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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

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see [www.iso.org/directives](http://www.iso.org/directives)).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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*.

Requests for official interpretations of any aspect of this Technical Report should be directed to the Secretariat of ISO/TC 44/SC 10 via your national standards body. A complete listing of these bodies can be found at [www.iso.org](http://www.iso.org).

# 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

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## 5 General information

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

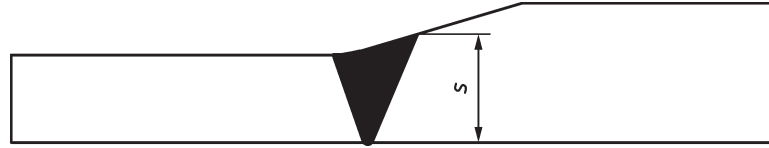
Equipment used for the PWHT should be suitable according to ISO 17663. It should permit the temperature control of the component with adequate accuracy and uniformity. The PWHT of products or components should be recorded by the manufacturer indicating the holding temperature, holding time, and the heating- 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,  $P$ ,<sup>[4]</sup> as given in

$$P = T_s (20 + \lg t_h) \times 10^{-3} \quad (1)$$

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 <sup>a</sup> <i>t</i>	Holding time	<i>P</i> <sub>crit</sub> (see <a href="#">Clause 6</a> )
		°C	mm	min	
1.1	Steels with $R_{eH} \leq 275$ MPa	550 to 600	$t \leq 35^a$	30	17,5
	— 16Mo3	550 to 620	$35 < t \leq 90$ $t > 90$	$t - 5$ $40 + 0,5t$	
1.2	Steels with $275$ MPa $< R_{eH} \leq 360$ MPa	530 to 580	$t \leq 35^a$	30	17,3
	— delivery condition M	530 to 580	$t \leq 35^a$	30	17,3
	— delivery condition QT	550 to 600 <sup>b</sup>	$35 < t \leq 90$	$t - 5$	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 $< R_{eH} \leq 460$ MPa	530 to 580			17,3
2.2	Thermomechanically treated fine-grain steels with $R_{eH} > 460$ MPa	— <sup>d</sup>			
3.1	Quenched and tempered fine-grain steels with $> 360$ MPa $< R_{eH} \leq 690$ MPa				
	— 20MnMoNi4-5 <sup>c</sup>	550 to 620 <sup>b</sup>			17,5
	— 360 MPa $< R_{eH} \leq 500$ MPa <sup>a</sup>	530 to 580 <sup>b</sup>			—
	— 500 MPa $< R_{eH} \leq 690$ MPa	— <sup>d</sup>			
3.2	Quenched and tempered fine-grain steels with $R_{eH} > 690$ MPa	— <sup>d</sup>			
4.1	Low vanadium alloyed Cr-Mo-(Ni) steels with, by mass: Mo $\leq 0,7$ %; V $\leq 0,1$ %; Cr $\leq 0,3$ %; Ni $\leq 0,7$ %				



Table 1 (continued)

Material group (ISO/TR 15608)	Material	Holding temperature	Material thickness <sup>a</sup> <i>t</i>	Holding time	<i>P</i> <sub>crit</sub> (see Clause 6)
		°C	mm	min	
	— 18NiCuMoNb5-5	580 to 640 <sup>b</sup>	<i>t</i> ≤ 15 <sup>c</sup> 15 < <i>t</i> ≤ 60 35 < <i>t</i> ≤ 90 <i>t</i> > 90	30 2 <i>t</i> 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	<i>t</i> ≤ 20 20 < <i>t</i> ≤ 35 35 < <i>t</i> ≤ 90 <i>t</i> > 90	30 60 <i>t</i> , min 60 40 + <i>t</i>	
5.1	Cr-Mo-steels free of vanadium with, by mass: 0,75 % < Cr ≤ 1,5 %; Mo ≤ 0,7 % <sup>a, f</sup>				
	— 25CrMo4, 26CrMo4-2			— <sup>e</sup>	
	— 13CrMoSi5-5	620 to 680 <sup>b</sup>	<i>t</i> ≤ 15	30	18,7
	— 13CrMo4-5	630 to 700 <sup>g</sup>	15 < <i>t</i> ≤ 60	2 <i>t</i>	
	— All others	620 to 680 <sup>g</sup>	<i>t</i> > 60	60 + <i>t</i>	18,5
5.2	Cr-Mo-steels free of vanadium with, by mass: 1,5 % < Cr ≤ 3,5 %; 0,7 % < Mo ≤ 1,2 % <sup>f</sup>				
	— 10CrMo9-10 <sup>h</sup>	670 to 730	<i>t</i> ≤ 15	30	19,2
	— 11CrMo9-10 <sup>h</sup>	660 to 720 <sup>b</sup>	15 < <i>t</i> ≤ 60 <i>t</i> > 60	2 <i>t</i> 60 + <i>t</i>	
	— 12CrMo9-10	660 to 720 <sup>b, i</sup>	<i>t</i> ≤ 125 <i>t</i> > 125	2,4 <i>t</i> 225 + 0,6 <i>t</i>	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	<i>t</i> ≤ 15	30	19,5
	— X16CrMo5-1	700 to 750	15 < <i>t</i> ≤ 60 <i>t</i> > 60	2 <i>t</i> 60 + <i>t</i>	—
5.4	Cr-Mo-steels free of vanadium with, by mass: 7 % ≤ Cr ≤ 10 %; 0,7 % < Mo ≤ 1,2 %	740 to 780	<i>t</i> ≤ 12 12 < <i>t</i> ≤ 60 <i>t</i> > 60	30 2,5 <i>t</i> 90 + <i>t</i>	—
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 + <i>t</i> , min. 180	—