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Welding — Post-weld heat treatment parameters for steels

Soudage — Paramètres de traitement thermique après soudage des aciers

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Foreword

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The committee responsible for this document is ISO/TC 44, *Welding and allied processes*, Subcommittee SC 10, *Unification requirements in the field of metal welding*.

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Welding — Post-weld heat treatment parameters for steels

1 Scope

This Technical Report provides recommendations for post-weld heat treatment (PWHT) of steels with recommendations for holding temperatures and holding times for different materials and material thicknesses. These recommendations are limited to stress relieving for non-alloy steels (groups 1, 2, 3, 4, and 11) and to tempering for Cr-Mo-(Ni) steels (groups 5 and 6) and martensitic stainless steels (group 7.2), and are independent of type of product or location. The recommendations do not supersede any guidance given in material supplier specifications, e. g. thermo-mechanically treated fine-grain steels.

This Technical Report does not specify when PWHT is required. Such requirements are given in product standards, material specifications, or material data sheets.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

EN 10052, *Vocabulary of heat treatment terms for ferrous products*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in EN 10052 and the following apply.

3.1
cooling rate
variation in temperature as a function of time during cooling cycle

[SOURCE: ISO 4885:1996, 3.37]

3.2
heating rate
variation in temperature as a function of time during heating cycle

[SOURCE: ISO 4885:1996, 3.78]

3.3
holding temperature
temperature at which the product or component is kept in order to achieve specified properties

Note 1 to entry: The holding temperature depends on the type of heat treatment, type of material, and material thickness.

Note 2 to entry: Normally the holding temperature is expressed as a temperature range.

[SOURCE: ISO 17663:2009, 3.3]

3.4
holding time
time the product or component is kept at the holding temperature

Note 1 to entry: The holding time starts when the temperature in all measuring points has reached the minimum value of the range of the holding temperature and stops when one of the measuring points falls below that temperature.

Note 2 to entry: The holding time depends on the type of heat treatment, material, and material thickness.

[SOURCE: ISO 17663:2009, 3.4]

3.5
post-weld heat treatment
PWHT
heat treatment carried out after welding in order to decrease residual welding stress, and/or to adjust to desired properties and/or the microstructure

4 Symbols and abbreviated terms

4.1 Symbols

P	Hollomon–Jaffe parameter
t	material thickness, in mm

NOTE Symbols other than those specified here are used in other International Standards.

4.2 Abbreviated terms

NT	normalized and tempered
PWHT	post-weld heat treatment
QT	quenched and tempered

5 General information

PWHT should be performed in accordance with a written procedure which describes the parameters critical to the PWHT process.

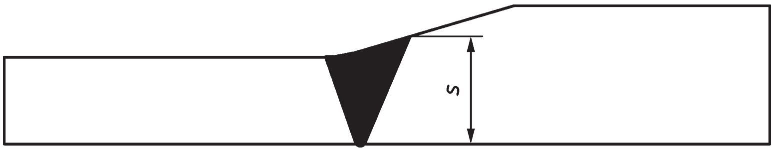
Equipment used for the PWHT should be suitable according to ISO 17663. It should permit the temperature control of the component with adequate accuracy and uniformity. The PWHT of products or components should be recorded by the manufacturer indicating the holding temperature, holding time, and the heating- and cooling-rate.

6 Heat treatment conditions

PWHT, with the exception of those materials mentioned in Clause 8, should be applied to steels in accordance with Table 1 upon completion of welding. If PWHT of materials, not listed in Table 1, is considered necessary, the PWHT holding time and holding temperature should take into account recommendations of the application standard, as well as the recommendations of the material and welding consumable manufacturer to achieve the required material properties.

Where welded joints are connecting parts with different thicknesses, the thickness to be used in applying the requirements for PWHT should be as follows:

a) for butt welds (excluding in T joints), the thickest part of the weld of the two parts (see Figure 1);



Key

s weld thickness

Figure 1 — Example of thickest part of the weld

b) for butt welds in T joints, the thickness of the weld;

c) for fillet welds, the throat thickness of the weld;

d) for butt-welded set-on nozzles, the thickness of the nozzle;

e) for set-through nozzles, the thickness of the plate or shell;

f) for set-in nozzles, the thickness of the weld.

PWHT may be carried out on steels of thickness lower than those specified by Table 1. Such instances may include products subject to stress corrosion cracking or at risk of brittle fracture.

When additional welds or weld repairs have been made after PWHT, a further heat treatment is normally carried out. The thickness to be used in defining the holding time required at temperature should be the thickness of the weld applied after the PWHT.

In Table 1, a P_{crit} value is introduced. This parameter, a critical Hollomon–Jaffe value, should not be exceeded without proving the mechanical properties.

PWHT as per Table 1, particularly in the upper range of holding temperature and/or holding time, may unduly impair the physical properties, e.g. yield strength, tensile strength, and toughness of the material.

A higher PWHT temperature than tempering temperature for NT- and QT-materials could impair the mechanical properties of the material.

The whole PWHT cycle consisting of heating rate, holding temperature, holding time, and cooling rate can have an essential influence on the mechanical properties. The data for heating and cooling can be taken out of the relevant product standards. If required by application standards or specifications, the PWHT cycle should be qualified by a procedure test including parent metal. This belongs especially for multi-PWHT cycles.

The additional effect of multiple heating cycles should be considered. This effect is explained by the Hollomon-Jaffe parameter, *P*,[4] as given in

$$P = T_s \left(20 + \lg t_{\text{h}}\right) \times 10^{-3} \quad (1)$$

where

T_s is the holding temperature, in Kelvin;

t_{h} is the holding time, in hours.

NOTE The Hollomon-Jaffe parameter describes the effect of tempering for a certain time, *t*, at a certain temperature, *T*, and a parameter, *C*, that is unique to the material used. This mathematical relationship has proved to be of particular value in highly complex welding procedure qualifications where considerable costs can arise by application of multiple-stage PWHT in the production process. The Hollomon-Jaffe parameter may be used in the calculation and application of more cost effective single-cycle PWHT.

7 Application of PWHT

7.1 General

PWHT can be applied with a furnace or with local heating (e.g. induction or resistance). Reference should be made to ISO 17663 for the methods of application.

The PWHT temperatures and times should be in accordance with Table 1.

7.2 Heating and cooling

During the heating and cooling periods, for temperatures up to 500 °C, variation in temperature throughout the product or component should not exceed 150 °C within 4 500 mm and the temperature gradient should be gradual. Above 500 °C, this variation should not exceed 100 °C.

When the product or component has attained a uniform holding temperature (see Table 1), this temperature should be held for the period specified in Table 1.

Table 1 — PWHT parameters for steel

Material group (ISO/TR 15608)	Material	Holding temperature	Material thickness[a] t	Holding time	P_{crit} (see Clause 6)
		°C	mm	min	
1.1	Steels with $R_{eH} \le 275$ MPa	550 to 600	$t \le 35$[a]	30	17,5
	— 16Mo3	550 to 620	$35 < t \le 90$ $t > 90$	$t - 5$ $40 + 0{,}5t$	
1.2	Steels with 275 MPa < $R_{eH} \le$ 360 MPa				
	— delivery condition M	530 to 580	$t \le 35$[a]	30	17,3
	— delivery condition QT	550 to 600[b]	$35 < t \le 90$	$t - 5$	17,5
	— delivery condition N (except 16Mo3)	550 to 600	$t > 90$	$40 + 0{,}5t$	17,5
	— 16Mo3, 18MnMo4–5 and 18 Mo5	550 to 620			17,5
1.3	Normalized fine-grain steels with $R_{eH} > 360$ MPa	530 to 580			17,3
2.1	Thermomechanically treated fine-grain steels with 360 MPa < $R_{eH} \le 460$ MPa	530 to 580			17,3
2.2	Thermomechanically treated fine-grain steels with $R_{eH} > 460$ MPa	—[d]			
3.1	Quenched and tempered fine-grain steels with > 360 MPa < R_{eH} ≤ 690 MPa				
	— 20MnMoNi4–5[c]	550 to 620[b]			17,5
	— 360 MPa < $R_{eH} \le 500$ MPa[a]	530 to 580[b]			—
	— 500 MPa < $R_{eH} \le 690$ MPa	—[d]			
3.2	Quenched and tempered fine-grain steels with $R_{eH} > 690$ MPa	—[d]			
4.1	Low vanadium alloyed Cr-Mo-(Ni) steels with, by mass: Mo ≤ 0,7 %; V ≤ 0,1 %; Cr ≤ 0,3 %; Ni ≤ 0,7 %				

Table 1 *(continued)*

Material group (ISO/TR 15608)	**Material**	**Holding temperature** °C	**Material thickness**[a] t mm	**Holding time** min	P_{crit} (see Clause 6)
	— 18NiCuMoNb5–5	580 to 640[b]	$t \le 15$[c] $15 < t \le 60$ $35 < t \le 90$ $t > 90$	30 2t 120	—
	— 15MnCrMoNiV5–3		d		
4.2	Low vanadium alloyed Cr-Mo-(Ni) steels with, by mass: Mo ≤ 0,7 %; V ≤ 0,1 %; Cr ≤ 0,7 %; Ni ≤ 1,5 %				
	— 15NiCuMoNb5–6-4	530 to 620	$t \le 20$ $20 < t \le 35$ $35 < t \le 90$ $t > 90$	30 60 t, min 60 40 + t	
5.1	Cr-Mo-steels free of vanadium with, by mass: 0,75 % < Cr ≤ 1,5 %; Mo ≤ 0,7 %[a, f]				
	— 25CrMo4, 26CrMo4–2	—[e]			
	— 13CrMoSi5–5	620 to 680[b]	$t \le 15$	30	18,7
	— 13CrMo4–5	630 to 700[g]	$15 < t \le 60$	2t	
	— All others	620 to 680[g]	$t > 60$	60 + t	18,5
5.2	Cr-Mo-steels free of vanadium with, by mass: 1,5 % < Cr ≤ 3,5 %; 0,7 % < Mo ≤ 1,2 %[f]				
	— 10CrMo9–10[h]	670 to 730	$t \le 15$	30	19,2
	— 11CrMo9–10[h]	660 to 720[b]	$15 < t \le 60$ $t > 60$	2t 60 + t	
	— 12CrMo9–10	660 to 720[b,i]	$t \le 125$ $t > 125$	2,4t 225 + 0,6t	19,3
5.3	Cr-Mo-steels free of vanadium with, by mass: 3,5 % < Cr ≤ 7 %; 0,4 % < Mo ≤ 0,7 %				
	— X11CrMo5, X12CrMo5	680 to 750	$t \le 15$	30	19,5
	— X16CrMo5–1	700 to 750	$15 < t \le 60$ $t > 60$	2t 60 + t	—
5.4	Cr-Mo-steels free of vanadium with, by mass: 7 % ≤ Cr ≤ 10 %; 0,7 % < Mo ≤ 1,2 %	740 to 780	$t \le 12$ $12 < t \le 60$ $t > 60$	30 2,5t 90 + t	—
6.1	High vanadium alloyed Cr-Mo-(Ni) steels with, by mass: 0,3 % < Cr ≤ 0,75 %; Mo ≤ 0,7 %; V ≤ 0,35 %	680 to 730	all	90 + t, min. 180	—

Table 1 *(continued)*

Material group (ISO/TR 15608)	Material	Holding temperature °C	Material thickness[a] t mm	Holding time min	P_{crit} (see Clause 6)
6.2	High vanadium alloyed Cr-Mo-(Ni) steels with, by mass: 0,75 % < Cr ≤ 3,5 %; 0,7 % < Mo ≤ 1,2 %; V ≤ 0,35 %				
	— 12CrMoV12–10 — 13CrMoV12–10	690 to 710[b]	$t \le 125$ $t > 125$	$2{,}4t$ $225 + 0{,}6t$	19,4
6.3	High vanadium alloyed Cr-Mo-(Ni) steels with, by mass: 3,5 % < Cr ≤ 7,0 %; Mo ≤ 0,7 %; 0,45 % < V ≤ 0,55 %	—[d]			
6.4	High vanadium alloyed Cr-Mo-(Ni) steels with, by mass 7,0 % < Cr ≤ 12,5 %; 0,7 % < Mo ≤ 1,2 %; V ≤ 0,35 %				
	— X10CrMoVNb9–1	730 to 770[j]	$t \le 12$ $12 < t \le 60$ $t > 60$	30 $2t$, min 60 $90 + t$	20,5
	— X10CrWMoVNb9–2	740 to 770[j]	$t \le 12$ $12 < t \le 60$ $t > 60$	30 $2t$, min 60 $90 + t$	
	— X20CrMoV11–1 — X20CrMoNiV 11–1 — X20CrMoV12–1	730 to 770[j]	$t \le 12$ $12 < t \le 60$ $t > 60$	30 $2{,}5t$ $90 + t$	—
7.2	Martensitic stainless steels with, by mass C ≤ 0,35 %; 10,5 % ≤ Cr ≤ 30 %				
	— X3CrNi13–4	530 to 570	all	240	—
8.1	Austenitic stainless steels with Cr ≤ 19 %	Generally not applicable[d]			
8.2	Austenitic stainless steels with Cr > 19 %				
9.1	Ni alloy steels with Ni ≤ 3,0 %	530 to 580	$t \le 35$[a] $35 < t \le 90$ $t > 90$	30 $t - 5$ $40 + 0{,}5t$	—
9.2	Ni alloy steels with 3,0 % < Ni ≤ 8,0 %[b, k]				
9.3	Ni alloy steels with 8,0 % < Ni ≤ 10 %	[e]			
10.1	Austenitic ferritic stainless steels with Cr ≤ 24 %	Generally not applicable[d]			
10.2	Austenitic ferritic stainless steels with Cr > 24 %				

Table 1 *(continued)*

Material group (ISO/TR 15608)	Material	Holding temperature	Material thickness[a] t	Holding time	P_{crit} (see Clause 6)
		°C	mm	min	

[a] For thickness ≤ 35 mm, post-weld treatment is normally only necessary in special cases [e. g. to reduce the danger of stress corrosion cracking or hydrogen-induced cracking (sourgas)].

[b] Higher temperatures can be applied, subject to conditions given in application standards.

[c] For thickness ≤ 15 mm, PWHT is optional.

[d] If PWHT is considered necessary, the PWHT holding time and holding temperature should take into account recommendations from the material manufacturer, as well as the welding consumable manufacturer to achieve the required materials properties.

[e] Normally welded with austenitic filler metal; in view of possible carbon diffusion, PWHT should be avoided.

[f] According to EN 13480–4, [2] no PWHT is required if all the following conditions are fulfilled:

— tubes with outside diameter ≤ 114,3 mm;

— nominal wall thickness ≤ 7,1 mm;

— minimum pre-heating temperature 200 °C.

[g] According to EN 13445–4,[3] no PWHT is required if all the following conditions are fulfilled:

— tubes with nominal diameter < 120 mm;

— nominal wall thickness < 13 mm.

[h] According to EN 13445–4,[3] no PWHT is required if all the following conditions are fulfilled:

— tubes with nominal diameter < 120 mm;

— nominal wall thickness < 13 mm;

— design temperature > 480 °C.

[i] In case of intermediate stress relieving (ISR): 630 °C to 650 °C.

[j] Intermediate cooling of the weld below the M_f temperature (typically 90 °C to 100 °C) should take place before PWHT to ensure full transformation to martensite.

[k] After the welding of the 3,5 % by mass Ni steels with thicknesses over 35 mm, it is permitted to weld, without new heat treatment, components that are not subject to pressure, provided the following conditions are met:

— the weld dimensions (weld thickness or corner joint throat) are ≤ 12 mm;

— a pre-heating temperature of a minimum of 100 °C is applied during the welding operation.

7.3 Heating in a furnace

In addition to 7.2 in the case of furnace PWHT, the temperature of the furnace at the time when the product or component is placed in or taken out of the furnace should not exceed:

— 400 °C for simple products or components of uncomplicated shape and t < 60 mm thickness;

— 300 °C for complex products or components of complicated shape or t ≥ 60 mm thickness.

The rate for heating or cooling of the product or component should not exceed the following:

— for thickness t ≤ 25 mm: 220 °C/h;

— for thickness 25 mm < t ≤ 100 mm: (5 500/t) °C/h;

— for thickness t > 100 mm : 55 °C/h.

The temperature specified should be the actual temperature of any part of the product or component being heat treated.

During the heating and holding periods, the furnace atmosphere should be controlled so as to avoid excessive oxidation of the surface of the product or component. There should be no direct impingement of flame on the product or component.

NOTE 1 1 °C is equivalent to 1 °K when defining temperature gradients.

NOTE 2 A complex component is one that can incorporate different materials having significant differences in thickness or involve a design containing multiple weldments.

8 Post-weld heat treatment of dissimilar ferritic joints

8.1 General

Where a product or component is manufactured from dissimilar ferritic steels, special consideration should be given to the effect of PWHT parameters on the mechanical properties.

8.2 Holding temperature

Where the temperature ranges in Table 1 for each material do not overlap, consideration should be given to redesigning the dissimilar weld to include a suitable transition material, or using a non-ferritic weld buttering, e. g. stainless steel or high nickel weld metal.

When the maximum temperature allowed in Table 1 of one material in the dissimilar combination is lower than the minimum temperature allowed for the second, then, one of the routes a) to c) should be followed.

a) Where the temperature ranges in Table 1 for each material overlap, tests should be carried out to verify the properties of the dissimilar weld at the PWHT range specified.

b) Redesign the combination to include a transition piece that overlaps the temperature range.

c) Butter the higher PWHT temperature range steel with the suitable filler material and PWHT at the higher temperature range. On completion, make the joint weld between the butter weld and the second steel and PWHT at the lower temperature range.

