

Recommendations for welding of N-A-XTRA®

1 Introduction

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N-A-XTRA® is a low-alloy structural steel supplied in the quenched and tempered condition and usually employed as-delivered in the subsequent fabrication processes. The steel is delivered in three different grades with yield points of 550, 620 resp. 700 N/mm². Details concerning its chemical composition and mechanical properties can be found in TKS material specification 215.

When welding the material it must be ensured that the unavoidable thermal effects resulting from the process do not adversely affect its properties more than is admissible for the loading conditions of 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 N-A-XTRA® and aspects of welding which should be observed are given in the following.

2 Weld seam preparation

Weld seam preparation for N-A-XTRA®, as in the case of conventional structural steels, is performed either by machining or thermal cutting (flame cutting, fusion 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 50 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 50 mm a preheat temperature of 75 °C should be applied, above 70 mm plate thickness the cutting area should be heated up to 100 °C. 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 100 to 150 °C in the region of the cut for plate thicknesses of more than 30 mm. In the case of high tension in the plate thickness direction it might be preferable to remove the hardened zone by machining.

The fusion faces and adjacent surfaces to be joined and 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 fusion 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 N-A-XTRA® by shielded manual-arc welding (SMAW), gas shielded-arc welding (GSAW) and submerged-arc welding (SAW). 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⁾
N-A-XTRA® 550	Root pass and single-pass fillet welds	SMAW	SH V 1	0.24
		GSAW	Union K 56 / M 21*	0.25
	Filler and cap passes	SMAW	SH Ni 2 K 90	0.28
		GSAW	Union MoNi / M 21*	0.26
		SAW	S 3 NiMo/UV 421 TT	0.30
N-A-XTRA® 620 and N-A-XTRA® 700	Root pass and single-pass fillet welds	SMAW	SH Ni 2 K 90	0.28
		GSAW	Union MoNi / M 21*	0.26
	Filler and cap passes	SMAW	SH Ni 2 K 100	0.33
		GSAW	Union NiMoCr / M 21*	0.33
		SAW	Union S 3 NiMoCr / UV 421 TT	0.35

*) Shielding gas approx. 80 % Ar, 20 % CO₂

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. When welding N-A-XTRA®-steels, the hydrogen content in the weld metal should not exceed 5 cm³ per 100 g of weld metal (<HD 5 acc. to ISO 3690). For this reason, the welding consumables must be protected during transportation and

storage against moisture absorption. Rod electrodes must be re-dried in accordance with the manufacturer's instructions immediately prior to use. Usually, drying takes place over a period from at least 2 hours up to a maximum of 10 hours at 300 to 350 °C. The electrodes are then stored at temperatures of 150 to 200 °C until use. Welding fluxes generally also have to be redried prior to use. Normally drying takes place over a period from at least 2 hours up to a maximum of 10 hours at 300 to 400 °C. In order to prevent the fluxes from becoming damp again after drying, it is advisable to store them in drying ovens at approx. 150 °C or in sealed, air-tight metal containers 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

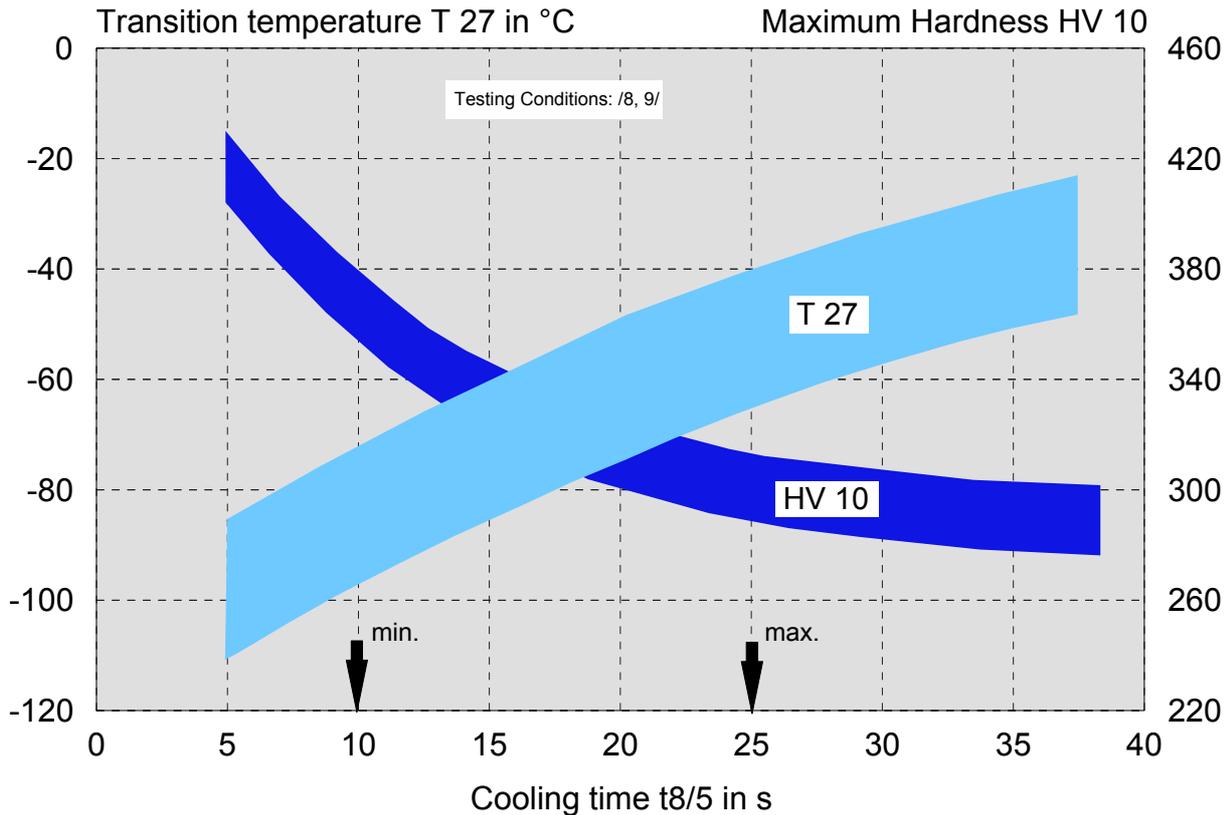
4.1 Mechanical properties of welded joints

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 characterises 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. 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 parent material. The danger also exists of an intolerably deleterious effect on the strength and toughness of the HAZ. When employing high-strength steels, it is advisable in the interests of cost efficiency to

ensure that the joints exhibit the same favourable strength 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. 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. To avoid a



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Fig. 1 Influence of welding conditions on the notch toughness and hardness of the affected zone of N-A-XTRA® multilayer welds

too high hardness in the HAZ a minimum cooling time has to be established. The same procedure should be considered for the weld metal

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 in described detail in /1,2/. The preheat temperature T_0 in °C is the temperature of the seam area immediately before the arc passes by. The heat input Q in kJ/mm is the energy when welding related to the bead length. Depending on the arc energy E and the thermal

efficiency of the welding process, the heat input Q can be calculated by the following equation:

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

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. For SAW the thermal efficiency factor of 1.0 has been assumed. Owing to the lower thermal efficiency of SMAW or GSAW this factor is 0.85. Therefore an increased arc energy of approx. 15% is suitable for the two latter 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 reducing the residual stresses of the welded joint. The lowest temperature before starting the first run is called preheat temperature T_p . In case of multipass welding the term used in reference to the second and all ensuing beads is the minimum interpass temperature T_i . Here it is self-evident that both temperatures should be sufficiently high to avoid cold cracking. They are therefore minimum temperatures. As T_p and T_i 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 them 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:

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

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.

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

In this equation the carbon equivalent CET is given in %, the plate thickness d in mm. The hydrogen content HD is given in $\text{cm}^3/100\text{g}$ 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 extremely high level of stresses e. g. welding of nozzles of tubular member node points higher preheat temperatures than calculated by the formula might be required. Further information about applying the CET-concept to avoid cold cracking in welding high tensile steels are given in /5/.

Fig. 2 provides information about the preheat temperature for welding N-A-XTRA®-steels depending on the plate thickness and the hydrogen content of the weld metal. The diagram is based on a typical CET for N-A-XTRA® with 0.36 % and an heat input Q of 2 kJ/mm . The diagram shows that the required preheat temperature to avoid cold cracking rises with increasing plate thickness and higher levels of hydrogen content in the weld metal. According to experience, one is on the safe side when using 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 %.

In the case of plate thicknesses of more than 30 mm it is advisable to post heat butt welds directly after completion for at least an hour at 150 to 250 $^\circ\text{C}$ to reduce their hydrogen content. This also applies to fillet welds with a thickness of more than 20 mm. This hydrogen-effusion post heat treatment should also be applied prior to the interpass cooling to ambient temperature of only partially filled welds. A hydrogen-effusion post heat treatment is particularly advisable with applying by the SAW-process.

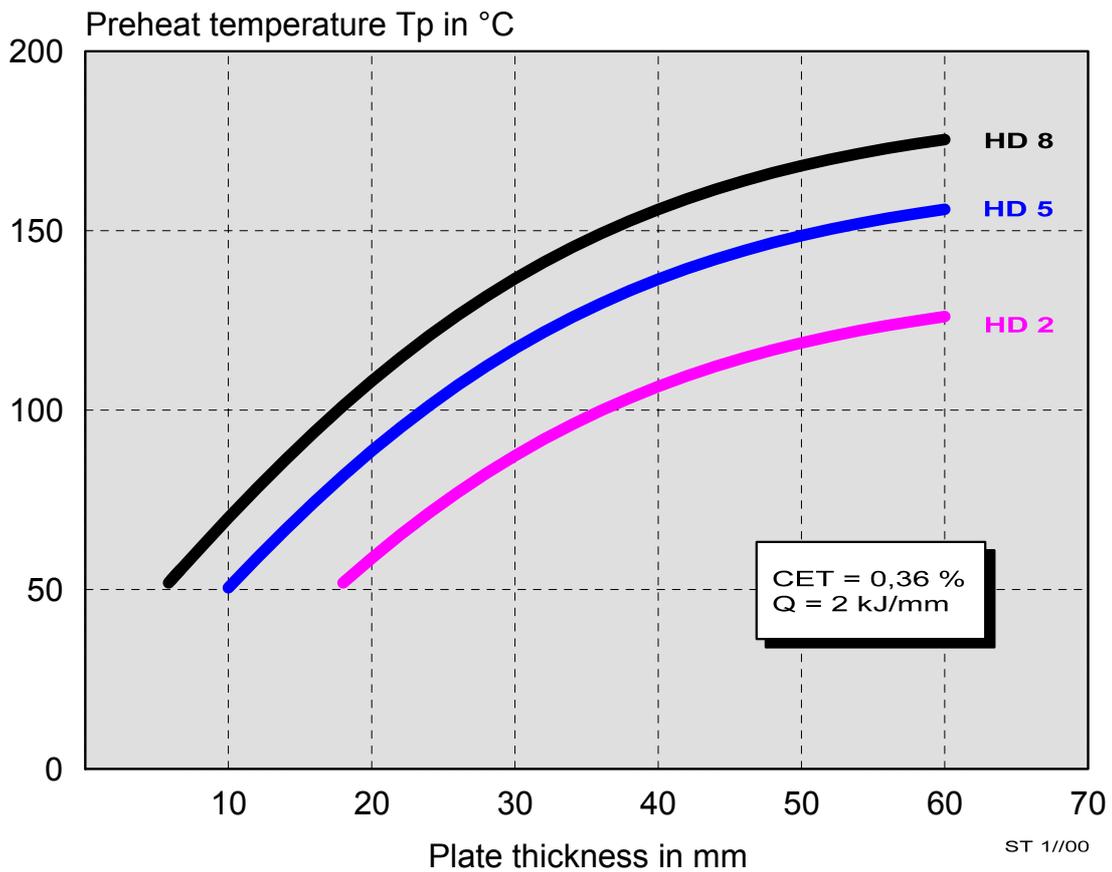
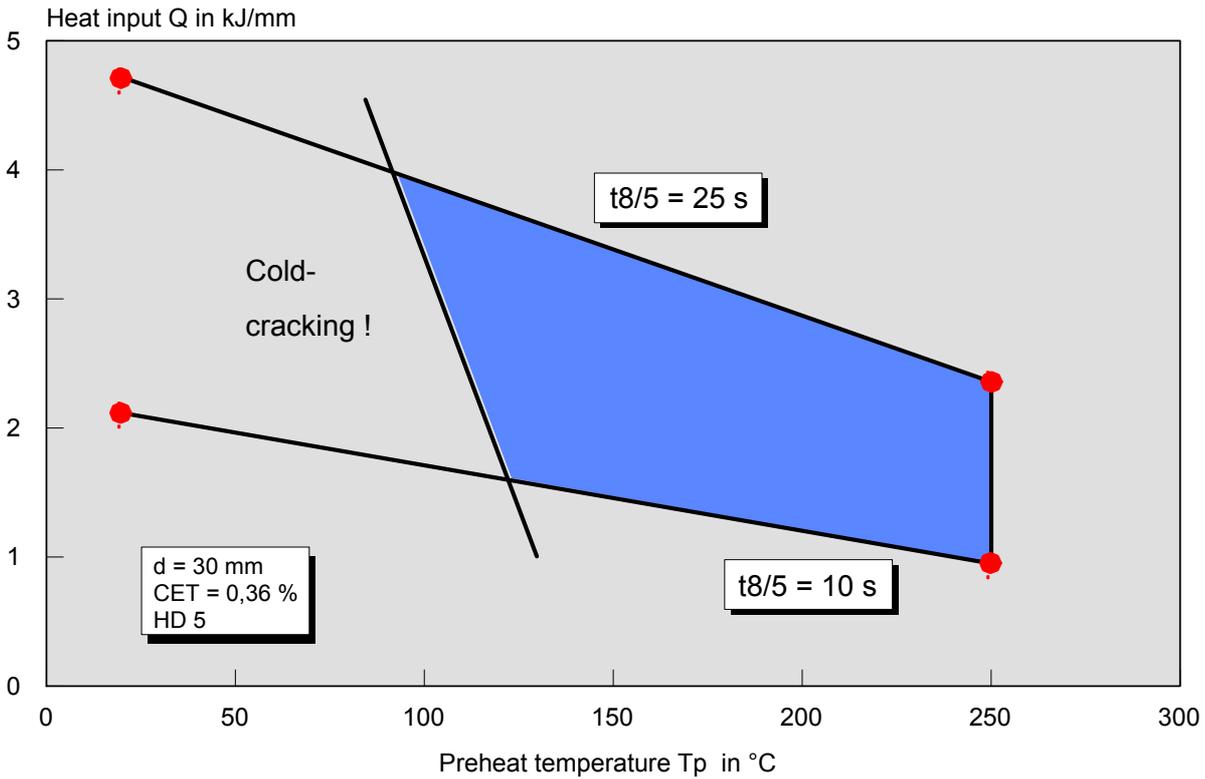


Fig. 2 Preheat temperature and interpass temperature for welding N-A-XTRA®-steels

4.3 Field of favourable welding conditions

By combining the predictions of Fig. 1 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 and a limited maximum hardness in the HAZ of welded joints. 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 $-40 \text{ }^\circ\text{C}$ is required in the HAZ of a N-A-XTRA® welded joint, according to Fig. 1 the cooling time $t_{8/5}$ has to be limited to 25 sec. Due to a maximum admissible hardness of 380 HV the shortest cooling time $t_{8/5}$ could be set with 10 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 the second at $280 \text{ }^\circ\text{C}$. The four results are plotted into a graph like Fig 3. 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.



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Fig. 3 Favoured field of welding conditions for N-A-XTRA® - steels on the basis of:

- minimum transition temperature $T_{27} = - 40 \text{ }^\circ\text{C}$
- maximum hardness in the HAZ = 380 HV 10

To solve the cold cracking problem the appropriate preheat temperature for a low and a high heat input should be calculated by formula (3). The two results are plotted into Fig. 3 and connected by a straight line. To avoid cold cracking preheat temperatures and welding conditions should be within the marked field right of this line; to the left, there is the risk of cold cracking .

5 Practical hints

N-A-XTRA® has been successfully applied for numerous highly stressed constructions, demonstrating its ready weldability. The following contains a number of practical hints which should be taken into consideration when welding N-A-XTRA®-steel. Reference should also be made in this connection to Stahl-Eisen-Werkstoffblatt 088 /1/ and DAST-Richtlinie 011 /6/.

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-alloy 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 20 mm, two-pass tack welding is recommended.
- 5.3 Prior to welding the backing run, the root beads 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 of the welds is not necessary in order to enhance their mechanical properties. If, owing to building regulations or for design reasons stress-relieving is necessary, it should be carried out within a temperature range of 530 to 580 °C. Annealing above 600 °C may lead to excessive changes in the mechanical properties of the weld with the result that a further quench-and-temper treatment is necessary. In such cases, filler metals must be used which will exhibit mechanical properties corresponding to those of the base material after the weld metal has been quenched and tempered.
- 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 detected.

Further information concerning N-A-XTRA® and its handling are given in */7-14/*. Fabricators using N-A-XTRA® for the first time are kindly advised to consult ThyssenKrupp Steel AG with regard to suitable welding conditions.



6 Literature

- / 1/ Stahl-Eisen-Werkstoffblatt 088: Weldable fine grained structural steels - Guidelines for processing, particular for fusion welding.
4th edition, April 1993, Verlag Stahleisen mbH, Düsseldorf / FRG
- / 2/ Degenkolbe, J., D. Uwer and H. Wegmann: Characterization of Weld Thermal Cycles with Regard to their Effect on the Mechanical Properties of Welded Joints by the Cooling Time $t_{8/5}$ and its Determination. IIW-Doc. IX-1336-84
- / 3/ Uwer, D. und H. Höhne: Characterization of the cold cracking behaviour of steels during welding. IIW-Doc. IX-1630-91.
- / 4/ Uwer D. und H. Höhne: Determination of suitable minimum preheating temperatures for the cold-crack-free welding of steels. IIW-Doc. IX-1631-91.
- / 5/ Uwer D. und H. Wegmann: Recommendations for avoiding cold cracking when welding structural steels. Thyssen Steel AG / FQP-Schweißtechnik
- / 6/ DASt-Richtlinie 011, Hochfeste schweißgeeignete Feinkornbaustähle StE 460 und StE 690, Anwendung für Stahlbauten. Ausgabe Februar 1988, Stahlbau-Verlags GmbH, Köln
- / 7/ European Standard prEN 1011: Guidelines for arc welding of ferritic structural steels
- / 8/ Determination of the effect of welding on the toughness in the heat-affected zone of multi-pass welds. IIW-Doc. IX-1340-84
- / 9/ Determination of the effect of welding on the maximum hardness in the heat-affected zone of welded joints. IIW-Doc. IX-1342-84
- /10/Müsgen, B.: High strength quenched and tempered steels - production, properties and applications. Metal Construction (1985), p. 495 - 500
- /11/Müsgen, B. und J. Degenkolbe: Untersuchungen zur Formgebung und Wärmebehandlung hochfester wasservergüteter Baustähle. "Bänder Bleche Rohre" (1978), H. 2, S. 56 - 62

/12/Müsgen, B. und K. Hoffmann: Improvement of the fatigue strength of welded high strength steels. Thyssen Technische Berichte (1979), Heft 1, S. 67 - 79

/13/Herr, D. und B. Müsgen: Wasservergütete Baustähle für Nutzfahrzeuge. Thyssen Technische Berichte (1979), Heft 1, S. 77 - 85

/14/Gerster, P.: MAG-Schweißen hochfester Baustähle im Fahrzeugbau. DVS-Berichte Band 209 (2000), S. 41 - 46.

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