# Recommendations for welding of ThyssenKrupp high hard XAR®

## 1. General

ThyssenKrupp Steel produces heavy plates for wear-exposed structures under the trade name XAR®. These steels are mainly used for excavating, mining and earth-moving machinery, conveying and crushing equipment and other machinery. For moderate wear a hardness of about 300 HB can be achieved via normalizing rolling. For higher wear resistance steels with hardnesses from 400 up to 600 HB have been developed. They exhibit a special chemical composition combined with a heat treatment by quenching or quenching and tempering. Due to their alloying and high hardness, certain measures have to be taken into account to ensure reliable welding. XAR® 400 and XAR® 450 are the standard wear-resistant steel grades which have the most processing-friendly chemical composition with relatively low carbon equivalents.

**Carbon equivalents for thicknesses up to 35 mm**

| Steel grade | CEV, typical [%] | | CET, typical [%] | |
|---|---|---|---|---|
| | t ≤ 8 mm | 8 - 35 mm | t ≤ 8 mm | 8 - 35 mm |
| XAR® 300 | 0.67 | | 0.41 | |
| XAR® 400 | 0.40 | 0.49 | 0.28 | 0.32 |
| XAR® 450 | 0.45 | 0.55 | 0.30 | 0.35 |
| XAR® 500 | 0.61 | | 0.41 | |
| XAR® 600 | 0.80 | | 0.54 | |

The susceptibility of steels to cold cracking can be estimated on the basis of their 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**

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

**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

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 pre-heating 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 cracks and other defects that might impair welding such as e.g. slag residues.

## 3. Welding filler metals

The risk of cold cracking occurring in the weld metal can be minimized by using austenitic welding filler metals.

If ferritic welding filler metals are used for cost reasons, preference should be given to the MAG solid wire, as it offers appreciable advantages because of the comparatively low hydrogen content in the weld metal. A soft, unalloyed weld metal (yield strength below 500 MPa) that has good ductility is also preferable. This applies especially to comparatively thin plates or fillet welds, because here the weld metal is diluted by the higher-alloy parent metal.

For butt welds or multi-layer fillet welds, an increased yield strength is sometimes required in the weld region of wear-resistant components. In such cases a medium alloyed welding filler metal (yield strength of weld metal from 500 to 700 MPa) can be used for filling and capping passes.

| Solid wires for MAG-welding | EN Classification | AWS Classification |
|---|---|---|
| **austenitic** | G 18 8 Mn (1.4370)<br>*according to EN 12072* | ER307<br>*acc. to AWS A 5.9* |
| **ferritic, $R_e$ < 500 MPa** | G 46 4 M G4Si1 or<br>G 50 5 M G3Ni1<br>*according to EN 440* | ER70S-6 or<br>ER80S-G<br>*acc. to AWS A 5.18* |
| **ferritic, 500 - 700 MPa** | G 62 5 M Mn3Ni1Mo or<br>G 69 5 M Mn4Ni1,5CrMo<br>*according to EN 12534* | ER90S-G or<br>ER100S-G<br>*acc. to AWS A 5.28* |

To avoid 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. The basic covered electrodes and welding flux have to be post-dried in accordance with the manufacturer's instructions immediately before use. Afterwards the covered electrodes have to be stored at 100°C to 150 °C until they are used for welding.

Other welding consumables which have not been listed here can also be used. The selection is not exclusive and should not be taken as any deprecation of the suitability of other filler metals.

## Solid wires for MAG-welding (shielding gas M 21)

| Type of welding filler metal | Manufacturer<br>BÖHLER | ESAB | LINCOLN | OERLIKON | THYSSEN |
|---|---|---|---|---|---|
| **austenitic** | A 7 CN-IG | OK Autrod 16.95 | LNM 307 | Inertfil 18 8 6 | Thermanit X |
| **ferritic, $R_e$ < 500 MPa** | BÖHLER EMK 8<br>BÖHLER DMO-IG | OK AristoRod 12.63 | LNM 27<br>LNM Ni 1 | CARBOFIL 1 a<br>CARBOFIL 2,5 Ni | Union K 56<br>Union K5 Ni |
| **ferritic, $R_e$ = 500 - 700 MPa*** | BÖHLER NiMo 1-IG<br>BÖHLER X 70-IG | OK AristoRod 13.29 | LNM NiMo1<br>LNM MoNiVa | CARBOFIL NiMo 1<br>CARBOFIL NiMoCr | Union MoNi<br>Union NiMoCr |

## Flux-cored wires for MAG-welding (shielding gas M 21)

| Type of welding filler metal | Manufacturer<br>Drahtzug Stein | ESAB | LINCOLN | OERLIKON | THYSSEN |
|---|---|---|---|---|---|
| **austenitic** | - | OK Tubrod 15.34 | (Cor-A-Rosta 307) | Fuxinox 307 PF | Thermanit TG 307 |
| **ferritic, $R_e$ < 500 MPa** | Megafil 731 B<br>Megafil 240 M | OK Tubrod 14.10 | Outershield MC 715-H<br>Outershield 81Ni1-H | Fluxofil 31 | Union BA 70<br>Union MV 70 |
| **ferritic, $R_e$ = 500 - 700 MPa*** | Megafil 740 B<br>Megafil 742 B | OK Tubrod 14.06<br>OK Tubrod 14.03 | Outershield 81K2-H<br>Outershield 690-H | Fluxofil 41 | Union MV NiMoCr |

## Covered electrodes for manual metal-arc welding

| Type of welding filler metal | Manufacturer<br>BÖHLER | ESAB | LINCOLN | OERLIKON | THYSSEN |
|---|---|---|---|---|---|
| **austenitic** | FOX A 7 CN | OK 67.43 | Jungo 307 | CITOCHROMAX N | Thermanit X |
| **ferritic, $R_e$ < 500 MPa** | FOX EV 50 | OK 55.00<br>OK 73.68 | Conarc 49C<br>Kryo 1 | TENACITO | Phoenix 120 K |
| **ferritic, $R_e$ = 500 - 700 MPa*** | FOX EV 65<br>FOX EV 85 | OK 75.75 | Conarc 60G<br>Conarc 80 | TENACITO 65 R | Phoenix SH V 1<br>Phoenix SH Ni 2 K 100 |

## Wires / fluxes for submerged arc welding

| Type of welding filler metal | Manufacturer<br>BÖHLER | ESAB | LINCOLN | OERLIKON | THYSSEN |
|---|---|---|---|---|---|
| **ferritic, $R_e$ < 500 MPa** | EMS 2 /<br>BÖHLER BB 24 | OK Autrod 12.24 /<br>OK Flux 10.72 | LNS 135 / P230<br>LNS 133U / P230 | OE-S2Mo / OP 139 | Union S 2 Mo /<br>UV 421 TT |
| **ferritic, $R_e$ = 500 - 700 MPa*** | 3 NiMo 1-UP<br>3 NiCrMo 2,5-UP/<br>Böhler BB 24 | OK Autrod 13.40 /<br>Flux 10.62 | LNS 164<br>LNS 168 /<br>Lincolnweld 8500 | OE-S3NiMo1<br>OE-S3NiMo2 /<br>OP 121TT | Union S 3 NiMo<br>Union S 3 NiMoCr /<br>UV 421 TT |

*$R_e$ = minimum yield strength of weld metal   *) not recommended for XAR 600*

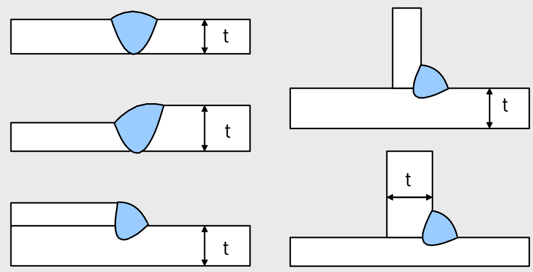
## 4. Avoidance of cold cracking

The avoidance of cold cracking requires special consideration for all the wear-resistant steels. Cold cracking is a time delayed phenomenon in the heat-affected zone or in the weld metal that can occur under conditions of hydrogen and stress exposure. An effective means for avoiding such cracking is preheating. It delays the cooling of the weld region and can thereby provide a hydrogen effusion. Measures to ensure a minimum input of hydrogen in the weld metal, such as cleaning and drying of the weld grooves, stable flow of shielding gas during MAG welding, and use of redried basic coated electrodes for manual arc welding, are also necessary. The welding sequence should be chosen with respect to minimized residual stresses.

If XAR® steels are welded with **austenitic** welding filler metals, generally there is no preheating necessary. The parts to be joined should have room temperature (at least 15 °C). For XAR® 600 with plate thicknesses above 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.

If **ferritic** consumables are used, sufficient preheating of the welding zone is required in many cases. Until the weld joint has been completed, the 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.

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




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]<br>I = welding current [A]<br>v = welding speed [cm/min] |
| **Heat input Q [kJ/mm]** | |
| $Q = 0.8 \cdot E$ | 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 possible by means of the computer programme ProWeld.

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

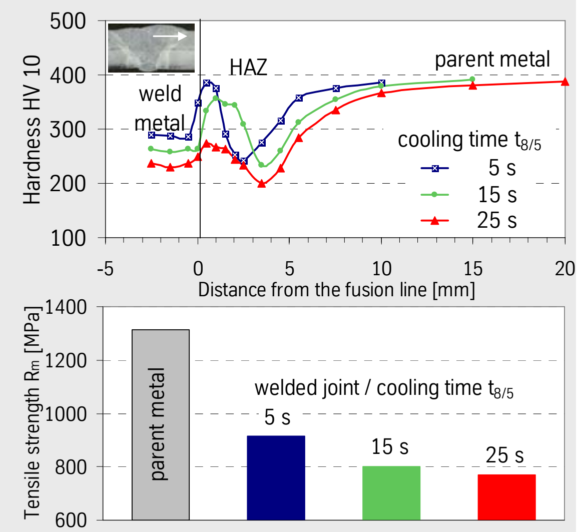
| Steel grade | Plate thickness t in mm ≤ 5 | ≤ 10 | ≤ 15 | ≤ 20 | ≤ 25 | ≤ 30 | ≤ 35 | ≤ 40 | ≤ 45 | ≤ 50 | ≤ 55 | ≤ 60 | ≤ 65 | ≤ 70 | > 70 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| XAR® 300 | - | 75 °C | 100 ° | 125 °C | | 150 °C | | 175 °C | | | | | | | |
| XAR® 400 | without | | | | 75 °C | | | 125 °C | | | 150 °C | | | | 175 ° |
| XAR® 450 | without | | | 75 °C | | 125 °C | | 175 °C | | | | | | | 200 ° |
| XAR® 500 | - | 100 °C | | 125 °C | | 150 °C | | 175 °C | | 200 °C | | | | | 200 ° + PH* |
| XAR® 600 | 150 ° | 175 ° | 200 ° | austenitic filler metals without | | austenitic filler metals 100 - 150 °C | | | | | | | | | |

** Post-heating 200 °C, 1 hour*


### 3. Welding conditions

The properties in the heat-affected zone of the weld undergo a change as a result of the temperature-time cycle during welding. The temperature-time cycle is dependent on the welding conditions, which can be characterised by the cooling time $t_{8/5}$. This is the time that is necessary to pass through the temperature range from 800 to 500 °C while a weld bead cools after deposition.

#### Hardness and strength of V butt joints
**XAR 400, t = 15 mm, MAG wire Union NiMoCr**

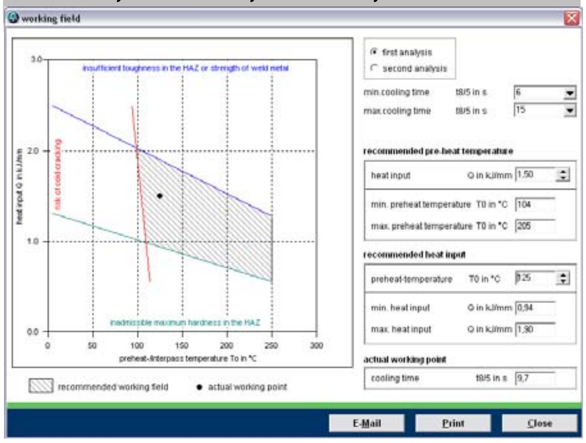



#### Recommended cooling time range

| Steel grade | Cooling time $t_{8/5}$ | |
|---|---|---|
| | minimum | maximum |
| XAR® 400, XAR® 450 | 5 s | 20 s |
| XAR® 500, XAR® 300 | 6 s | 15 s |
| XAR® 600 | 8 s | 15 s |

Excessively rapid cooling of the weld beads increases the risk of cold cracking in the weld region. Excessively slow cooling, on the other hand, results in lower hardness in the heat-affected zone and poorer toughness near to the fusion line. The welding conditions, expressed by the cooling time, influence the hardness minimum and the width of the softened zone on the one hand, and the strength of the welded joint on the other.

#### Calculation of heat input by means of ProWeld
**XAR 500, t = 20 mm, butt weld, MAG solid wire**




During welding it has to be assured that the cooling times are in the recommended range by using suitable welding conditions taking into account the necessary preheating temperature. Joining with lower-alloyed steels is generally not problematic if welding conditions are adapted to the XAR® steel. Assistance in choosing appropriate welding conditions is also offered by our computer programme ProWeld. General recommendations on arc welding are given in EN 1011- part 1 and part 2.