

Section 3

Heat Treatment

A. Scope

1. These Rules apply to preheating for, and heat input during welding and to post-weld heat treatment of welded components where required. For preheating of hull structural steels, see also Chapter 3, Section 1, H.4. and H.5.

2. Requirements relating to the heat treatment of hot or cold formed welded components (e.g. spherical or dished ends, T-pieces and elbows) are stipulated in the Society's Rules for Materials.

B. Equipment and Appliances for Heat Treatment

1. Equipment and appliances for preheating

Preheating may be carried out either in heat treatment equipment or by means of mobile heating appliances, e.g. gas burners or electrical induction or resistance heating appliances as applicable (resistance mats). A condition of their use is that the prescribed preheating and interpass temperatures must be capable of being kept constant and monitored throughout the welding operation.

The temperature may be monitored by means of suitable appliances or aids, e.g. contact thermometers, temperature sensors or temperature-sensitive crayons.

2. Fixed heat-treatment equipment (heat-treatment furnaces)

2.1 The fixed heat-treatment facilities (heat-treatment furnaces) must be of suitable size for the particular components and structures in question and be fitted with an appropriate temperature control facility. The furnaces must ensure that the particular heat treatment temperatures stipulated can be guaranteed and that the temperature is evenly and accurately controlled (DIN 17052, quality grade C).

2.2 An adequate number of temperature recorders shall be provided, subject to a minimum of 2 to each furnace. The temperature variation over the period shall be established and recorded. The temperature control device and the temperature and time recording instruments used shall be checked at regu-

lar intervals (at least once a year) and documentary proof of the inspection results submitted to the Society on request.

3. Other heat-treatment equipment

The primary requirements are given in B.1., but depend upon the particular requirements relating to the component or structure. The type and method of the heat treatment in question is subject to the Society's consent.

If no heat treatment furnace of sufficient size are available for the heat treatment of components, heat treatment may be carried out in mobile facilities (transportable furnaces) or in equipment which has been specially designed for the purpose, subject to the Society's consent. Such equipment shall comply with the requirements stated in 2.1 and 2.2 with regard to function, temperature control and temperature recording and shall be presented to the Society for inspection before being used. Care shall be taken to ensure that there is adequate insulation of the components or welds needing heat treatment. Unacceptable temperature gradients in the component shall be avoided.

C. Principles Relating to Heat Treatment

1. Heat treatment, temperature measurements and recording shall be performed by competent personnel. For this and the performance of heat treatment operations, cf European draft Standard (Document N 225) "Welding, quality requirements relating to heat treatment in conjunction with welding and forming".

2. The type, temperature and duration of the heat treatment process, in addition to the rates of heating and cooling are determined by the material, the thickness of the material, the production process and the nature of the component or structure. Cf also the provisions of EN 1011 Parts 1 to 4 and in the regulations given in Chapter 3. The information and recommendations provided by the manufacturer of the materials and welding consumables shall be observed.

3. Details of the pre- and post-weld heat treatment of a component or structure shall be included in the production documents submitted for inspection by the Society. Where the manufacturer's welding procedure specifications (WPS) are used, these shall contain the necessary information relating to preheating, heat input during welding and post-weld heat treatment.

4. The whole of the component is normally subject to post-weld heat treatment. The heat treatment of part or sections of welds or the heat treatment of partial areas, especially pressurized components, require the Society's consent in each individual case. A specification relating to this shall be submitted to the Society for examination.

5. Where welded joints are to be produced between different materials, in the case of complex welded components (e.g. LNG/LPG process pressure vessels and gas tanks), components which have high levels of cold forming (more than 3 %) or extensive structural and repair welds to castings, the need for, type and extent of any heat treatment shall be agreed with the Society.

6. Parts shall be properly prepared for heat treatment in due order. Flange facings and sealings must be adequately protected against scaling. Precautions shall be taken to protect against component distortions; components and structures shall be positioned accordingly. Unacceptable temperature gradients during the heat treatment process and during heating and cooling shall be avoided.

D. Weather Protection, Preheating, Heat Input during Welding

1. Weather protection, welding at low temperatures

1.1 The area in which welding work is performed is to be sheltered from wind, damp and cold, particularly if out of doors. Where gas-shielded arc welding is carried out, special attention is to be paid to ensuring adequate protection against draughts. When working in the open under unfavourable weather conditions it is advisable to dry welding edges by heating.

1.2 At ambient temperatures below + 5 °C, additional measures shall be taken, such as shielding of components, extensive preliminary heating and preheating, especially when welding with a relatively low heat input (energy input per unit length of weld), e.g. when laying down thin fillet welds or in the case of

rapid heat dissipation, e.g. when welding thick-walled components. Wherever possible, no welding should be performed at ambient temperatures below - 10 °C.

2. Preheating for the welding of ferritic steels

2.1 The need for preheating of ferritic steels and the preheating temperature depend on a number of factors. Chief among these are:

- the chemical composition of the base material (carbon equivalent) and the weld metal,
- the thickness of the workpiece and the type of weld joint (two or three dimensional heat flow),
- the welding process and the welding parameters (energy input per unit length of weld),
- the shrinkage and transformation stresses,
- the temperature dependence of the mechanical properties of the weld metal and the heat-affected zone,
- the diffusible hydrogen content of the weld metal.

2.2 The operating temperature to be maintained (minimum preheating temperature and maximum interpass temperature) for (hull) structural steels may be determined in accordance with EN 1011-2. Guide values for the preheating temperature are contained in Figures 3.1 and 3.2 shown below for two different energy inputs per unit length of weld ¹ and hydrogen contents HD ² of the weld metal, together with the various carbon equivalents CET ³.

¹ Energy input per unit length of weld:

$$E = \frac{U [\text{volts}] \cdot I [\text{amps}] \cdot \text{welding time} [\text{min}] \cdot 6 \left[\frac{\text{kJ}}{\text{mm}} \right]}{\text{length of weld} [\text{mm}] \cdot 100}$$

² HD 5 = max. 5 ml diffusible hydrogen per 100 g of weld metal

HD 15 = max. 15 ml diffusible hydrogen per 100 g of weld metal

³ Carbon equivalent:

$$\text{CET} = C + \frac{\text{Mn} + \text{Mo}}{10} + \frac{\text{Cr} + \text{Cu}}{20} + \frac{\text{Ni}}{40} \quad [\% \text{ in weight}]$$

The above formula for calculating the carbon equivalent CET in accordance with EN 1011-2 can be applied to steels which have yield strengths ranging from 300 to 1000 MPa and to the following chemical composition: 0.05 - 0.32 % C, max. 0.8 % Si, 0.5 - 1.9 % Mn, max. 0.75 % Mo, max. 1.5 % Cr, max. 0.7 % Cu, max. 2.5 % Ni, max. 0.12 % Ti, max. 0.18 % V, max. 0.005 % B, max. 0.06 % Nb.

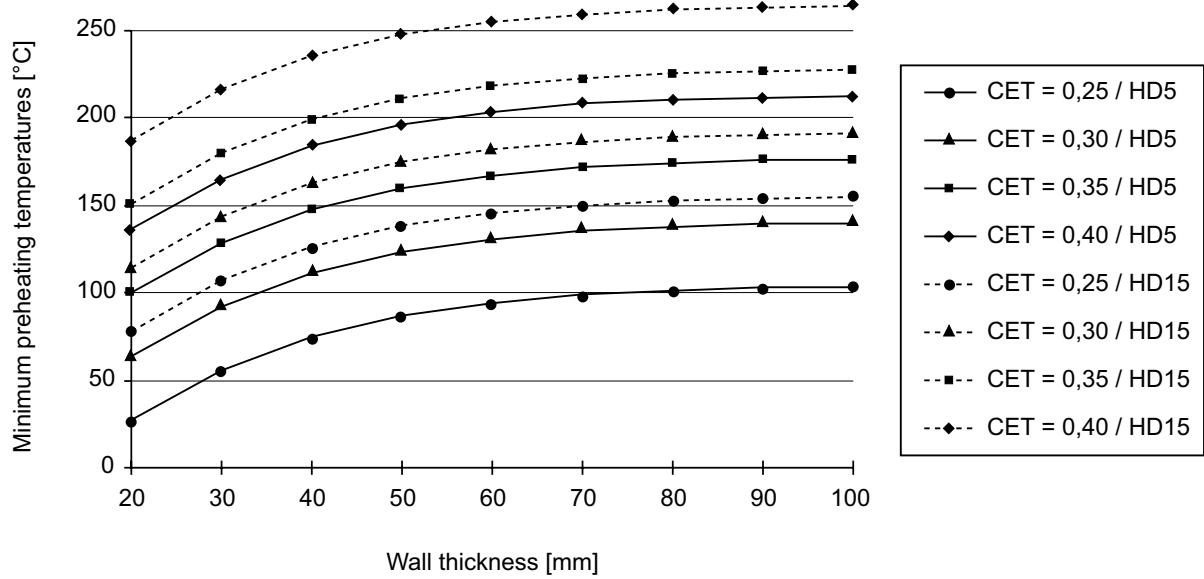


Fig. 3.1 Minimum preheating temperatures (operating temperatures) applicable to welding processes with a relatively low heat input (energy input per unit length ¹ $E \approx 0,5 \text{ kJ/mm}$) as a function of the carbon equivalent CET ³ of the base material and the hydrogen content of the weld metal

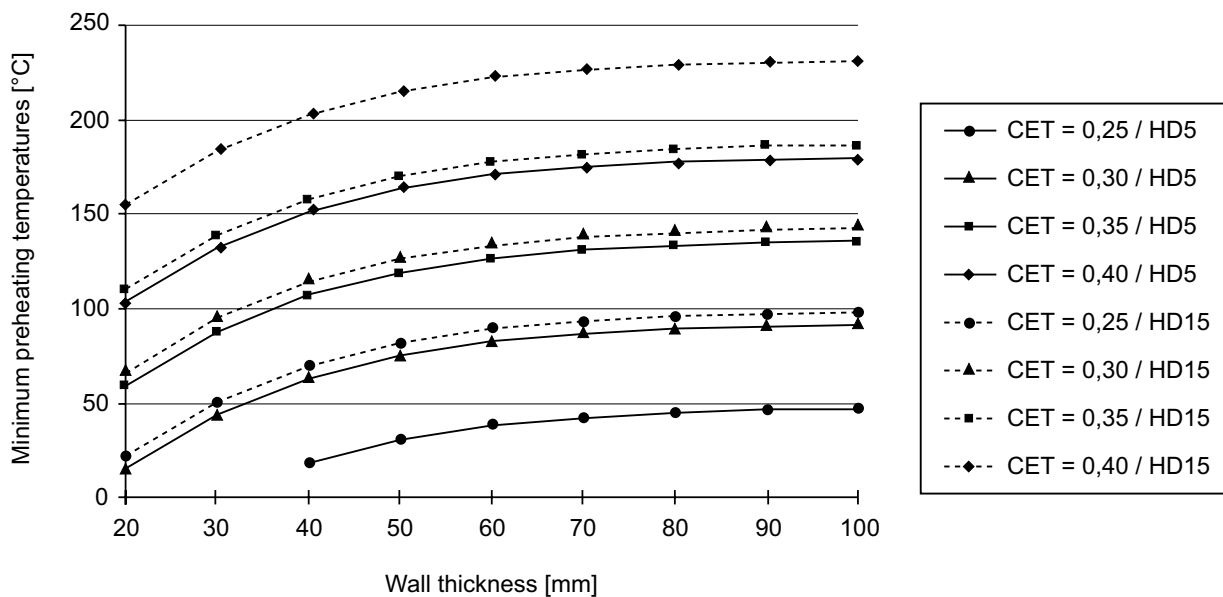


Fig. 3.2 Minimum preheating temperatures (operating temperatures) applicable to welding processes with a relatively high heat input (energy input per unit length ¹ $E \approx 3,5 \text{ kJ/mm}$) as a function of the carbon equivalent CET ³ of the base material and the hydrogen content of the weld metal

Note:

Table 3.1 below gives guide values for the carbon equivalents CET³ of some of the standard grades of steel. Basis were the information of the steel manufacturers. In case of doubt CET has to calculate by the actual analysis.

Table 3.1 Guide values for the carbon equivalent CET

Steel grades	CET [% in weight]	
	Average value ¹	Maximum value ¹
GL-A	0,27	0,28
GL-E	0,26	0,27
GL-D36	0,33	0,34
GL-E36TM	0,27	0,28
GL-D40	0,27	0,28
GL-E40TM	0,24	0,25
S275NL	0,25	0,27
S460NL	0,34	0,36
S460ML (TM)	0,27	0,28
S690QL	0,26	0,38
S890QL	0,38	0,41
2C22	0,26	0,29
34CrMo4	0,49	0,55
GS20Mn5	0,34	0,41

¹ For product thicknesses up to 50 mm.

2.3 Table 3.2 contains guide values for preheating high temperature Mo or CrMo alloy steels (used for steam boiler) in accordance with the Society's Rules for Materials; cf EN 1011-2.

2.4 Table 3.3 contains guide values for preheating nickel steels tough at sub-zero temperatures in accordance with the Society's Rules for Materials. For details of this and also particulars relating to the use of austenitic or nickel-based welding consumables, cf. EN 1011-2.

2.5 Depending on the complexity of the component, the welding process applied, the level of the residual stresses in the component and the (low) ambient temperature, the preheating temperatures shall be increased or the boundary wall thicknesses reduced as appropriate. For the effect of the various factors on the preheating temperature level, see Table 3.4

2.6 If the temperature of the workpiece is lower than the minimum operating temperature calculated on the basis of the above data, preheating is called for. Various methods are available:

- continuous heating prior to and during welding,
- alternate heating and welding,
- heating only prior to the start of welding, if the heat input during welding is sufficient to maintain the minimum operating temperature.

The heating method may be chosen at will, provided that it does not harm the material by localized overheating or cause a nuisance by making the welding area contaminated.

Table 3.2 Guide values for preheating high-temperature steels (used for steam boiler)

Category in accordance with DIN V 1738 (CR 12187)	Steel grade	Thickness [mm]	Minimum preheating temperature [°C] given an H ₂ content of the weld metal of		
			≤ 5 ml/100 g	> 5 – ≤ 10 ml/100 g	> 15 ml/100 g
1.2	16Mo3	≤ 15	20	20	100
		> 15 – ≤ 30	20	75	100
		> 30	75	100	not permitted
5.1	13CrMo4-5	≤ 15	20	100	150
		> 15	100	150	not permitted
5.2	10CrMo9-10 11CrMo9-10	≤ 15	75	150	200
		> 15	100	200	not permitted

Table 3.3 Guide values for preheating nickel steels tough at sub-zero temperatures

Category in accordance with DIN V 1738 (CR 12187)	Steel grade	Thickness [mm]	Minimum preheating temperature [°C] given an H ₂ content of the weld metal of	
			≤ 5 ml/100 g	> 5 – ≤ 10 ml/100 g
7.2	12Ni14 (3,5 % Ni)	> 10	100	150
7.3	12Ni19 (5 % Ni)	> 10	100	not permitted
	X8Ni9 (9 % Ni)	> 10	100	not permitted
	X7Ni9 (9 % Ni)	> 10	100	not permitted

Table 3.4 Effect of the various factors on the level of preheating

Shift in the preheating temperature to lower values	Factors influencing preheating	Shift in the preheating temperature to higher values
low alloying element content	chemical composition of the base material (hardenability), e.g. expressed by the carbon equivalent	higher alloying element content
thin	thickness of the workpiece or component (heat dissipation, rigidity, residual stress condition)	thick
butt joints (2 planes), thick (multiple run) welds	type of joint, weld shape and dimensions, heat input, heat dissipation	T-joints (3 planes) thin (single-run) welds
high	ambient or workpiece temperature (heat dissipation)	low
high	heat input (energy input per unit length of weld) during welding	low
low	hydrogen content of the weld metal (type and rebaking of the welding consumables and auxiliary materials)	high

2.7 Preheating is always necessary for tack and auxiliary welds whenever preheating is needed for the rest of the welding. Possible exceptions to this rule are tack and auxiliary welds where it can be guaranteed that subsequent welds are remelted the heat affected zone, for instance tacks for submerged arc welds.

2.8 Irrespective of the information given above, preheating is always necessary when making major auxiliary erection welds, e.g. when welding on handling lugs and when welding very large wall thicknesses and also thick-walled castings and forgings.

2.9 Preheating shall be applied uniformly throughout the thickness of the plate or component

over a distance of four times the plate thickness, minimum of 100 mm, on both sides of the weld. Localized overheating is to be avoided. Preheating with gas burners should be performed with a gentle, though not sooty, flame in order to prevent dirt being deposited in the area of the weld. For details on the recording of the preheating temperature, cf. EN ISO 13916.

2.10 To prevent cold cracks in higher-strength and high-strength (quenched and tempered) steels, thick-walled components or components of complex design, it is advisable to use measures which give the hydrogen introduced into the weld metal during welding sufficient time to escape. The following methods are well established:

- Maintenance of a specific minimum preheating and interpass temperature throughout the welding operation,
- Delayed cooling after welding,
- Holding at approx. 250 °C prior to cooling (hydrogen-reducing heat treatment) or
- Heat treatment immediately after welding (without cooling in between)

2.11 Where hull structural steels or fine-grained structural steels have undergone thermo-mechanical processing (TM steels), the need for and degree of preheating shall be decided on separately on the basis of the carbon equivalent and the results of the approval or welding procedure tests as applicable. Drying of the areas to be welded by heating may be sufficient.

3. Monitoring interpass temperatures

The guide values contained in Table 3.5 for the interpass temperatures relating to the various steels shall not be significantly exceeded.

4. Welding with controlled heat input per unit length of weld

In addition to controlling the preheating and interpass temperature, the heat input per unit length of weld shall be controlled during welding, especially in the case of weldable, high-strength (quenched and tempered) fine-grained structural steels. The heat input

per unit length of weld shall not fall below or exceed the values indicated by the steel manufacturer or those used in the welding procedure tests and specified in the welding procedure specifications (WPS) by any significant amount.

5. Preheating and heat input during the welding of other steels or metallic materials

5.1 Preheating is not normally required for austenitic materials. Preheating may be necessary for austenitic-ferritic materials. A maximum permitted interpass temperature which is normally between 150 °C and 180 °C shall be complied with in order to prevent hot cracks.

5.2 Ferritic and stainless martensitic steels shall be adequately preheated and welded using controlled heat input per unit length of weld. Guide values for the preheating and interpass temperatures are prescribed in EN 1011-3.

5.3 Preheating is not normally required for welding aluminium alloys, but should not exceed 50 °C. A maximum permitted interpass temperature of 100 °C to 120 °C shall be complied with in order to prevent undesirable phase dispersion. EN 1011-4 contains guide values for the preheating temperature to be applied and the interpass temperature.

Table 3.5 Guide values for the maximum interpass temperature during welding

Category in accordance with DIN V 1738 (CR 12187)	Steel grades	Maximum interpass temperature [°C]
1.1	Normal-strength hull structural steels and comparable structural steels	250
1.2	Higher-strength structural steels and comparable structural steels	250
1.2	High-temperature, low Mo alloy steels	250
2	Normalised or thermo-mechanically processed fine-grained steels with yield strengths of > 360 N/mm ²	250
3	Quenched and tempered or precipitation-hardened (excluding stainless) steels with yield strengths of > 360 N/mm ²	250
5	Steels with a max. Cr content of 10 % and a max. Mo content of 1,2 %	350
7	Nickel alloy steels with a max. Ni content of 10 %	250

E. Post-Weld Heat Treatment

1. Welded components shall be subjected to post-weld heat treatment where this is prescribed in Sections 1 to 5 of Chapter 3. Post-weld heat treatment is generally used for ferritic steels, in which case stress relief heat treatment or tempering is normally sufficient. Where consideration also has to be paid to other codes of practice in the manufacture of certain components or structures (e.g. TRD 201 relating to the construction of steam boilers, cf. Chapter 3, Section 2, A.2.2), the provisions relating to post-weld heat treatment contained in these codes of practice shall also be complied with.

Note:

The need for and type of post-weld heat treatment is determined by various factors, the most important of which are given below:

- *material characteristics and dimensions (wall thicknesses)*
- *minimum anticipated operating temperature (design temperature)*
- *type of operating and background environment (e.g. risk of corrosion)*
- *build-up of welds to inhibit elongation and shrinkage*
- *risk of distortion during subsequent machining*

2. If stress relief heat treatment after welding is insufficient and more extensive heat treatment is required (e.g. normalising or quenching and temper-

ing), the method of heat treatment shall be specially established in accordance with the material specification and the conditions of use and subject to agreement by the Society. This shall also apply in analogous manner to materials and material combinations other than those dealt with here and also to other methods of stress-relief.

3. The stress relief heat treatment shall be carried out by means of slow, even heating of the components to the prescribed temperature ranges (Table 3.6 contains guide values), holding in these ranges for two minutes per mm of wall thickness (but not less than 30 minutes), slow cooling to 400 °C in the furnace or heat treatment appliance, and then complete cooling in still air. For thick-walled components, the holding time need not be more than 150 minutes.

4. If there is a risk of the components being distorted during cooling, the heat treatment may, within certain limits, be carried out at a lower temperature with an increased holding time. The required temperatures and holding times shall be agreed with the Society.

5. Joints between ferritic and austenitic steels (weld metal) must not, as a general rule, be subjected to heat treatment due to the risk of carbon diffusion, except where the welds are made using nickel-base filler materials.

Table 3.6 Heat treatment temperatures for stress-relief heat treatment of welded joints using similar filler metals

Category in accordance with DIN V 1738 (CR 12187)	Steel grades	Examples of appropriate steels in accordance with the Society's Rules or the standards ¹	Heat treatment temperature [°C]
1.1	Normal-strength hull structural steels and comparable structural steels, grade of steel forgings and castings	GL Grade A – E	550 – 600
1.2	Higher-strength hull structural steels and comparable structural steels, grades of steel forgings and castings	GL Grade A 36 - E 36	530 – 580
1.2	High-temperature, low Mo alloy steels	16Mo3	550 – 620
2	Normalised or thermo-mechanically processed fine-grained steels with yield strengths > 360 N/mm ²	GL Grade A 39 – E 39 S 460 TM	530 – 600
3	Quenched and tempered fine-grained structural steels with yield strengths > 360 N/mm ²	S 690 QL	530 – 580
5 5.1 5.2	Steels with a max. Cr content of 10 %, max Mo content of 1,2 %	13CrMo4-5 10CrMo9-10, 11CrMo9-10,	630 – 680 670 – 720
7 7.1 7.2 7.3 7.3 7.3	Nickel steels with a maximum Ni content of 10 %	13MnNi6-3 (0,5 % Ni) 12Ni14 (3,5 % Ni) 12Ni19 (5 % Ni) X8Ni9 (9 % Ni) X7Ni9 (9 % Ni)	530 – 560 530 – 560 530 – 560 ² ²
¹ Steel grades not listed here are to be classed together with comparable grades. ² Heat treatment should be avoided.			