

Guidance on the specification of Pressure vessels

PUBLICATION 211

Edition 2

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THE ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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ENGINEERING EQUIPMENT AND MATERIALS USERS' ASSOCIATION

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Overview

The purpose of this Publication is to provide guidance on the specification of pressure vessels for circumstances not addressed in design codes. Additionally, this Publication aims to compare international standards, particularly those from the USA, with UK and European equivalents. It has been prepared by the Pressure Vessels Committee (PRV) of EEMUA, the Engineering Equipment and Materials Users' Association. As such, this Publication brings together the practical lessons learnt about design, manufacturing and testing of pressure vessels by users in EEMUA member companies.

EEMUA 211 is composed of four Chapters:

1. Considerations on the avoidance of repeat post-weld heat treatment

Post-weld heat treatment (PWHT) may be of considerable importance to the structural integrity of a pressure vessel. This Chapter examines the circumstances under which repeat PWHT may be waived.

2. Design for exceptional internal pressure

This Chapter describes methods for assessing both existing and new pressure vessels for exceptional internal pressures. Simple and advanced design methods are provided for two levels of service performance.

3. Minimum nozzle loadings and nozzle design

There are three sections to this Chapter which all relate to improvement in the specification and reliability of nozzles. In the first, tables of minimum design loadings are provided to ensure that nozzles, made in steel, nickel alloys or glass reinforced plastics, are suitable for certain minimum loadings. In the second, requirements on standoff and minimum pipe schedule are given for nozzles made from pipe. In the third, particular designs of small bore nozzles are specified.

4. Evaluating creep damage to pressure equipment

This Chapter gives a basic appreciation of creep and how to assess situations where creep is suspected. It is primarily intended to be used in relation to pressure vessels and similar equipment but does not specifically address piping where additional factors influence its design and assessment.

1. Considerations on the avoidance of repeat post-weld heat treatment

1.1 Introduction

Post-weld heat treatment (PWHT) relieves the residual stress at welds. It is beneficial in avoiding brittle fracture (for which the design codes give rules) and environmentally assisted cracking (for which purchasers determine requirements). In fabricating new equipment, PWHT may be planned into the manufacturing process and is generally very cost effective.

However, with existing vessels, carrying out repeat PWHT may present many practical difficulties. There may be restrictions at the site on keeping the components hot over the length of time needed. It may be difficult or impossible to provide sufficient heat. Undertaking PWHT in an oven, which is the standard practice for new fabrication, may not be feasible. The disturbance to adjacent equipment caused by carrying out PWHT may also be unacceptable.

Occasionally the need may arise to weld on a vessel after its original fabrication and heat treatment has been completed. Such a welding operation might be necessary almost immediately, before or during commissioning the vessel, due to a design change; however, the need is more likely to occur in-service. New clips or studs may be needed for insulation supports or new anchors for fire-proofing materials. Components such as doubler plates or nozzles may be needed because of corrosion, or due to a process or mechanical design change. Overlay welding may be necessary to build up the thickness of a corroded part. In the extreme, for a major modification, a full circumferential butt-weld may be needed.

This Chapter indicates the thicknesses of components on which the codes currently permit welding without PWHT. It also discusses the welding techniques by which welds on thicker components can be made without repeat PWHT. It applies predominantly to vessels made in ferritic (i.e. carbon, carbon manganese or low alloy) steels.

1.2 Exemptions from PWHT given in the codes

1.2.1 When PWHT is a code requirement

1.2.1.1 Main pressure parts

For avoidance of brittle fracture, PWHT is usually specified for a given material above a certain thickness in the codes. Table 1 overleaf indicates the maximum thicknesses of components which may be welded without PWHT for vessels operating above 0°C in accordance with ASME VIII Div. 1⁽¹⁾ or BSI PD 5500⁽²⁾. The rules apply particularly to new vessels, but are also a major influence when the feasibility of modifying existing vessels is under review.

Table 1 applies to the greater thickness of the two components being welded. A vessel may have been given PWHT because of the thickness of the main plates, but it may be that the proposed modification is on a component with a thickness less than that shown in Table 1 overleaf. For example, if the modification is to a nozzle and the wall thickness of the nozzle is less than that in Table 1, welding to the nozzle - a new flange for example - is permissible without repeat PWHT. Care

should be taken that the length of the nozzle is such that the heat of welding does not affect the shell. The flange itself should be checked for the need for PWHT and rules are given in the codes for determining the nominal thickness for resistance to brittle fracture of different components, e.g. flanges and compensation pads.

Table 1 Maximum thickness which may be welded without PWHT for vessels operating above 0°C

Code	Material			
	ASME P1/ BSI PD 5500 Band M0 & M1 (C Mn steel)	ASME P3/ BSI PD 5500 Band M2 (C Mo steel)	ASME P4/ BSI PD 5500 Band M7 & M9 (1¼ and 2¼ Cr Mo steels)	ASME P5/ BSI PD 5500 Band M10 (5 Cr Mo steel)
ASME VIII Div. 1 (Paragraph UCS-56)	32mm (38mm with 95°C preheat)	16mm with 95°C preheat and 0.25% C max.	16mm with 120°C preheat and 0.15% C max.	16mm with 150°C Preheat and 0.15% C max.
BSI PD 5500 (Section 4)	35mm (40mm if minimum 27J at -20°C)	35mm (40mm if minimum 27J at -20°C)	PWHT required	PWHT required

1.2.1.2 Appurtenances

The requirements given in the codes as they apply to small attachments, or appurtenances, are summarised in Table 2 opposite. Details of the clips are listed in the left hand column and the three right hand columns refer to vessels manufactured in one of the following conditions:

- with no PWHT; or
- given PWHT to avoid process side environmentally assisted cracking (see Section 1.2.2); or
- subjected to PWHT because of code requirements to avoid brittle fracture.

The requirement for repeat PWHT is given in Table 2 as either a 'YES' or a 'NO'.

Table 2 Requirement for repeat PWHT on clips welded to vessels

Appurtenance	Material grade	Is repeat PWHT required? (YES/NO)		
		Original condition of the vessel		
		No PWHT	PWHT for process reasons	PWHT per code
External clip < 38mm* C/S Shell		NO	YES (but may be waived depending on process requirements)	NO
Internal clip < 38mm* C/S Shell		NO	YES	NO
External clip > 38mm* C/S Shell		N/A	YES	YES
Internal clip > 38mm* C/S Shell		N/A	YES	YES
External clip on Low Alloy Shell	1 ¼ Cr 1 Mo 2 ¼ Cr 1 Mo P-3	N/A	YES	YES
Internal clip on Low Alloy Shell	1 ¼ Cr 1 Mo 2 ¼ Cr 1 Mo P-3	N/A	YES	YES
Internal clip onto cladding	CSteel base material	N/A	N/A	NO
	Cr Mo base material	N/A	NO	
Internal clip through cladding, welded to base material		N/A	YES	YES

N/A - not applicable

* Based on the rules in ASME VIII Div. 1, i.e. 38mm throat fillet welds with 93°C pre-heat are acceptable without PWHT for carbon steel (C/S) P1 band material. Other codes may differ.

1.2.2 When PWHT is a service requirement

PWHT may be specified by the purchaser to avoid environmentally assisted cracking with certain process fluids. In these circumstances, when there is any welding on the surface which is in contact with the process fluid, repeat PWHT is required. The only exception to this is that small clips or rings may be welded without PWHT to an internal corrosion resistant cladding (e.g. in austenitic stainless steel or nickel alloy) if it is fitted. This is subject to appropriate checks being made that the cladding thickness is adequate and the controls applied to the welding are acceptable.

For the surface which is not in contact with the process fluid, normally the outside of the vessel, the welding of small clips without PWHT may be acceptable in some circumstances because of the small heat affected zone associated with such welds. However, if the vessel is thin walled, repeat PWHT may still be needed depending on the type of environmentally assisted cracking which is being avoided.

1.2.3 Further aspects

1.2.3.1 BSI PD 5500

In BSI PD 5500 Clause 4.4.3.1, welding on lightly loaded and non-pressure parts of previously heat treated vessels is permitted without repeat PWHT, providing it can be demonstrated that the material will not be adversely affected. This permits welding without repeat PWHT under carefully controlled conditions on a limited range of components.

1.2.3.2 ASME VIII Division 1

ASME VIII Div. 1 (Clauses UG-55, UG-4b) contains rules for the attachment of lugs, clips and other non-pressure parts by arc welding (Clause UW-5b). It requires a suitable weld procedure, qualified to ASME IX⁽³⁾, to be used. To assess whether PWHT is required, the nominal thickness, which is the thickness of the weld at the point of attachment of the non-pressure part to the pressure part, (see ASME VIII Div. 1 Clause UW-40f (5f)) is used in conjunction with ASME VIII Div. 1 Tables UCS-56 and UCS-56.1.

1.2.3.3 Temper bead welding

ASME VIII Div.1 and the National Boiler Inspection Code⁽⁴⁾ specify high preheat/temper bead repair options that exempt PWHT for P-1, P-3, P-4 and P-5A materials.

Temper bead welding is an advanced technique, where advice should be sought from welding specialists experienced in this field when the feasibility of the job is first being considered. Several runs of weld are usually needed to obtain the tempering and therefore it is mainly used on repairs. For the attachment of a clip, it may be more practical to weld a thick pad onto the vessel using temper bead welding and weld the clip to the pad by conventional means.

The skill of the welder and the control of the welding technique are likely to be the major factors in the success of temper bead welding. Welding procedure and welder qualification tests would need to be carefully monitored and the test pieces thoroughly evaluated. For more information on the technique, see Welding Research Council Bulletin No. 412⁽⁵⁾ and Brett et al⁽⁶⁾.

1.2.3.4 Nickel alloy filler

Attachment of small appurtenances to the external surface of vessel components in carbon or carbon manganese steel may be made using suitable non-hardenable nickel alloys. The risk of hydrogen cracking is significantly reduced through the use of an austenitic nickel alloy filler metal, compared to carbon manganese or low alloy steel ferritic filler metals. There are also other potential additional practical advantages, as nickel alloy electrodes generally do not require re-drying prior to use. The potential for galvanic corrosion should be assessed prior to the use of nickel alloy filler metal for welding carbon-manganese or low alloy steel.

However, the risk of cracking in the ferritic base material due to high hardness (as opposed to hydrogen) is not altered by the use of an austenitic filler. Appropriate levels of pre-heat should be applied and maintained during the

welding operation. In a procedure test, a thorough check should be made of the hardness of the heat affected zone to ensure that it is within acceptable limits.

1.2.3.5 Stud welding

Studs for attaching insulation or fireproofing may be attached by discharge welding and this is considered to be acceptable in some circumstances. Stud welding and resistance welding are recognised welding techniques but neither ASME VIII Div. 1 nor BSI PD 5500 makes mention of them. Means for checking such welds using non-destructive examination are very limited.

1.2.3.6 Repair welding

Some codes require PWHT to be applied after repair welding with a ferritic filler metal, regardless of whether or not the base material was originally subject to PWHT. However, this requirement is waived if a nickel alloy or stainless steel electrode is used. It may therefore be very advantageous to use the latter.

In any repair welding, a critical review needs to be made of the weld procedure, the state of the material and the information available from NDT. There should also be a trial (preferably on material which may have been in service) to demonstrate that the repair can be satisfactorily carried out. Where creep is a factor, the available operating life with the repair may be limited.

There may be practical issues associated with major repairs, such as the cutting of a hole in the shell for access which then has to be re-welded.

1.2.4 General requirements for welds where PWHT is waived

The following general requirements apply for welds where PWHT is waived:

- An approved Welding Procedure Specification and a Procedure Qualification Record should be available. (As PWHT is an essential variable both need to, of course, apply where there is no PWHT). Where welding is being carried out on material which has been in service, the approval needs to take into account any environmental effects on the parent material.
- All welding should be made with the required pre-heat.
- All welds should be given 100% surface inspection (by magnetic particle or dye penetrant methods). A volumetric inspection (by ultrasonics or X-ray) should also be made. Advanced inspection techniques should be considered to provide a high level of scrutiny.
- Those supervising the work should have a thorough understanding of any potential mechanisms for deterioration or cracking in the weldment, i.e. the weld, heat affected zone and adjacent parent material.
- A materials specialist should always be consulted before attempting any weld.
- A welding and/or materials specialist should be consulted if doubt exists over the correct welding approach to be taken during the repair or modification of the vessel.

1.3 Example from the power industry

Boiler Shell Weld Repair⁽⁷⁾ describes in considerable detail a major repair carried out on three boilers in low alloy steel at Sizewell 'A' Power Station. The welds were 57 mm thick in cylinders of 6.86 m diameter.

The boiler shells had been subject to PWHT originally (in the 1960's) and, after detailed consideration of several other options, PWHT was repeated following repairs at site made in 1996. The issues associated with carrying out PWHT after the repair, or waiving it, are well described.

In order to carry out PWHT, the problems to be solved were:

- the thermal stresses induced in the shell;
- the support of the tube bank during PWHT;
- the ability of the shell material to withstand further heat treatment; and
- the loads transmitted during the PWHT to the reactor nozzles.

According to ASME XI⁽⁸⁾, a repair without PWHT is permissible providing:

- the repaired depth does not exceed 50% of the plate thickness;
- a temper bead repair technique is developed and validated; and
- the repair is reassessed to either the original code of construction or the current equivalent code.

This option of making the repair without PWHT was thoroughly assessed. The residual stresses were modelled using finite element analysis. A very substantial programme of weld procedure development and welder qualification was carried out. However, it was finally decided that a feasible repair with PWHT could be made and the work was satisfactorily completed in this way.