STRENX™
PERFORMANCE STEEL

WELDING STRENX

900-1100 MC- AND PLUS- STEEL GRADES

SSAB

WELDING

In order to achieve good weld quality and meet the required mechanical properties requested by designers in the welded joints, it is important to plan and prepare the welding procedure properly. When the designer specifies the type of weld and required properties, the welding parameters can be selected based on the same criteria. The most important parameters to consider before the welding procedure is determined are:

- Welding method
- Joint preparation
- Welding consumable
- Shielding gas
- Preheat and interpass temperature
- Heat input
- Cooling time ($t_{8/5}$)

WELDING METHODS

All conventional welding methods can be used, for example:

- MAG with solid wire or cored wire (FCAW, MCAW)
- SAW
- MMA
- TIG
- Laser hybrid (laser+MAG) welding
- Laser welding

WELDING OF STRENX 900-1100 MC- AND PLUS- STEEL GRADES

Strenx 900-1100 MC- and Plus- steel grades are hot rolled products produced by SSAB (Table 1). For more information about Strenx 900-1100 MC- and Plus- steel grades see the data sheets at www.ssab.com.

Table 1: Properties of Strenx 900-1100 MC- and Plus- steel grades

Steel grade	Thickness [mm]	Yield strength $R_{p0.2}$, min [MPa]	Tensile strength R_m, [MPa]	Elongation A_5 min %	Impact toughness Charpy V Energy[1] J / °C Minimum	CEV[2] % Typical	CET[3] % Typical
Strenx 900 MC	3-10	900	930-1200	8	27 / -40	0.50-0.53	0.25-0.27
Strenx 900 Plus	3-6	900	930-1200	11	27 / -40	0.50	0.34
Strenx 960 MC	3-10	960	980-1250	7	27 / -40	0.51-0.57	0.28-0.30
Strenx 960 Plus	3-6	960	980-1250	10	27 / -40	0.50	0.34
Strenx 1100 MC	4-7	1100	1250-1450	7	27 / -40	0.54-0.55	0.32-0.33

1) The specified minimum value corresponds to a full size specimen

2) CEV = C + Mn/6 + (Cr+Mo+V)/5 + (Cu+Ni)/15 (wt-%)

3) CET = C + (Mn+Mo)/10 + (Cr+Cu)/20 + Ni/40 (wt-%)

JOINT PREPARATION

Milling and thermal cutting (gas, plasma or laser cutting) can be used for joint preparation. No preheating is required for thermal cutting. A thin oxide layer is formed on the cut surface through thermal cutting. It is recommended to remove this oxide layer before welding. If plasma cutting is used it is recommended to use oxygen as plasma gas.

Recommended joint configurations are presented in Figure 1. For MAG welding in combination with single-V butt welds a common bevel angle is 50° - 60°, but other values can also be used. For fillet welds gaps between the sheets should be avoided.

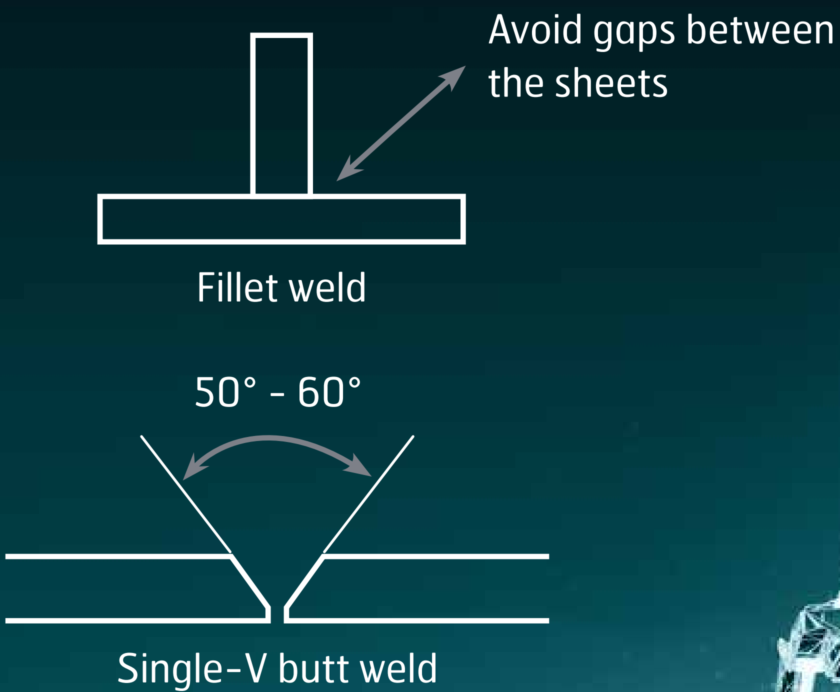

Figure 1. Examples of joint configurations for MAG welding of sheets in the thickness range 3-10 mm.

Make sure that the joint is dry and clean, free of any impurities like rust, oil, white frost and moisture before welding.

WELDING CONSUMABLES

The highest strength of welding consumables available today on the market is class 89 according to EN standards and 120 AWS standard. These high strength consumables are matching for Strenx 900 MC/Strenx 900 Plus, falling slightly below Strenx 960 MC/Strenx 960 Plus and undermatching for Strenx 1100 MC. When the required strength of the welded joint has to be in the vicinity of those for the parent metal, high strength consumables according to Table 2 are recommended.

Table 2: Recommended high strength consumables for Strenx 900-1100 MC- and Plus- steel grades.

	MMA	MAG Solid wire	MAG Flux cored wire	MAG Metal cored wire	SAW (Solid wire/flux combination)	TIG
AWS class	A5.5 E120X	A5.28 ER120S-X	A5.29 E12XT-X	A5.28 E120C-X	A5.23 F 12X	A5.28 ER120S-X
EN class	EN 757 E89X	EN 16834-A G89X	EN 18276-A T89X	EN 18276-A T89X	EN 26304-A S89X	EN 16834-A W89X

If the welded joint is located in a low stress area, welding consumables with lower strengths than those presented in Table 2 can also be used.

The welding consumables used for Strenx 900-1100 MC- and Plus- steel grades should have low weld metal hydrogen content; maximum 5 ml/100 g weld metal. Therefore, only low-hydrogen type consumables should be used.

SHIELDING GAS

The most common shielding gas for MAG welding of Strenx 900-1100 MC- and Plus- steel grades is a mixture of argon and carbon dioxide (Ar, 8-25 CO_2). In manual welding CO_2 levels in the upper range are often used, and in automatic and robot welding CO_2 levels in the lower range are normally used.

PREHEAT AND INTERPASS TEMPERATURES

Table 3: Typical carbon equivalent values for Strenx 900-1100 MC- and Plus- steel grades.

Steel grade	Thickness (mm)	CEV[1] % Typical	CET[1] % Typical
Strenx 900 MC	3 - 7.9	0.50	0.25
	8 - 10	0.53	0.27
Strenx 900 Plus	3 - 6	0.50	0.34
Strenx 960 MC	3 - 7.9	0.51	0.28
	8 - 10	0.57	0.30
Strenx 960 Plus	3 - 6	0.50	0.34
Strenx 1100 MC	4 – 4.9	0.54	0.32
	5 - 7	0.55	0.33

1) CEV and CET see Table 1

Preheating is a common way to avoid hydrogen cracking. The need for preheating depends on several factors, such as chemical composition of the steel and consumables, sheet thickness, heat input and hydrogen content in the weld. Carbon equivalent formulas are used for describing the amount of alloying elements in the steels. The most common carbon equivalent formulas are CEV and CET (see Table 1).

Typical carbon equivalent values for Strenx 900-1100 MC- and Plus- steel grades are provided in Table 3. These values are low in relation to the high strength levels of the steels. Due to the low carbon equivalent values and thin sheet thicknesses of the Strenx 900-1100 MC- and Plus- steel grades, the resistance to hydrogen cracking is high and preheating is therefore normally not needed. When the workplace temperature is below +5 °C preheating to a temperature of at least 60 °C is necessary to obtain dry welding edges.

Table 4: Recommended maximum interpass temperature for Strenx 900-1100 MC- and Plus- steel grades.

Steel grade	Sheet thickness (mm)	Max interpass temperature, °C
Strenx 900 MC	3 – 10	100
Strenx 900 Plus	3 - 6	150
Strenx 960 MC	3 – 10	100
Strenx 960 Plus	3 – 6	150
Strenx 1100 MC	4 - 7	150

If the carbon equivalent of the consumable is higher than the carbon equivalent of the sheet, the welding consumable is the determining factor for the preheat temperature. This is normally the case for the consumables in Table 2. Manufacturers of consumables normally do not specify preheat temperatures for the consumables in the data sheets. However the minimum preheat temperature for a specific consumable can be calculated according to the European standard EN 1011-2, Method B or by using WeldCalc software from SSAB. It is recommended to perform this calculation or to carry out real welding tests before a new consumable is used in the production.

Multi-pass welding can increase the temperature in the welded joint to a level that will reduce the mechanical properties of the welded joint. If the interpass temperature is too high it may decrease the strength and impact toughness of the welded joint. Therefore, a maximum interpass temperature is recommended for the Strenx MC- and Plus- steel grades (Table 4).

HEAT INPUT

To obtain high static strength and high impact toughness in the welded joint, it is important not to exceed the maximum recommended heat input (Q).

The heat input can be calculated through the formula:

Q = k x U x I x 60/(V x 1000)

Q = Heat input [kJ/mm]

U = Voltage [V]

I = Current [A]

V = Travel speed [mm/min]

k = Thermal efficiency

The following thermal efficiency values can be used for the different welding methods:

MMA k = 0.8

MAG k = 0.8

SAW k = 1.0

TIG k = 0.6

Recommended maximum heat inputs versus sheet thickness are shown in Figure 2-4 for the Strenx 900-1100 MC- and Plus- steel grades. In the case of different sheet thicknesses, the recommended heat input is based on the thinnest sheet in the welded joint. The heat inputs shown in Figure 2-4 are valid for butt welds. For fillet welds the maximum heat input can be increased by approximately 30%.

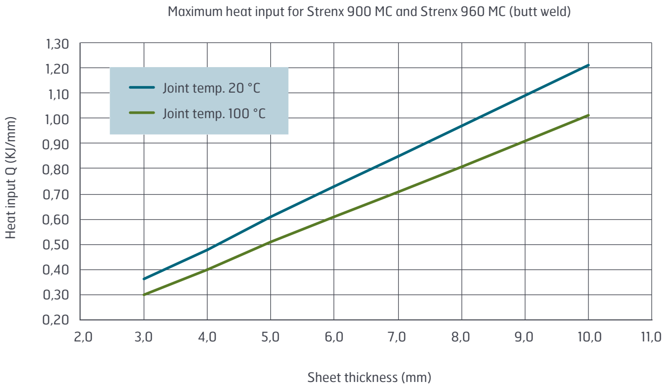

Figure 2: Recommended maximum heat input (Qmax) versus sheet thickness for Strenx 900 MC and Strenx 960 MC (butt weld).

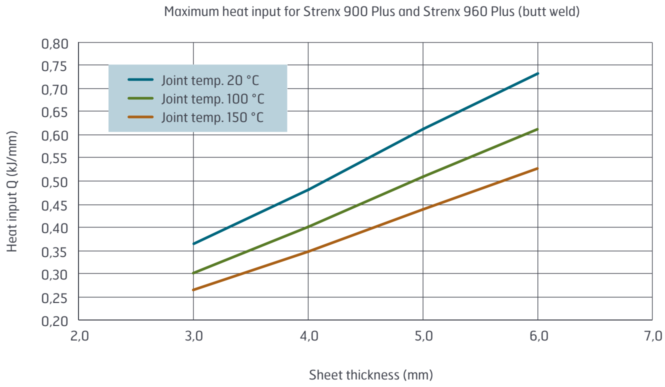

Figure 3: Recommended maximum heat input (Qmax) versus sheet thickness for Strenx 900 Plus and Strenx 960 Plus (butt weld).

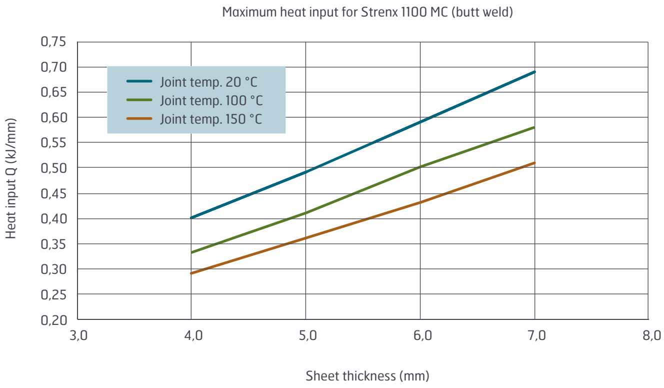

Figure 4: Recommended maximum heat input (Qmax) versus sheet thickness for Strenx 1100 MC (butt weld).

COOLING TIME ($t_{8/5}$)

The main factors influencing the cooling time between 800 °C and 500 °C ($t_{8/5}$) are heat input (Q), type of joint, sheet thickness and preheat/interpass temperature. The cooling time can be measured (by thermocouple or similar device) or it can be calculated according to formulas in the European welding standard EN 1011-2 or by using WeldCalc software from SSAB.

The $t_{8/5}$ value has a significant influence on the mechanical properties of welded joints. With an excessive $t_{8/5}$ value both strength and impact toughness can be reduced, and a $t_{8/5}$ value that is too low can reduce the impact toughness. The recommended ranges of the $t_{8/5}$ values for the Strenx 900-1100 MC- and Plus- steel grades are shown in Table 5. The recommended maximum $t_{8/5}$ -values in Table 5 correspond to the recommended maximum heat inputs shown in Figure

Table 5: Recommended cooling time ($t_{8/5}$) for Strenx MC- and Plus- steel grades.

Steel grade	Recommended $t_{8/5}$-values
Strenx 900 MC	1 – 15[1] s
Strenx 900 Plus	1 – 15[1] s
Strenx 960 MC	1 – 15[1] s
Strenx 960 Plus	1 – 15[1] s
Strenx 1100 MC	1 – 10[2] s

s = seconds 1) MAG 3-15 s 2) MAG 3-10 s

For MAG welding it is not recommended to use $t_{8/5}$ values lower than 3 seconds due to the risk of low impact toughness and the risk of welding defects. However, for laser welding and laser hybrid welding $t_{8/5}$ values lower than 3 seconds can be used.

The following measures are recommended for obtaining high strength in the welded joints when MAG welding is used:

- In the case of a single-V butt joint, do not use an unnecessarily large bevel angle. The lower the volume of molten material deposit in a single run, the smaller the amount of heat;
- Use a low heat input;
- When multi-run welding, use as low interpass temperature as possible;
- In case of butt joint perform welding from both sides;
- High strength consumables of strength class 89 as per EN 16834 / EN 18276 and class 120 as per AWS should be used (Table 2).

With laser welding and laser hybrid welding, high strength of the welded joints can be obtained for Strenx 900-1100 MC- and Plus- steel grades due to the low $t_{8/5}$ values for these welding methods. For laser hybrid welding it is also possible to use consumables of lower strength than class 89 (EN) and class 120 (AWS) and still obtain welded joints with matching strength.

Regarding strength of welded joints, it should be noted that the strength of a welded butt joint is influenced by the type of tensile specimen used. If the tensile testing is performed with tensile specimens with weld reinforcement, the strength of the joint is higher than for a tensile specimen without weld reinforcement (Figure 5). In most welded structures the weld reinforcements are not removed.

With a maximum cooling time $t_{8/5}$ of 15 seconds, which is recommended in Table 5 for Strenx 900 MC and Strenx 960 MC, the impact toughness of the welded joints will be good and the strength will be undermatching in relation to the parent steel. Good impact toughness here means that the minimum guaranteed impact toughness of the base metal is fulfilled also for the welded joint (weld metal and heat affected zone). This is the case for both high strength and low strength consumables. Undermatching welded joints can often be accepted, for example, if the weld is placed in a low stress area or when the design allows it. However if the cooling time $t_{8/5}$ is reduced to maximum 4 seconds it is also possible to obtain matching welded joints for Strenx 900 MC and Strenx 960 MC.

With high strength consumables and a maximum cooling time $t_{8/5}$ of 15 seconds it is possible to obtain good impact toughness and high strength of the welded joints for Strenx 900 Plus and Strenx 960 Plus. If tensile specimens with the weld reinforcement not removed are used in the testing, matching welded joints can be obtained. If tensile specimens without weld reinforcement are used, matching or in some cases for Strenx 960 Plus slightly undermatching welded joints are obtained. The higher strength of the welded joints for Strenx 900-960 Plus in comparison with Strenx 900-960 MC is due to the higher alloying content (higher carbon equivalent value CET, see Table 1) for Strenx 900-960 Plus. An increased amount of alloying elements results in reduced soft zones in the heat affected zone (HAZ).

With high strength consumables in combination with a maximum cooling time $t_{8/5}$ of 10 seconds, as recommended in Table 5 for Strenx 1100 MC, the impact toughness of the welded joint will be good and the strength of the joint will be undermatching in relation to the parent steel. This is the case even if tensile specimens with weld reinforcement are used in the testing. To obtain matching welds for Strenx 1100 MC welding with low $t_{8/5}$ –values ($t_{8/5} \leq 4$ seconds) are required.

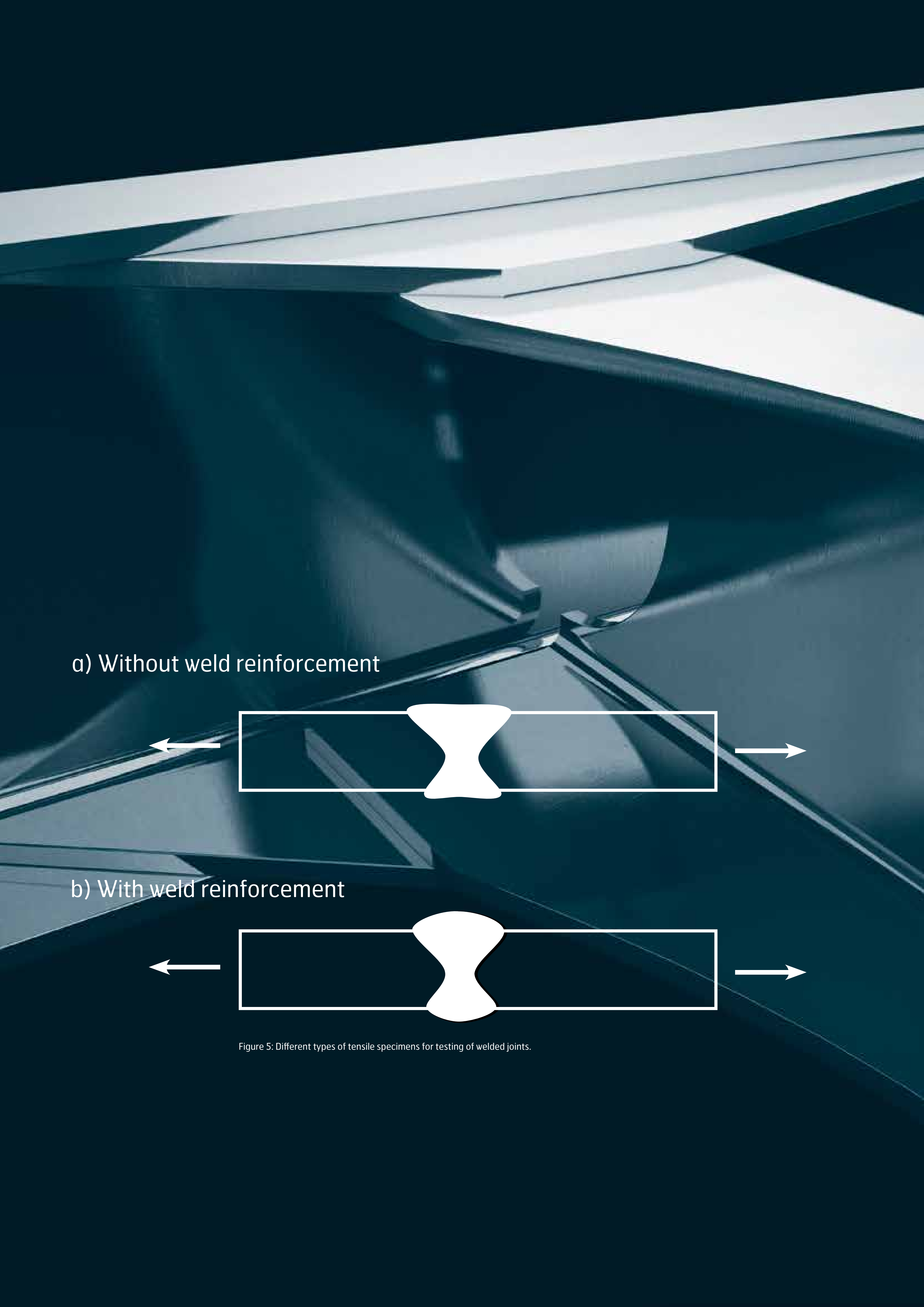

Figure 5: Different types of tensile specimens for testing of welded joints.

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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.

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