Recommendations for welding of XABO® 1100

1 Introduction

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XABO® 1100 is a low-alloyed structural steel supplied in the quenched and tempered condition and usually employed as-delivered in subsequent fabrication processes. The steel is delivered with a minimum yield strength of 1100 N/mm². Details concerning their chemical composition and mechanical properties can be found in the TKS material specification 247

When welding XABO® 1100 it must be ensured that the unavoidable thermal effects resulting from the process do not adversely affect the properties more than is admissible for the application concerned. As the welding conditions decisively influence the properties of the joints, it is the fabricator's responsibility to ensure, by selecting the appropriate parameters, that the requisite mechanical properties are present both in the weld metal and in the heat-affected zone (HAZ) of the welds. Details concerning the filler metals for XABO® 1100 and aspects of welding which should be observed are given in the following.

2 Weld seam preparation

Weld seam preparation for XABO® 1100, as in the case of conventional structural steels, is performed either by machining or thermal cutting (flame cutting, plasma- or Laser-cutting). If a high quality cut is required, the material should be descaled in the region of the cut prior to the thermal cutting operation. Preheating prior to thermal cutting is normally not necessary for plates with a thickness of less than 30 mm. If, however, the workpiece temperature is below 5 °C, a 100 mm wide zone on both sides of the planned cut should be heated up to at least luke warm. For plate thicknesses above 30 mm to 40 mm a preheat temperature of 75 °C should be applied. The preheat temperature should cover the whole plate thickness. This should be checked before starting the cutting operation on the reverse side of the plate. If the cut edges are to be subsequently cold formed, e. g. by bending or folding, or in case of tensioning in the plate thickness direction it is advisable to preheat a zone of around 100 mm wide to about 150 °C in the region of the cut for plate thicknesses of more than 20 mm. In the case of high tension in the plate thickness direction it might be preferable to remove the hardened zone by machining.

The cut faces and adjacent surfaces to be joined as well as the immediate surrounding area should be cleaned prior to the commencement of welding. Cutting slag, scale and rust should be removed either by brushing or by grinding. It should also be ensured by drying or preheating that the material in the joint region is moisture free. The cut faces should be checked either visually or by means of a penetrant flaw detection process for discontinuities and other defects which may disturb the welding operation.

3 Welding consumables

In the case of root passes and single-pass fillet welds, the weld metal undergoes an alloying through dilution with the parent material. As a result, the yield and tensile strength of the weld metal as compared with those of the "pure" weld metal are increased. For this reason, lower alloyed consumables are usually employed for root passes and single-pass fillet welds than for the filler and cap passes, particularly in the case of high strength steels. The following table lists consumables supplied by THYSSEN Schweißtechnik Deutschland GmbH, Hamm, which have proven successful in the welding of XABO® 1100 by shielded manual-arc welding (SMAW) and gas shielded-arc welding (GSAW). Needless to say that other consumables corresponding to those mentioned can also be used. The selection below is not exclusive and should not be taken as any deprecation of the suitability of other consumables which have not been listed.

Steel Grade	Application	Welding process	Filler metals	Typical CET (%) [1)]
XABO® 1100	Root pass and single-pass fillet welds	SMAW	SH Ni 2 K 90 SH Ni 2 K 100	0,28 0,33
		GSAW	Union MoNi / M 21 Union NiMoCr / M 21	0,30 0,33
	Filler and cap passes	SMAW	SH Ni 2 K 130 SH Ni 2 K 150	0,35 0,49
		GSAW	Union X 90 / M 21 Union X 96 / M 21	0,38 0,41

*) Shielding gas approx. 80 % Ar, 20 % CO_2

1) CET= Carbon equivalent, see Page 6

To avoid cold cracking it should be ensured that the hydrogen content in the weld metal is kept as low as possible. For this reason, the welding consumables must be protected during transportation and storage against moisture absorption. Rod electrodes must be redried in accordance with the manufacturer's instructions immediately prior to use. The electrodes are then stored at temperatures of 150 to 200 °C until use. Further details concerning the correct handling and treatment of welding consumables can be found in Stahl-Eisen-Werkstoffblatt 088 **/1/**.

4 Selecting correct welding conditions

4.1 Mechanical properties of welded joints

The mechanical properties of welded joints are determined in the first instance by the chemical composition of the steel and weld metal, and by the temperature-time-cycles occurring during the welding operation. Allowance is made for the influence of the chemical composition by matching the alloy composition of the filler metal to that of the steel. The most important factors influencing the temperature-time-cycles are the welding process employed, the preheating temperature, the heat input, the thickness of the workpiece and the weld geometry. These influencing factors are usually incorporated into a single parameter which characterizes the temperature-time-cycle, namely the cooling time $t_{8/5}$ **/1, 2/**. This is the time during which the bead and its HAZ cools down from 800 to 500 °C. The concentration of the different influencing factors to one distinguishing factor makes it a lot easier to overview the relationship which exists between the welding conditions on the one hand and the mechanical properties of the joint on the other.

If the welded passes cool down too rapidly from the austenitic range (low preheating temperature combined with low heat input), the strength of the weld metal would be considerably higher than that of the base material, thus adversely affecting the ductility of the welded joint. It also increases the danger of cold cracking in the weld metal and the HAZ. For SMAW the cooling time $t_{8/5}$ should be at least 8 s. As a prerequisite for such a short cooling time the hydrogen content of the weld metal has to be as low as possible. With respect to the cold cracking behaviour in GSAW cooling times $t_{8/5}$ less than 5 s should be avoided. If, on the other hand, the welded passes cool down from the austenitic range too slowly (high preheating temperature combined with excessive heat input), the strength properties of the weld metal become inferior to those of the base material. The danger also exists of an intolerably deleterious effect on the strength and toughness of the HAZ. When employing high-stength steels, it is advisable in the interests of cost efficiency to ensure that the joints exhibit the same favourable stength properties as the base material. This can only be achieved by applying the appropriate welding conditions. The following sections offer advice how to determine appropriate welding conditions.

To start with, it should be clarified in which range of the cooling time $t_{8/5}$ the required mechanical properties are met. In many cases a certain toughness in the HAZ is required. A graph like **Fig. 1** shows e.g.the determination of the maximum cooling time up to which the toughness in the HAZ is still reached. The graph shows the transition temperature T_{27} of multilayer welded joints depending on the cooling time $t_{8/5}$. The transition temperature is

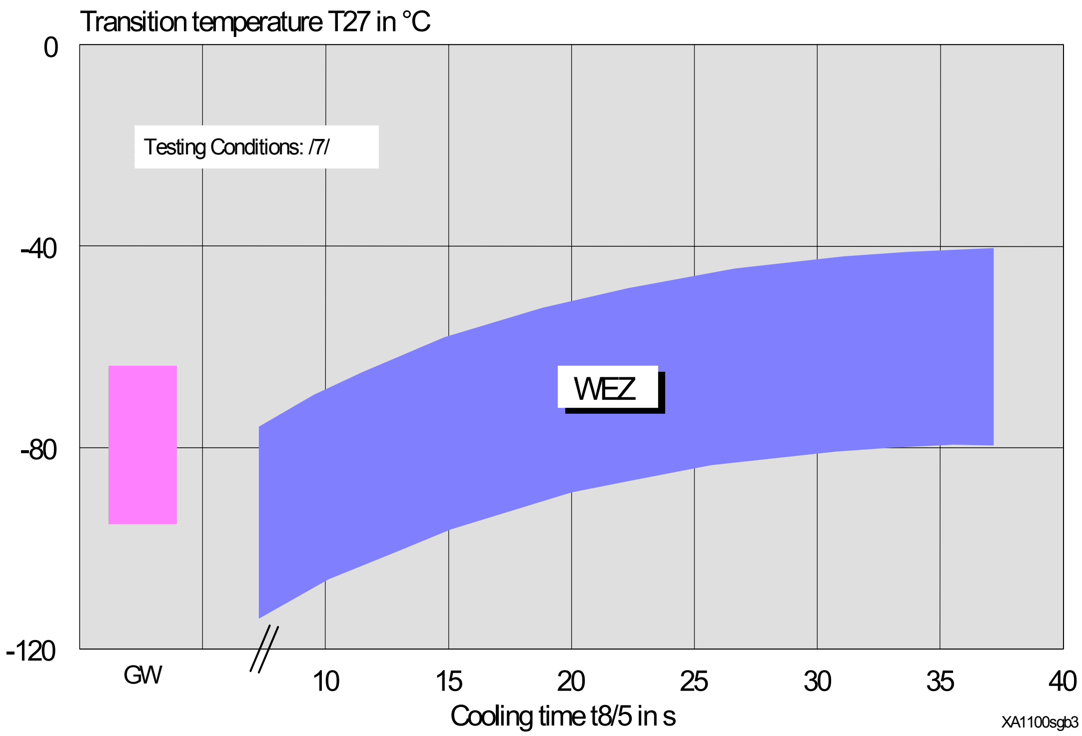

Fig. 1: Influence of welding conditions on the notch toughness of the heat affected zone of XABO® 1100 multilayer welds

the temperature where an inpact toughness of 27 J is determined. As can be seen from the graph the T_{27} deteriorates with increasing cooling times. It is therefore necessary to limit the preheat temperature and the heat input. The same considerations should be made for the weld metal. **Fig. 2** gives an example of mechanical properties in the weld metal of GSAW-joints as a function of the cooling time $t_{8/5}$. It becomes quite obvious that the mechanical properties of the weld metal are considerably influenced by the welding conditions resp. cooling time $t_{8/5}$. If the mechanical properties of the base metal are to be met, a certain cooling time should not be exceeded.

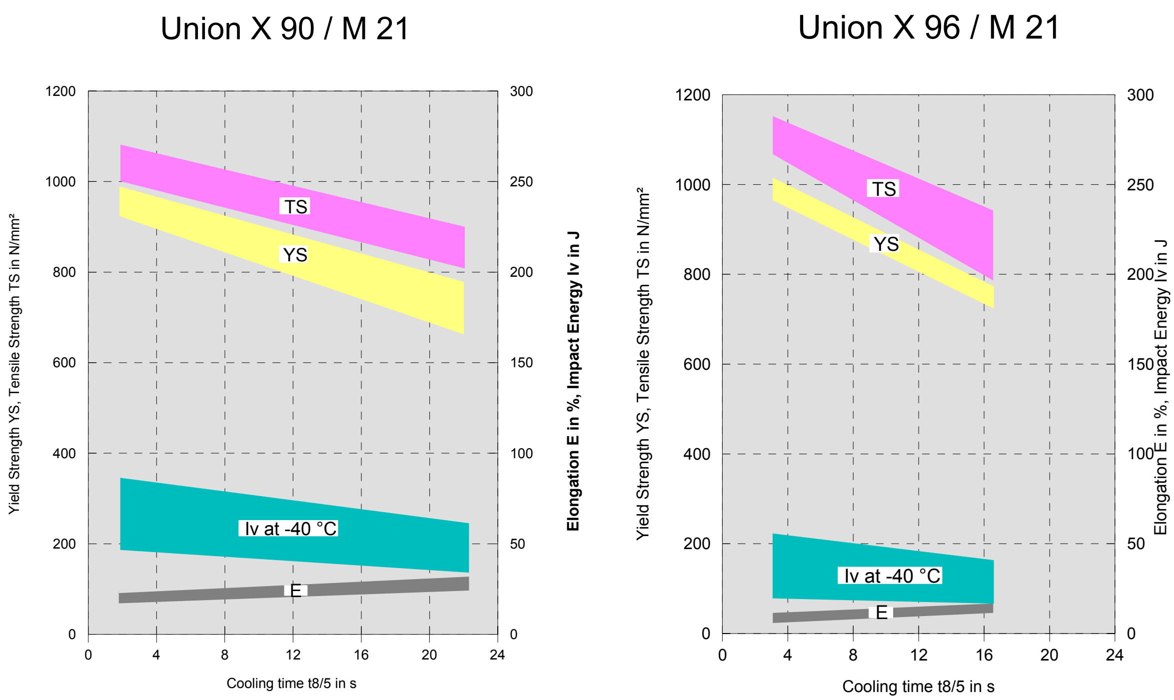

Fig. 2: GSAW-process using consumables Union X 90 / M 21 and Union X 96 / M 21
Influence of welding conditions on the weld metal properties

Once the appropriate cooling time range has been established, suitable combinations of preheat temperature and heat input can be determined by equations or graphs which are described in detail in **/1,2/**. The preheat temperature To in °C is the temperature of the seam area immediatly before the arc passes by. Depending on the arc energy E and the thermal efficiency k of the welding process, the heat input Q in kJ/mm can be calculated by the following equation:

$$Q = k \cdot E = k \cdot \frac{U \cdot I}{v \cdot 1000} = k \cdot \frac{U \cdot I \cdot t}{l \cdot 1000} \qquad (1)$$

The arc voltage U is in (V), the welding current I is in (A) and the welding speed v is given in (mm/sec). In case of the SMAW-process, instead of the welding speed v, the melting time of the electrode t (sec) and the bead length deposited l (mm) is taken into account. The thermal efficiency factor of SMAW or GSAW amounts to 0.85. Therefore an increased arc energy of approx. 15% is suitable for the two processes.

When appropriate welding conditions are set the next step concentrates on welding without cold cracking.

4.2 Avoidance of cold cracking

In order to avoid cold cracking, it is frequently necessary to preheat prior to welding. This retards the cooling rate of the individual passes, thus promoting hydrogen effusion from the weld. Furthermore, preheating has a favourable effect on the residual stress of the welded joint. The temperature before starting the first run is called the preheat temperature Tp. In case of multipass welding the term used in reference to the second and all ensuing beads is the interpass temperature Ti. Here it is self-evident that both temperatures should be sufficiently high to avoid cold cracking. They are therefore minimum temperatures. As Tp and Ti are generally identical only the term "preheat temperature" is used in the following.

The cold cracking behaviour of steels and weld metals has a substantial influence on the welding costs. Therefore there is quite an interest to classify steels and weld metal according to their cold cracking behaviour. The carbon equivalent CET which derives from cold cracking investigations **/3/** is most suitable for this purpose. It reads:

$$\text{CET in \%} = C + (Mn+Mo) / 10 + (Cr+Cu) / 20 + Ni / 40 \qquad (2)$$

The cold cracking behaviour is not only determined by the chemical composition of the steel and the weld metal, characterized by CET, but also essentially by the plate thickness d, the hydrogen content of the weld metal HD, the heat input Q during welding and the stress level of the welded joint **/4/**. The effect of CET, d, HD and Q on the preheat temperature can be summarized in the following formula.

$$T_p \text{ in °C} = 700\ CET + 160 \tanh(d/35) + 62\ HD^{0,35} + (53\ CET - 32)\ Q - 330 \qquad (3)$$

In this equation the carbon equivalent CET is given in %, the plate thickness d in mm. The hydrogen content HD is given in $cm^3/100g$ and refers to the deposited weld metal according to ISO 3690. The heat input Q is given in kJ/mm. For the calculation the internal stresses are assumed to be up to the yield strength of the parent metal or weld metal. In welded joints with a more favourable stress level lower preheat temperatures are justified. In case weldments with an extremly high level of stresses e.g. welding of nozzles of tubular member node points higher preheat temperatures than calculated by the formular might be required. Further information about applying the CET-concept to avoid cold cracking in welding high tensile structural steels are given in **/5/**.

Fig. 3 provides information about the preheat temperature for welding XABO® 1100 depending on the plate thickness and a hydrogen content of HD 2, which is characteristic for GSAW. The diagram is based on a typical CET of 0.38 % to 0.44 % for XABO® 1100-plates and a heat input Q of 1 kJ/mm. The diagram shows that the

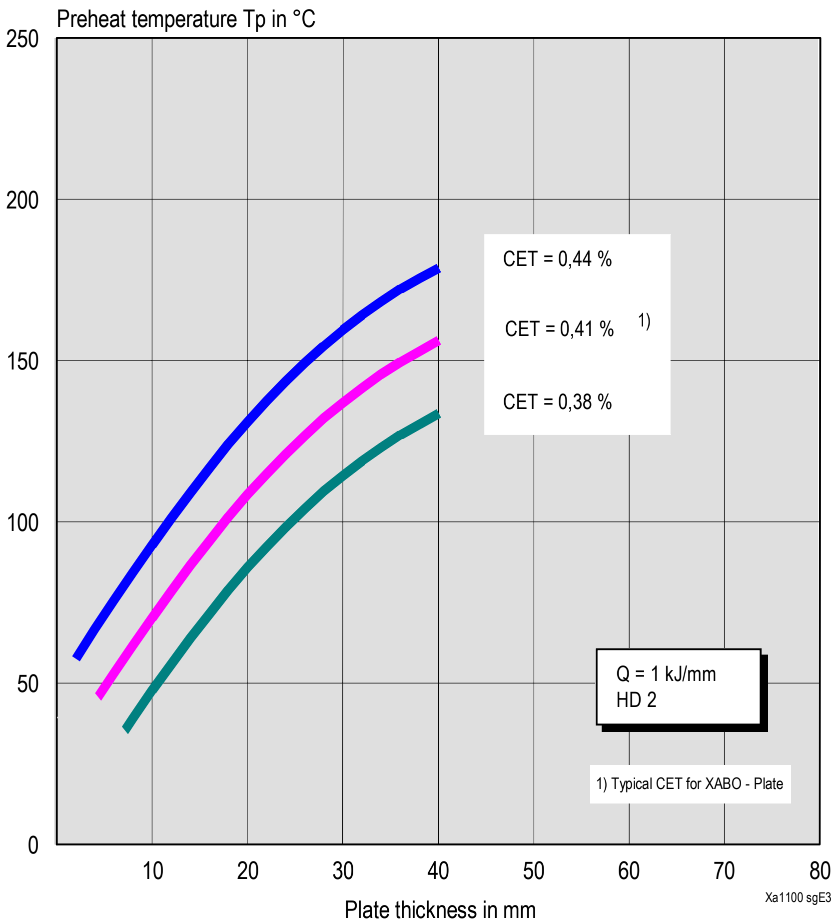

Fig. 3: Preheat temperature and interpass temperature for welding XABO® 1100

required preheat temperature to avoid cold cracking rises with increasing plate thickness and the increase of the CET. According to experience, one is on the safe side when using a preheat temperature calculated by equation (3) provided that the CET of the base metal exceeds that of the weld metal by at least 0.03 %. Otherwise the calculation has to be based on the CET of the weld metal increased by 0.03 %. Therefore the diagram also contains the increased CET-value of 0.44 % for commonly used consumables.

In the case of plate thicknesses of more than 20 mm it is advisable to post heat butt welds directly after completion for at least one hour at 200-250 °C to reduce the hydrogen content. This also applies to fillet welds with a thickness of more than 15 mm. The hydrogen-effusion post heat treatment should also be applied prior to the interpass cooling to ambient temperature of only partially filled welds.

4.3 Field of favourable welding conditions

By combining the predictions of Fig.1, Fig.2 and Fig.3 it is possible to determine a characteristic field of favourable welding conditions (FWC) for defined requirements. Those could be e. g. the minimum impact toughness in the HAZ of welded joints and a minimum cooling time for the welding process. These FWCs can help to optimise the welding conditions considerably and, by that, result in an economical production of welded structures. If e. g. the transition temperature of at least -60 °C is required in the HAZ of a

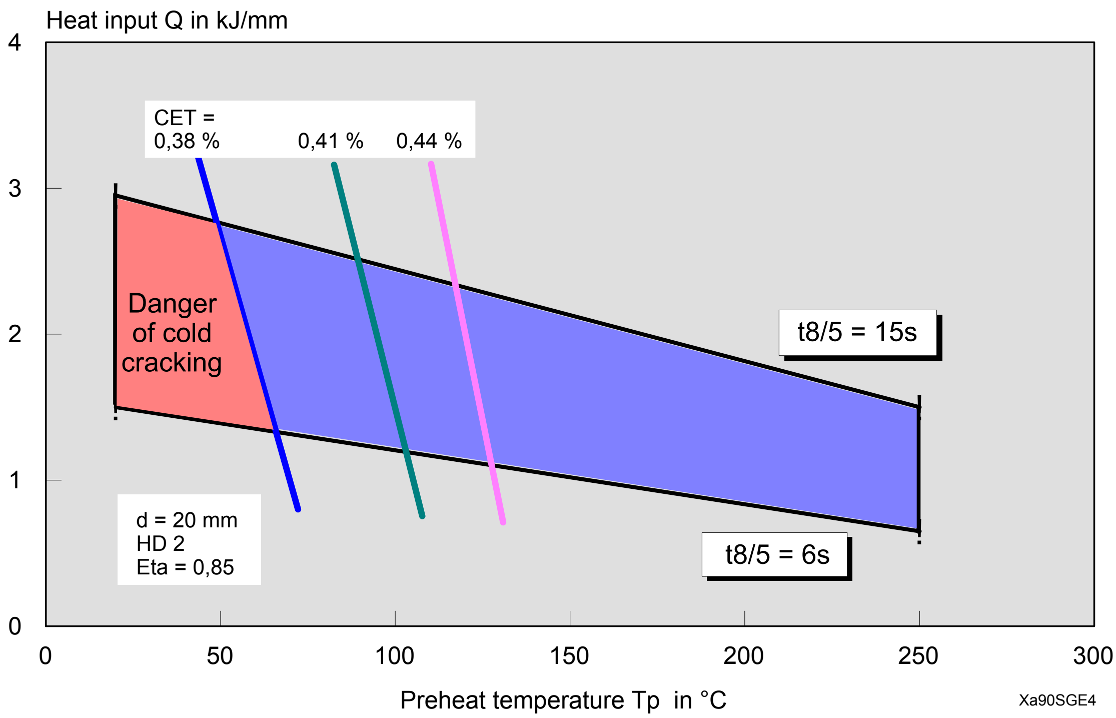

Fig. 4: Favoured field of welding conditions (FWC) for XABO® 1100 on the basis of:

- minimum transition temperature T_{27} in the WEZ = - 60 °C
- minimum cooling time 6 s, maximum cooling time 15 s

XABO® 1100 welded joint, according to Fig. 1 the cooling time $t_{8/5}$ has to be limited to 15 sec. This cooling time has to be reduced, if the mechanical properties of the base metal are also required in the weld metal. Due to the cold cracking behaviour and for economical reasons the shortest cooling time $t_{8/5}$ should be set with 6 sec. If the random conditions like plate thickness, form of the joint and welding process are clear, it is no problem to calculate the heat input for two cooling times, e.g. at ambient preheat temperature and at 250 °C. The four results are plotted into a graph like **Fig 4**. By connecting the four points the FWC becomes apparent. All possible welding conditions which meet the required mechanical properties of the weldment are found within this FWC. To avoid cold cracking the preheat temperatures for a low and high heat input (e.g. 1kJ/mm and 3 kJ/mm) should be calculated, taking into account the CET-value, the plate thickness and the hydrogen content of the weld metal. By plotting the two results into the graph and connection them the line divides the cold crack free area from that part where cold cracking might appear.

5 Practical hints

The high strength structure steel XABO® 1100 has been successfully applied for numerous highly stressed constructions, demonstrating its ready weldability. The following contains some practical hints which should be taken into consideration when welding XABO® 1100. Reference should also be made in this connecting to the already mentioned Stahl-Eisen-Werkstoffblatt 088 **/1/**.

5.1 In the case of fillet welds and where high quality joints are required, it is advisable to remove the paint coating of primed plates from the joint area prior to welding.

5.2 Tack welding is usually carried out by the GSAW process with low-alloyed wire electrodes or by the SMAW process using soft basic electrodes. The tack length should be at least 50 mm. In the case of plate thicknesses exceeding 15 mm, two-pass tack welding is recommended.

5.3 Prior to welding the backing run, the root layer should be ground and, if allowed to cool down to a temperature below the minimum preheating temperature, checked for cracks.

5.4 When depositing the cap pass, the bead sequence should be selected so that there is no contact between the last bead and the parent material.

5.5 Stress-relieving after welding is not recommendable. It may lead to excessive changes of the mechanical properties of the plates achieved by the quench- and temper treatment.

5.6 The non-destructive inspection of joints which have not undergone a hydrogen-effusion post weld heat treatment should not be carried out until at least 48 h after completion of the welding work. This is in order to ensure that any delayed cold cracking which may have occurred can be reliably etected.

Further information concerning XABO® 1100 and its handling are given in **/6-11/**. Fabricators using XABO® 1100 for the first time are kindly advised to consult Thyssen Krupp Steel AG with regard to suitable welding conditions.

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