Recommendations for welding of ThyssenKrupp high protect SECURE

1. General

ThyssenKrupp Steel produces heavy plates for ballistic protection under the trade name SECURE. These steels are mainly used for civilian vehicles and buildings. The ballistic protection and high hardness from 400 up to 600 HB are the result of a special chemical composition combined with a heat treatment by water or oil quenching. Due to their alloying and high hardness, certain measures have to be taken into account to ensure reliable welding. SECURE 200 is a thermo-mechanically rolled steel which has a processing-friendly chemical composition with low carbon equivalent.

Carbon equivalents for thickness up to 40 mm

Steel grade	CE_{IIW}, typical	CET, typical
SECURE 200	0,42 %	0,30 %
SECURE 400	0,72 %	0,47 %
SECURE 450	0,74 %	0,42 %
SECURE 500	0,72 %	0,47 %
SECURE 600	0,80 %	0,55 %

The susceptibility of steel to cold cracking can be estimated on the basis of its chemical composition. Particularly suitable for this is the carbon equivalent CET derived from extensive cold cracking tests. The relevant research work conducted by ThyssenKrupp Steel AG on the avoidance of cold cracking has led to the CET concept and its adoption in EN 1011-2.

Calculation of carbon equivalents

IIW- formula

$$CE = C + \frac{Mn}{6} + \frac{Cr + Mo + V}{5} + \frac{Cu + Ni}{15}$$

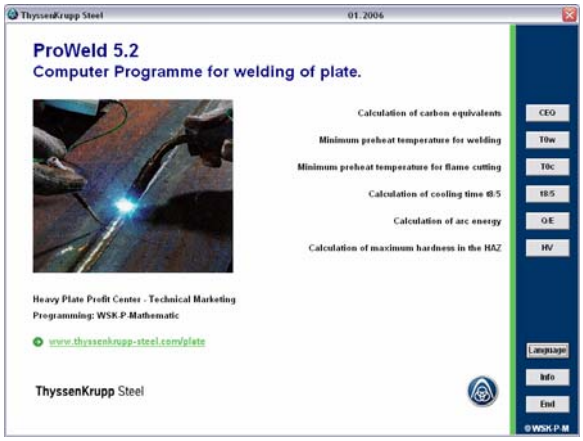
CET- concept (EN 1011-2, Annex C.3)

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

2. Weld seam preparation

A careful weld seam preparation, i.e. even gaps, thickness of root face, and angle of bevel, are a precondition for reducing the residual stresses within the welding zone and thus leads to a higher protection against cracks. Before commencing the welding tasks, the welding zone has to be cleaned. Scale, rust or residual paint have to be removed by brushing or grinding. Also, it must be ensured by drying or preheating that the welding zone is free from any humidity. The weld edges should be checked by visual inspection, or by means of a dye penetrant technique, for voids and other defects that might impair welding such as e.g. slag residues.

3. Welding conditions



When welding SECURE steels, cooling times $t_{8/5}$ between 5 s and 20 s should be applied in the welding zone. These cooling times must be assigned suitable welding conditions taking into account the necessary preheating temperature. Assistance in choosing appropriate welding conditions is offered by our computer programme ProWeld.

Joining with other steels is generally not problematic if welding conditions are adapted to the SECURE.

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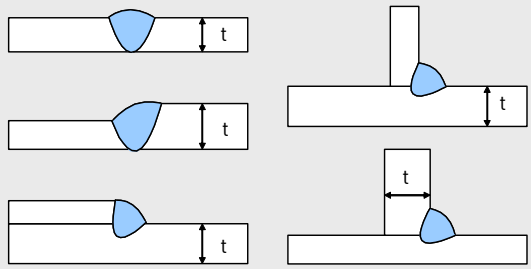
The welding, processes and welding filler metals must be selected to achieve the lowest possible hydrogen content in the welding material in order to avoid cold cracks in the welding zone.

SECURE 200 can be delivered in thicknesses of up to 15 mm. Due to its extremely low carbon equivalent, a preheating is generally not necessary.

The other SECURE steels are welded preferably with austenitic welding filler metals. The parts to be joined should have room temperature (at least 15 °C). For plate thicknesses in excess of 25 mm, it is recommended to preheat to 100°C - 150°C when welding with austenitic consumables in order to take into account the stresses to be expected in the welding zone.

Relevant plate thickness t for the determination of the preheat temperature according to the CET-concept



If ferritic consumables are used, sufficient preheating of the welding zone is required in most cases. Until the weld joint has been completed, the work piece temperature should not fall below the preheating temperature. Taking into account the mechanical properties of the base material, preheating temperatures and interpass temperatures in excess of 200 °C should be avoided.

The table on the bottom of the page shows the preheating temperatures recommended for the maximum single plate thickness, when welding SECURE steels with ferritic consumables and a heat input of 1 kJ/mm.

Heat input during welding

Arc energy E [kJ/mm]	
$E = \frac{U \cdot I \cdot 60}{v \cdot 10000}$	U = welding voltage [V] I = welding current [A] v = welding speed [cm/min]
Heat input Q [kJ/mm]	
Q = 0,8 · E	MAG-welding, mixture gas M21 / manual metal-arc welding basic
Q = E	submerged-arc welding

For a more exact determination of the preheating temperature in individual cases the chemical composition specified in the test report for the plate should be used. Easy calculation of preheat temperatures in cases, where the hydrogen content and heat input essentially deviate from the levels assumed here, is also possible by means of the computer programme ProWeld.

4. Welding filler metals

For welding of SECURE 200 unalloyed or low alloyed welding filler metals can be used (e.g. Union MoNi). The yield strength of 550 MPa in the weld metal should not be exceeded.

Preheat temperature for MAG-welding using ferritic filler metals
heat input Q = 1.0 kJ/mm, hydrogen content HD = 2 ml/100 g

Steel grade	Plate thickness t in mm							
	≤ 5	≤ 10	≤ 15	≤ 20	≤ 25	≤ 30	≤ 35	> 35
SECURE 400	100 °C	125 °C	150 °C		175 °C		200 °C	austenitic 100 - 150 °C
SECURE 450	75 °C		100 °C	125 °C		150 °C		
SECURE 500	100 °C	125 °C	150 °C		175 °C		200 °C	austenitic 100 - 150 °C
SECURE 600	150 °C	175 °C	200 °C	austenitic filler metals without		100 - 150 °C		

For welding the steels SECURE 400, 450, 500 and 600 the following austenitic welding filler metals have proven to be suitable:

Austenitic welding filler metals

Manufacturer	Manual metal-arc welding	Gas-shielded metal-arc welding
Boehler Thyssen	Thermanit X	Thermanit X
ESAB	OK 67.45	OK Autrod 16.95
FILARC	Filarc BM 307 L	Filarc PZ 6070 Filarc PZ 6470
OERLIKON	SAFDRY R 307	NERTALIC 51 SAFDUAL 651

For ferritic welding an unalloyed welding material has to be preferred to achieve a good formability of the welds. This applies in particular when welding the **tack seams** of thin plates or **fillet welds**, because the welding material is mixed up by the higher alloyed base material. For manual metal-arc welding (SMAW) it is recommended for example to use the basic covered electrode Phoenix 120 K (EN 499: E 42 5 B 32 H5, AWS A 5.1: E7018-1), for gas-shielded metal-arc welding (GMAW) the wire electrode Union K 52 (EN 440: G3Si1 / AWS A 5.18: ER70S-6) has proven to be suitable.

If a yield point and tensile strength largely comparable to the base material are required for the welded joint, then an appropriately matched welding filler metal should be used. When ferritic welding **butt welds** and in the case of multi-layer fillet welds, the following welding filler metals have proven to be suitable:

Ferritic welding filler metals

Manufacturer	Manual metal-arc welding	Gas-shielded metal-arc welding
Boehler Thyssen	SH V 1 SH Ni 2 K 100	Union MoNi Union NiMoCr
ESAB	OK 48.08 OK 48.68	OK Autrod 12.51 OK Autrod 13.09
FILARC	Filarc 35 Filarc 108	Filarc PZ 6000 Filarc PZ 6130
OERLIKON	Tenacito 65 R Tenacito 75	Fluxofil 40 Fluxofil 42

In the interest of safety against cold-cracking it must be ensured that the hydrogen content of the welding material is as low as possible. Therefore, the welding filler metals have to be protected against any absorption of moisture during transportation and storage. The basic covered electrodes and welding flux have to be post-dried in accordance with the manufacturer's instructions immediately before use. After wards the covered electrodes have then to be stored at 100°C to 150°C until they are used for welding.

5. Other notes

In many applications, it has become clear that the welding of SECURE steels has been mastered by users. Finally, some recommendations based on practical experience, which have proven themselves in connection with appropriate welding fabrication, are given:

- In the case of fillet welds and high quality requirements on the joints, it is recommended to remove the paint coat of primed plates in the welding zone.
- In the case of tack-welding the tack length should be at least 50 mm. In the case of plate thicknesses of more than 20 mm it is recommended to carry out tack-welding in two layers.
- Before counter-welding, root beads should be ground and, when an intermediate cooling of the weld has taken place, a relevant crack test is recommended.
- In the case of top layer welding, it is advantageous to select the welding sequence such that the final bead is not in contact with the base material.