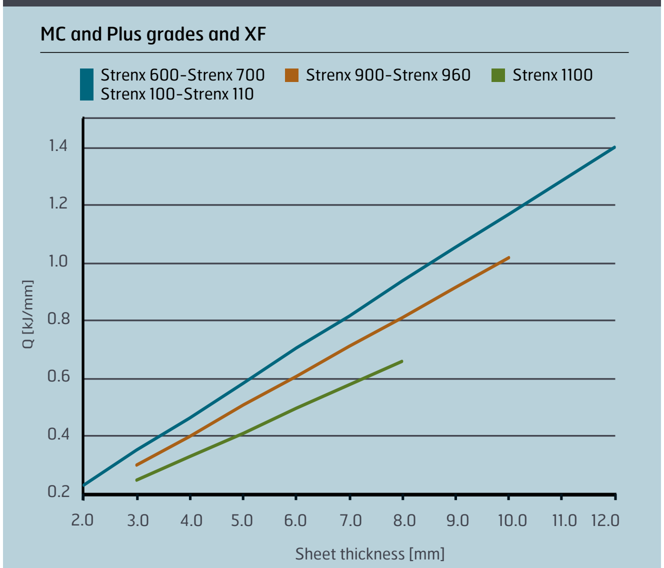
Recommended maximum heat input for the joint temperature of +100°C



Recommended maximum heat input for the joint temperature of +175°C



Recommended maximum heat input for the joint temperature of +100°C

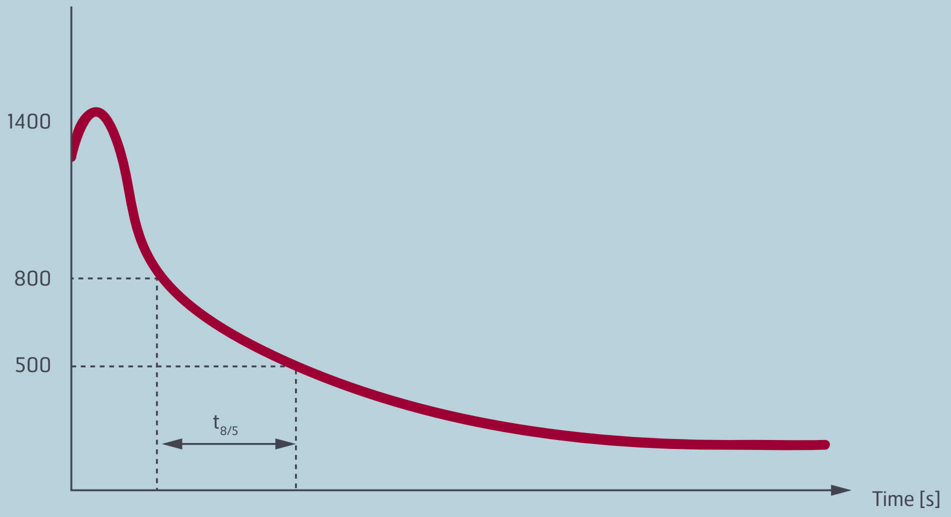


The $t_{8/5}$ value

The thermal cycle of welding can be defined by the cooling time in the HAZ between 800°C and 500°C. This parameter is called the $t_{8/5}$ value and it is illustrated in the figure below.

It is approximately constant throughout different parts of a joint as long as the peak temperature for a welding procedure reaches above 900°C.

The $t_{8/5}$ definition



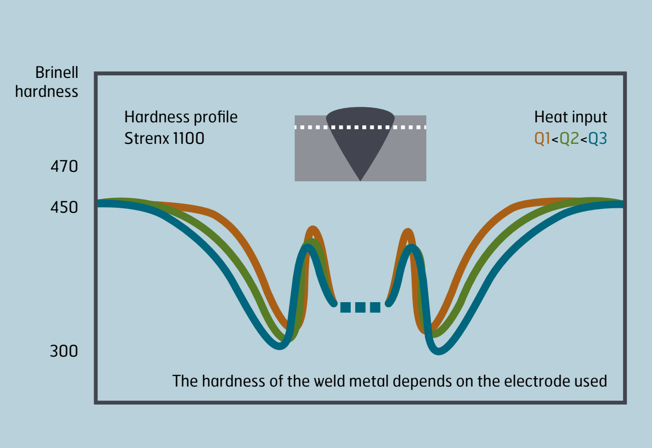
There is no need to calculate the $t_{8/5}$ value but it provides a good understanding of the welding process. Each Strenx grade has a specific recommended $t_{8/5}$ interval. Calculations of the $t_{8/5}$ value can be made with WeldCalc™ where suitable allowable intervals are stated for each steel grade.

$t_{8/5}$ values, min 27J at -40°C	
Strenx 960-1300	5-15 s
Strenx 1100 MC	1-10 s
Strenx 900 MC, Strenx 900 Plus, Strenx 900 Section, Strenx 900 Tube MH, Strenx 960 MC, Strenx Tube 960 MH Strenx 960 Plus	1-15 s
Strenx 900	5-20 s
Strenx 700, Strenx Tube 700 QLH	5-25 s
Strenx 700 MC, Strenx 700 MC Plus, Strenx 700 Section, Strenx Tube 700 MH, Strenx Tube 700 MLH, Strenx Tube 700 QLH, Strenx 100 XF, Strenx 110 XF, Strenx 650 MC, Strenx 650 Section, Strenx 600 MC	1-20 s

HARDNESS DISTRIBUTION IN THE JOINT

The hardness distribution in the HAZ depends on the steel grade, the thickness of the plates and the heat input applied during welding. The hardness in the weld is governed by its strength. The higher the strength in the joint, the higher the hardness values.

Heat input versus softening in the HAZ



MAXIMUM RECOMMENDED PREHEAT/ INTERPASS TEMPERATURE DURING WELDING AND THERMAL CUTTING

The maximum preheat/interpass temperatures are stated in order to avoid degradation of the mechanical properties in the complete welded structure. The stated maximum preheat temperatures are valid for welding when using preheating.

Max preheat/interpass temperatures [°C]

Steel name	Max preheat/interpass temp [°C]	Steel name	Max/interpass temp (°C)
Strenx 100**	300	Strenx 900**	300
Strenx 100 XF	100	Strenx 900 Plus	150
Strenx 110 XF	100	Strenx 900 MC	100
Strenx 600 MC	100	Strenx Section 900	100
Strenx 650 MC	100	Strenx Tube 900 MH	100
Strenx 650 Section	100	Strenx 960**	300
Strenx 700**	300	Strenx 960 Plus	150
Strenx 700 MC	300	Strenx 960 MC	100
Strenx 700 MC Plus	100	Strenx Tube 960 MH	100
Strenx Section 700	100	Strenx 1100	200
Strenx Tube 700 MH	100	Strenx 1100 MC	100
Strenx Tube 700 MLH	100	Strenx 1300	200

** Interpass temperatures up to +400°C can be applied in certain situations. Since Strenx Cr-grades are only welded with a one pass technique, maximum preheat temperatures are not stated.

WELDING CONSUMABLES

Unalloyed, low alloyed and stainless steel consumables are the most common when welding Strenx.

Strengths of unalloyed and low alloyed welding consumables

The strength of the welding consumables should be selected according to the figures 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
- Lower residual stresses in the joint

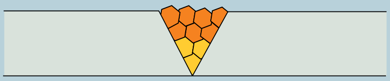
For multi pass joints in Strenx grades that require preheating it is an advantage to weld with consumables of different strengths. Tack welds and the first passes are welded with low strength consumables. Then high strength consumables are used for the remainder of passes. This technique can increase both the toughness and the resistance to hydrogen cracking in the joint.

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. Solid wires used in MAG and TIG welding can typically produce these low hydrogen contents in the weld metal. Hydrogen content for other types of welding consumables can be obtained from the manufacturer.

Examples of consumables are given at www.ssab.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.

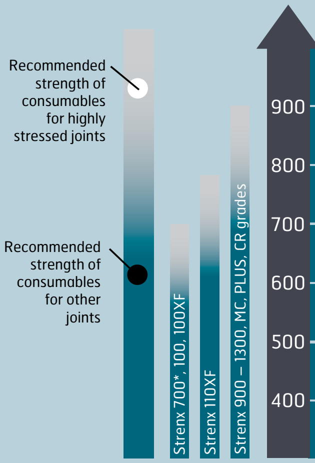
Welding consumables



Welding consumables with higher strength

Welding consumables with lower strength

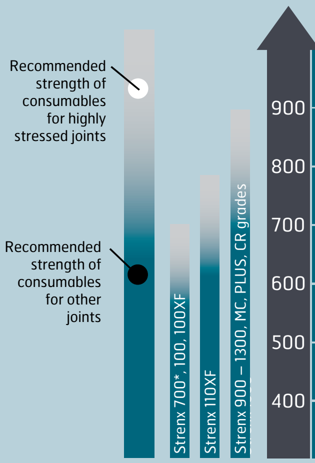
Welding consumables, EN class



MMA	SAW (solid wire/-flux combinations)	MAG (solid wire)	MAG (all types of tubular cored wires)	TIG
EN ISO 18275 (-A) E 89X	EN ISO 26304 (-A) S 89X	EN ISO 16834 (-A) G 89X	EN ISO 18276 (-A) T 89X	EN ISO 16834 (-A) W 89X
EN ISO 18275 (-A) E 79X	EN ISO 26304 (-A) S 79X	EN ISO 16834 (-A) G 79X	EN ISO 18276 (-A) T 79X	EN ISO 16834 (-A) W 79X
EN ISO 18275 (-A) E 69X	EN ISO 26304 (-A) S 69X	EN ISO 16834 (-A) G 69X	EN ISO 18276 (-A) T 69X	EN ISO 16834 (-A) W 69X
EN ISO 18275 (-A) E 62X	EN ISO 26304 (-A) S 62X	EN ISO 16834 (-A) G 62X	EN ISO 18276 (-A) T 62X	EN ISO 16834 (-A) W 62X
EN ISO 18275 (-A) E 55X	EN ISO 26304 (-A) S 55 X	EN ISO 16834 (-A) G 55 X	EN ISO 18276 (-A) T 55X	EN ISO 16834 (-A) W 55X
EN ISO 2560 E 50X	EN ISO 14171 (-A) S 50X	EN ISO 14341 (-A) G 50X	EN ISO 17632 (-A) T 50X	EN ISO 636 (-A) W 50X
EN ISO 2560 E 46X	EN ISO 14171 (-A) S 46X	EN ISO 14341 (-A) G 46X	EN ISO 17632 (-A) T 46X	EN ISO 636 (-A) W 46X
EN ISO 2560 E 42X	EN ISO 14171 (-A) S 42X	EN ISO 14341 (-A) G 42X	EN ISO 17632 (-A) T 42X	EN ISO 636 (-A) W 42X

* Including MC, PLUS, CR grades

Welding consumables, AWS class



MMA	SAW (solid wire/-flux combinations)	MAG (solid wire)	MAG (flux cored wires)	MAG (metal cored wires)	TIG
AWS A5.5 E120X	AWS A5.23 F12X	AWS A5.28 ER120S-X	AWS A5.29 E12XT-X	AWS A5.28 E120C-X	AWS A5.28 ER120X
AWS A5.5 E110X	AWS A5.23 F11X	AWS A5.28 ER110S-X	AWS A5.29 E11XT-X	AWS A5.28 E110C-X	AWS A5.28 ER110X
AWS A5.5 E100X	AWS A5.23 F10X	AWS A5.28 ER100S-X	AWS A5.29 E10XT-X	AWS A5.28 E100C-X	AWS A5.28 ER100X
AWS A5.5 E90X	AWS A5.23 F9X	AWS A5.28 ER90S-X	AWS A5.29 E9XT-X	AWS A5.28 E90C-X	AWS A5.28 ER90X
AWS A5.5 E80X	AWS A5.23 F8X	AWS A5.28 ER80S-X	AWS A5.29 E8XT-X	AWS A5.28 E80C-X	AWS A5.28 ER80X
AWS A5.5 E70X	AWS A5.23 F7X	AWS A5.28 ER70S-X	AWS A5.29 E7XT-X	AWS A5.28 E70C-X	AWS A5.28 ER70X

*Including MC, PLUS, CR grades

SHIELDING GAS

The choice and mixture of shielding gases depend on the welding situation. Mixtures of Ar and CO_2 are the most common.

Effects of various shielding gas mixtures

- Facilitates striking of the arc
- Reduced spatter
- Low amount of oxides

Ar (inert gas) → Ar/CO_2 → (active gas) CO_2

- Stable arc
- Low porosity
- More weld spatter/clogging of the welding nozzle
- High penetration of the weld metal

Examples of shielding gas mixtures

Welding method	Arc type	Position	Shielding gas
MAG, solid wire	Short Arc	All positions	18-25% CO_2 rest. Ar
MAG, cored wire	Short Arc	All positions	18-25% CO_2 rest. Ar
MAG, solid wire	Spray Arc	Horizontal (PA, PB, PC)	15-20% CO_2 rest. Ar
MAG, FCAW	Spray Arc	All positions	15-20% CO_2 rest. Ar
MAG, MCAW	Spray Arc	Horizontal (PA, PB, PC)	15-20% CO_2 rest. Ar
Robotic and automated MAG	Spray Arc	Horizontal (PA, PB, PC)	8-18% CO_2 rest. Ar
TIG	Spray Arc	All positions	100% Pure Ar

In all welding methods based on shielding gas, the flow of shielding gas depend 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.

ADDITIONAL RECOMMENDATIONS FOR WELDING OF STRENX

Resistance to lamellar tearing and hot cracks

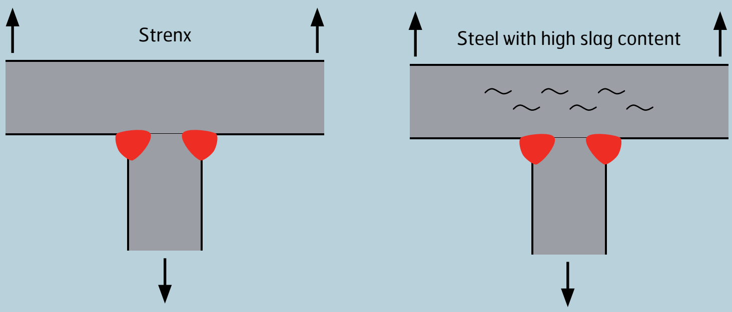
The Strenx grades are produced with very low levels of contaminants such as sulphur and phosphorus. This fact contributes to the beneficial mechanical properties in the HAZ and in the unaffected parent metal. In addition, it also leads to increased resistance to welding discontinuities in terms of hot cracking and lamellar tearing.

Lamellar tearing is a result of inclusions placed parallel to the plate surface where a tensile load direction is present in a perpendicular direction to the plate surface.

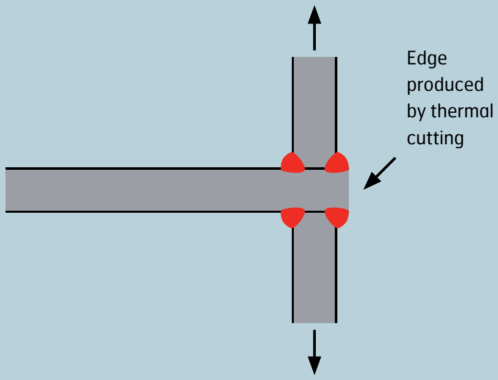
For joints loaded perpendicular to the direction of the plate surface, avoid sharp defects by placing joints away from the edge of the plate. For joints in thinner plate gauges, thermal cutting produces an edge with a higher surface quality than shering and punching.

Hot cracking

- Prior to welding, keep the joint free from contaminants such as oil and grease. Remove these substances with a suitable method.



Lamellar tearing. Difference between a steel with high slag inclusions and Strenx steels



It is recommended to use thermal cut edges in t-joints with welds close to the cut edge

As for welding of all types of steel, normal precautions for avoiding discontinuities should be taken. For additional information on this issue, download TechSupport 47 at www.ssab.com.

Welding on Strenx primer

Strenx 100, 700, 900, 960, 1100 and 1300 can be ordered with a primer that counteracts corrosion. Welding can be carried out directly on the primer due to its low zinc content. The primer can easily be brushed or grinded away in the area around the joint. Removing the primer prior to welding can minimize the porosity in the weld and 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 MAG welding process, with basic types of flux cored wires, and the MMA welding process offer the lowest porosity. As in all welding operations good ventilation must be maintained to avoid harmful effects on the welder and his surroundings. For further information, download TechSupport 25 from www.ssab.com./downloads-center.

Welding Strenx CR grades ordered with an oil film

In order to avoid corrosion damage the sheet steel is normally coated with a thin oil film. The oil film is so thin that it does not give any porosity problems. The oil is gasified and quickly disappears during welding.

Post weld heat treatment

Strenx grades except Strenx 1100-1300 and Strenx 1100 MC can be stress relieved by post weld heat treatment, although this is seldom necessary. Strenx 1100-1300 and Strenx 1100 MC should not be exposed to this method, since this may impair the mechanical properties of the whole structure. Contact SSAB for further information regarding suitable temperatures and holding times.

For best possible results, the primer can be removed.

Storage

If Strenx is stored in an environment where impurities may accumulate on the surface of the sheet, some precautions have to be taken. To avoid welding defects, some form of cleaning of the steel may be necessary before welding.

Material groupings according to the European Norm EN 15608

When performing welding procedure qualifications according to the European norm, the steel groupings are set to:

Material grouping		
Steel	Plate thickness [mm]	Material grouping according to EN 15608
Strenx 700	≤ 53.0	3.2
Strenx 700	> 53.0	3.1
Strenx 100	All plate thicknesses	3.1
Strenx 900, 1100, 1300	All plate thicknesses	3.2
Strenx 100XF, 110XF and Strenx grades ending with MC	All plate thicknesses	2.2
Strenx 900 Plus, 960 Plus	All plate thicknesses	3.2

SSAB is a Nordic and US-based steel company. SSAB offers value added products and services developed in close cooperation with its customers to create a stronger, lighter and more sustainable world. SSAB has employees in over 50 countries. SSAB has production facilities in Sweden, Finland and the US. SSAB is listed on the Nasdaq OMX Nordic Exchange in Stockholm and has a secondary listing on the Nasdaq OMX in Helsinki.

420-UK-Strenx-Welding of Strenx V1-2017-AplusM-Österbergs

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