A Review of Postweld Heat Treatment Code Exemptions

Similarities and differences of exemptions from PWHT for C-Mn and low-alloy steels in several current codes are reviewed, and some rationalizations are considered

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This article compares and contrasts the current rules and guidelines present in various fabrication standards (mainly U.S. and UK) regarding the postweld heat treatment (PWHT) requirements of welds and the limits for as-welded construction made in pipes, pressure vessels, and structures, including bridges, buildings, and offshore structures, as discussed below. It is recognized that some codes now include provision for repair without PWHT (Refs. 1–3), and that there have also been investigations aimed at providing recommendations for acceptable thickness limits for the as-welded condition for general structural conditions (Refs. 4, 5). It is noted that steel making technology has changed over the last thirty years or so (although steels are also produced in parts of the world where steel making technology lags behind best practice). However, the fabrication codes were generally devised for older, normalized steels with higher carbon contents (Refs. 6, 7), and often with no toughness requirement.

In addition, a number of methods available for gaining exemption from PWHT are examined, including specially designed weld repair procedures and a case-specific fracture mechanics approach (in Part 2). The general method adopted is that of Ref. 8, for which fracture mechanics testing, e.g., as in Ref. 9, is normally required. This investigation relates only to C-, C-Mn, and low-alloy steels. Some of the similarities and differences are considered, and testing required to move toward elimination of the apparent anomalies is considered. In compiling this article, the views of representatives of fabricators and end users have been sought.

The objectives of the study were to identify the types of materials where industry considers that there are grounds for seeking wider exemption from PWHT; to compare and contrast the limiting thickness requirements above which PWHT is required and the associated Charpy test requirements for the as-welded condition in standards relevant to the fabrication industry; to investigate the methods available for gaining exemption from PWHT, namely the use of specially designed repair procedures and the specification of a minimum Charpy energy, calculated by a fracture mechanics approach; and to identify whether a future program of toughness testing and residual stress measurements on specific steels is needed to demonstrate a case for exemption from PWHT.

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Table 1 — Limiting Thickness for which Postweld Heat Treatment Is Not Required for C-Mn Steels According to Various Standards

Code	ASME P1 Group 1/C-Mn, and BS EN Group 1	ASME P3 Groups 1 and 2, and BS EN Group 1.4	ASME P4 Groups 1 and 2, and BS EN Group 5.1	ASME P5 Group 1, and BS EN Group 5.2	Comments	
ASME VIII (14)	32 mm increase to 38 mm with 93°C preheat	16 mm, 93°C preheat, C≤0.25%	16 mm, 121°C preheat, C≤0.15%	16 mm, 149°C preheat, C≤0.15%	≥ 27J at 20°C for 32 mm and R_e ≤448MPa (≥ 20J at 20°C for ≥ 34 mm and R_e ≤345MPa)	Toughness requirement increases as strength increases; allowable thickness increases as toughness increases and as strength decreases.
ASME B31.1 (15)	19 mm	16 mm, 95°C preheat, C≤0.25%	13 mm, 120°C preheat, C≤0.15%	13 mm, 150°C preheat, C≤0.15%	No explicit Charpy test requirement in the standard.	
ASME B31.3 (16)	19 mm	19 mm	13 mm, 149°C preheat	13 mm, 177°C preheat, C≤0.15%	R_e≤448MPa, C_v≥ 18J R_e≤517MPa, C_v≥ 20J R_e<656MPa, C_v≥ 27J	Room temperature Charpy toughness requirement for carbon- and low alloy steels:
ASME B31.8 (17)	32 mm				No explicit Charpy test requirement in the standard.	
API 650 (18)	32 mm increase to 38 mm with 90°C preheat				Gp I-III & IIIA (defined in the standard) C_v ≥ 20J. Gp IV-VI C_v ≥ 41J; Gp VIA, C_v≥ 48J if Q & T or TMCP	
API 620 (19)	32 mm, increase to 38 mm with 93°C preheat				PWHT required for nozzles and attachments when wall thickness exceeded.	
					C_v≥ 34J (≥ 40J for Q&T grades)	Test temperature ≤ (design metal temperature –17°C).
					C_v ≥ 34J	For design metal temperature > –40°C, if tested at or below this temperature
					C_v ≥ 40J	Acceptable for design metal temperatures ≤–40°C.
					C_v ≥ 27J (≥ 34J in longitudinal direction)	Test temperature of –196°C for liquefied hydrocarbon gasses.
AWS D1/1 (29)					Limits set by contract drawings or specifications.	
JIS B.8243 (20)	32 mm, increase to 38 mm with 95°C preheat	16 mm, C≤0.25% 95°C preheat preheat;	Tubing 16 mm, C ≤0.15, 120° 120°C preheat; PWHT all thicknesses of vessel	Tubing 16 mm, C ≤0.15, Cr ≤3.0, 120°C preheat; PWHT all thicknesses of vessel	R_m <490MPa, C_V≥ 20J R_m ≥ 490MPa, C_V≥ 27J	At T ≤ minimum operating temperature.
Stoomwezen(21)	32 mm, C≤0.23%, may increase to 40 mm				Fine-grained steel: C ≤0.23 and CE ≤0.55 and R_e ≤370 MPa and KV (perpendicular) ≥ 31J at 0°C and also KV (parallel) ≥ 27J at –50°C and 32 mm <t≤40 mm and weld metal KV (perpendicular) ≥ 31J at 0°C, and as long as there is no accumulation of weldments or extensive local stiffening, and a hydrotest is carried out.	
					Fine-grained steel; C≤0.23 and CE ≤0.55 and R_e ≤450MPa and t≤32 mm, and as long as there is no accumulation of weldments or extensive local stiffening, there is no toughness requirement.	

Review of Current Practice and Code Requirements

Fabrication Standards for C-Mn Steel Pressure Vessels, Piping, and Offshore Structures

A survey was carried out in 1971 (Ref. 10) that showed that the requirements of various codes, in terms of the material thickness above which PWHT was required, varied considerably. Later work in 1980 (Ref. 11) showed that, while considerable harmonization had taken place, significant divergence remained. More recent work by Mohr (Ref. 12) and also by Salkin (Ref. 13), who reviewed the differences in thickness limits, in temperature ranges, and in hold times covering a range of steel types, has highlighted the limits and provisions for exemption from PWHT. These studies showed there was still some variation between codes. The results are included in Table 1, where the requirements of the U.S. codes relate to ASME P1 to P5 steels. The table has been extended to include requirements for Charpy test properties, and to cover a range of other codes and standards.

Several of the codes have a similar thickness limit, at ~32 mm, above which PWHT is required. Provision is made in several codes (Refs. 14, 18–20, 25) to extend this limit to 38 or 40 mm if certain conditions, generally the imposition of a preheat of the order of 93°C (200°F), are met. The notable exceptions are ASME B31.1 (Ref. 15) and B31.3 (Ref. 16), with a thickness limit of 19 mm, and EEMUA 158 (Ref. 28) that specifies a limit of 40 mm for nodes, with a limit of 50 mm applying

Table 1 — Continued

Code	ASME P1 Group 1/C-Mn, and BS EN Group 1	ASME P3 Groups 1 and 2, and BS EN Group 1.4	ASME P4 Groups 1 and 2, and BS EN Group 5.1	ASME P5 Group 1, and BS EN Group 5.2	Comments	
BS 2971 (22)	35 mm				No Charpy test requirement.	
BS 1113 (23)	30 mm, increase to 35 mm with 100°C preheat, C≤0.25%	13 mm, increase to 35 mm with 100°C preheat, C≤0.25%	≤13 mm thick and ≤127 mm diameter, C≤0.15%	≤13 mm thick and ≤127 mm diameter, C≤0.15%	C_v >40J	
BS EN 12952 (24)	<35 mm		<13 mm	<13 mm	C_v ≥ 27J for transverse specimens (preferred) or C_v≥ 35J for longitudinal.	T_{CV} ≤ lowest scheduled operating temperature (T_{CV}.20°C).
BS 2633 (25)	30 mm, increase to 35 mm 100°C preheat, C≤0.25%	≤12.5 mm thick and ≤127 mm diameter	≤12.5 mm thick and ≤127 mm diameter, 120°C preheat	≤12.5 mm thick and ≤127 mm diameter, 150°C preheat, C≤0.15%	No Charpy test required.	
PD 5500 (26)	35 mm, increase to 40 mm if C_v, ≥ 27J at –20°C	12.5 mm, increase to 19 mm with 100°C preheat	PWHT required for all thicknesses	PWHT required for all thicknesses		
PD 5500 (26) (Service temperature <0°C)	40 mm, but see comments				R_e<450MPa, C_v≥ 27J R_e≥ 450MPa, C_v≥ 40J	T_{CV} = 2.94 (MDMT–10)°C (PD 5500 Annex D)
PrEN 13445 (27)	35 mm		≤15 mm thick, or ≤13 mm thick and ≤120 mm diameter	≤15 mm thick, or ≤13 mm thick and ≤120 mm diameter and design temperature <480°C	C_v≥ 27J or C_v≥ 40J	Test temperature depends on strength, toughness level, and design reference temperature.
EEMUA 158 (28)	Minimum design throat thickness: –40 mm nodes 50 mm plain regions				R_e≥ 275 MPa, C_v≥ 27J R_e≥ 355MPa, C_v≥ 36J R_e≥ 450MPa, C_v≥ 45J	C_v at –40°C, for assumed MDMT = –10°C.
BS 5950 (30) & BS 5400(31)	$t_{max} = k.50.(\frac{355}{fy})^{1.4}.(1.2)\ (\frac{MDMT-T_{27J}}{10})$				C_V required at MDMT, k = 2 for as-welded joints but reduces with stress concentrations preent.	

to other regions. The apparent harmony is, however, in part illusory, because the steels employed in the United States and the United Kingdom are generally different in chemical composition (an issue that is considered in more detail later), and may well have different inherent Charpy test properties.

It should be noted that the basic requirements of BS 1113 (Ref. 23) and BS 2633 (Ref. 25), which are shown in Table 1, relate to steels with ≤0.25%C, and those of Stoomwezen (Ref. 21) to steels with ≤0.23%C; in these standards, PWHT is required for steels with higher carbon contents. In BS 2633 (Ref. 25), PWHT is not required for steels ≤35 mm thick if the service temperature is above 0°C, while PD 5500 (Ref. 26) has the same requirement for steels up to 40 mm thick. In Pr EN 13445 (Ref. 27), PWHT is only necessary in special cases, for example in H_2S service. In some of the British Standards (Refs. 22, 25, 26), PWHT is required, even up the limiting thickness shown, if it is specified by the purchaser.

The general trends revealed by the tabulation are for the permitted thickness without PWHT to decrease with increasing alloy content of steels and/or for increased preheat to be required, together with reductions in maximum carbon level permitted. For low-alloy steels containing ≤1.5%Cr and ≤0.5%Mo (including ASME P4 groups 1 and 2 steels), and also for 2.25%Cr-1%Mo steels (including ASME P5 group 1 steels), there is greater uniformity among the standards, and there are some strong similarities between the BS 2633 requirements and those of ASME VIII and ASME B31.1 and B31.3.

In Table 1, it will be noted that in ASME VIII (Ref. 14), API 650 (Ref. 18), BS 1113 (Ref. 23), and BS 2633 (Ref. 25), there is a marginal increase in the thickness limit if a preheat at a minimum temperature of ~93°C (200°F) is used. The reason for this is not known, and has not been discovered in the contacts made with representatives of the fabrication industry. It may reflect an anticipated increase in toughness or avoidance of hard local brittle zones from a slight reduction in as-welded HAZ hardness, as well as a reduced likelihood of hydrogen-assisted fabrication cracking.

Fabrication Standards for Buildings and Bridges

The material thickness requirements for bridges and buildings, as specified in BS 5950: 2000 (Ref. 30) and BS 5400: 2000 Part 3 (Ref. 31), have been examined. These specifications are much less prescriptive regarding requirements for exemption from PWHT; most welded connections in bridges and buildings, including those in thick sections, are left in the as-welded condition, and the emphasis is on the use of materials with sufficient fracture toughness not to require PWHT. Indeed, BS 5950 does not consider PWHT at all. However, these codes do provide material thickness limits. Unlike some of the pressure vessel and piping codes examined previously, the limiting thickness requirements are dependent upon service temperature, yield strength, and Charpy impact properties.

A summary of strength and impact values for current European structural steel products is given in Ref. 5. All the new European structural steel grades are supplied to a minimum Charpy impact level. The minimum Charpy toughness requirements are 27 J at –50°C for most grades, with some requirements being 40 J at –20°C (which is approximately equivalent to 27 J at –30°C). However, there may be a limiting thickness up to which the impact toughness is guaranteed. For example, in BS EN 10025 (Ref. 32), this limiting thickness for nonalloyed grades is 250 mm for plates and 100 mm for sections.

The limiting thickness values in BS 5950 (Ref. 30) and BS 5400 (Ref. 31) are presented as general equations; the form of these equations is the same for both specifications, although differences exist in calculating the so-called k-factor.

The equations, the background to which is explained in more detail in Ref. 5, are shown below.

$T_{min} \geq T_{27J} - 20$ *BS 5950 and BS5400:*

$$t \leq 50k\left(\frac{355}{\sigma_y}\right)^{1.4} 1.2\left(\frac{T_{min} - T_{27J}}{10}\right)$$

$T_{min} < T_{27J} - 20$ *BS 5950:*

$$t \leq 50K\left(\frac{355}{\sigma_y}\right)^{1.4}\left(\frac{35 + T_{min} - T_{27J}}{15}\right)1.2\left(\frac{T_{min} - T_{27J}}{10}\right)$$

BS 5400: not permitted

where t is the maximum permitted thickness of the part under stress in mm; k is the k-factor (see below); σ_y is the nominal yield strength of the part; T_{min} is the design minimum temperature of the part in °C; T_{27J} is the temperature in degrees Celsius for which a minimum Charpy energy of 27 J is specified by the product standard for impact tests on longitudinal V-notch test pieces.

The k-factor is the product of four subfactors relating to susceptibility to brittle fracture, as follows:

$$k = k_d \cdot k_g \cdot k_\sigma \cdot k_s$$

and takes values ranging from <0.25 to 4. Low values of k denote higher susceptibility to brittle fracture, e.g., high applied stress, high strain rate, or the presence of stress concentrations. The subfactors each account for a different aspect of susceptibility to brittle fracture, as follows:

- k_d accounts for the weld detail, and takes values between 0.5 and 2, which can be increased by 50% if PWHT is applied.
- k_g accounts for the presence of gross stress concentrations and takes values up to 1.
- k_σ takes account of stress levels, with values ranging from 1 to 2.
- k_s takes account of high strain rates, with values of 0.5 (for areas likely to be loaded under impact) and 1 (for all other areas).

As an example, the maximum permitted thickness of a grade 355 steel in the as-welded condition, subjected to Charpy testing at the material design minimum temperature (MDMT), would be 50 mm for the condition k = 1, i.e., with simple weld details, quasi-static strain rates, and no gross stress concentrations. This is broadly comparable with the upper range of allowable thicknesses of Table 1. However, the limiting thickness for the same as-welded joint could be as low as 14 mm under the same applied stresses and strain rates, if gross stress concentrations and poor weld details are present. If high-strain-rate loading also applies, e.g., bridge parapets, it could be even lower at 7 mm. Conversely, for simple welded joints under low applied stress, the limiting thickness could be as high as 100 mm, and even 150 mm if the fabrication is subjected to PWHT.

The fracture avoidance rules given in BS 5400 Part 3 (Ref. 31) are based on fracture mechanics calculations, calibrated against other considerations such as the results of full-scale tests on simulated bridge details, and case histories of bridge failure. Details of these calculation methods are described in Ref. 5.

The steels employed in the United States and the United Kingdom are generally different in chemical composition, and may well have different inherent Charpy test properties.

Eurocode 3 — Design of Steel Structures

The requirements of Eurocode 3 (Ref. 33) have also been examined. Note that the document examined is a draft for development (DD ENV), and so is subject to change before final issue as a Eurocode. The document contains a procedure based on fracture mechanics principles and the Master Curve correlation between fracture toughness and Charpy energy.

Basically, the procedure determines the required fracture toughness for a steel component, depending on factors such as steel strength grade, section thickness, loading speed, lowest service temperature, applied stress, application of PWHT, type of structural element, and consequences of failure.

The provisions of the draft Eurocode (Ref. 33) are fairly similar to those of BS 5400 (Ref. 31) (and therefore similar to the upper range of Table 1) for the case k = 1, i.e., where there are no gross stress concentrating features or fatigue-sensitive weld details. However, whereas under BS 5400 the maximum permitted thickness for the same as-welded joint under similar applied stress and at a similar strain rate could range from 14 to 50 mm, it would remain 50 mm throughout under the draft Eurocode.

The draft Eurocode (Ref. 33) and BS 5400-3 (Ref. 31) requirements are compared and contrasted in detail in Ref. 5, where concern is expressed at some of the potentially unsafe provisions of the former.

Review of Documentation for Low-Alloy Steels

Low-alloy steels in piping and pressure vessel codes, primarily from the United States and United Kingdom, have also been reviewed. The information is also summarized in Table 1. See Table 2 for the compositions of relevant ASME P numbers. For such steels, there are some strong similarities in the requirements relating to exemptions from PWHT between the U.S. and UK codes. In Table 1, BS 2633 (Ref. 25) stipulates a similar preheat to the U.S. codes. However, the requirements of ASME B31.3 (Ref. 16) differ from the other codes in that PWHT is not required for ASME P3 Grades 1 and 2 steels up to 19 mm thick, while this code requires a higher preheat for P4 Grades 1 and 2 and P5 Grade 1 steels. It should be recognized that the situation is appreciably more complex than these numbers in Table 1 suggest, as different recommendations apply to specific weldments. See, for example, the footnote to ASME VIII Division 1 Table UCS-56 (Ref. 14), which includes clauses relating to nozzle connections, and the welding of pressure parts to nonpressure parts. The additional requirement to gain exemption from PWHT for tubes less than or equal to 13-mm thickness and less than or equal to 120-mm diameter in P5-type steels in Pr EN 13445 (Ref. 27) is that the design temperature should exceed 480°C.

Table 2 — Summary of Information on Relevant ASME P Numbers

ASME P Number	Steel Type
P1 group 1	C-Mn
P3 groups 1 and 2	C-0.5%Mo; 0.5%Cr-0.5%Mo
P4 groups 1 and 2	C-0.5%Cr-1.25%Mn-Si;1%Cr-0.5%Mo;1.25%Cr-0.5%Mo-Si
P5 group 1	2.25%Cr-1%Mo; 3%Cr-1%Mo

Differences between Material Grouping Systems in the ASME, CEN, and British Standard Codes

The grouping of materials used for welding has been carried out under the auspices of the different code standards committees in both Europe, including the United Kingdom, and the United States. In the United States, steels have been allocated a P number or S number, but since 1998, materials used for welder qualification may conform to other national or international standards or specifications, provided that the requirements for mechanical properties and specified analysis limits of the P or S number are met. In the United Kingdom, materials have been given group numbers in BS 4870 (Ref. 34) (for welding procedures) and BS 4871 (Ref. 35) (for welder qualifications). Both of these standards have been superseded by European standards BS EN 288 (Ref. 36) and BS EN 287 (Ref. 37). A submission was made to the committee compiling CR TR 15608, the draft guidelines for a metallic material grouping system (Ref. 38) by Sperko (Ref. 39). In his proposed Annex to CR TR 15608, he attempted to unify the ASME and CRTR 15608 grouping. He examined 985 relevant U.S. steel specifications and found the following:

1) 196 steel compositions could be classified within an ASME P1 Group.

2) Of the 196, only 91 C-Mn steels could be given a CR TR 15608 group number.

This study has indicated that, in terms of an ASME or CEN grouping system, material grouping does not provide a basis for exemption from PWHT. It would clearly be of considerable benefit in moving toward more uniform PWHT requirements if steel producers were to extend the practice of dual, or even multiple, certification of steels, so that greater uniformity is achieved in the compositions of steels. The practice would also facilitate the eventual unification of standards.

Code Requirements

Although the fundamental details of the differences in the separate codes for pressure vessels and piping, in terms of preheat and other requirements, have not been included, Table 1 indicates that rationalization of the PWHT exemption of all the codes would not be easy to achieve. For C-Mn steels, a comparison of codes, in terms of maximum wall thickness where PWHT is not required and maximum carbon equivalent of material permitted, has suggested an even more widely spread divergence. The codes are for different engineering applications. Differences between these may include different design stress criteria, different inherent Charpy test requirements, and (through the inspection codes) different allowable defect sizes. The codes were drawn up by different professional bodies, based on extensive experience and engineering practice. Therefore, differences arose and inconsistent requirements ensued. The gross differences that have arisen are likely to preclude the issue of a unified code requirement giving exemption from PWHT.

Three of the main groups of steel users with an interest in obtaining exemption from PWHT are the petrochemical industry through the Engineering Equipment and Materials Users Association (EEMUA) Material Technology Committee, the power generation industry (through the Electricity Generators Welding Panel (EGWP)) and the general structural industry. The data covered in this review suggest that reconciliation of the requirements of these user groups may not be possible. It would clearly be of benefit to the power generation industry to increase the thickness threshold for PWHT, for example to the 40 mm embodied in EEMUA 158 (Ref. 28) for C-Mn steels. Examination of the data also raises questions about the need to give a PWHT to weldments covered by BS 1113 (Ref. 23) and BS 2633 (Ref. 25) when the carbon content exceeds 0.25%. This limitation appears questionable, in the absence of such a condition in the other codes, but should be considered in relation to the Charpy properties of the steels concerned.

C-Mn and Cr-Mo Steels

For C-Mn and Cr-Mo steels, the lower thickness threshold embodied in ASME B31.1 (Ref. 15) and B31.3 (Ref. 16), compared with the other standards, may reflect the likelihood that the welding will be carried out in the field, and that defect rates and defect sizes may be greater than for shop welds. Girth welds in steel pipes have been subjected to a fracture mechanics assessment by Mohr (Ref. 40), who assumed the presence of root defects, and who concluded that the fracture resistance of pipes thicker than 19 mm was at least equal to that of thinner walled pipes. As PWHT is not required by ASME B31.1 for thinner walled pipes, presumably because the fracture resistance has been found to be sufficient, Mohr questioned the need for PWHT of thicker walled pipe if a fixed (rather than a proportional) flaw size is assumed in the calculations. However, all of these considerations need to be seen in the context of the inherent Charpy properties of the materials concerned, and this is not explicitly treated in some of the codes involved.

The position of the general structural industry is that the scale and size of structures is so large that PWHT of the overall structure is impracticable, and PWHT is only considered for local sub-assemblies under exceptional circumstances. Virtually all welded connections in bridges and buildings, including those in thick sections, are left in the as-welded condition, and the emphasis is on the use of materials with sufficient fracture toughness not to require PWHT. Fracture mechanics calculations were used in defining the fracture avoidance rules given in BS 5400 Part 3 (Ref. 31), and these were calibrated against other information, including the results of full-scale tests on simulated bridge details, and case histories of bridge failure. The detailed history of the piping codes is not known, but it is likely that custom and practice made a greater contribution, no doubt with some experience of failures incorporated. Also, it is noted that ASME B31.1 (Ref. 15) and ASME B31.8 (Ref. 17) provide for nonimpact tested steels to be used. However, since the code development took place, steel-making technology has changed significantly, steel toughness levels have generally improved substantially, and (at least within Europe) steel specifications commonly incorporate impact toughness requirements. It is, therefore, likely that limiting thicknesses could be increased, and thus PWHT omitted, as was shown to be acceptable for the steel vessels subjected to an ECA by Leggatt et al. (Ref. 41).

General Discussion

In spite of the disparities between the PWHT requirements of the pressure vessel and piping standards depicted in Table 1, some rationalization could be effected by building on the similarities that do exist. One possible approach would be to define a modest limiting thickness, perhaps ~32 mm, for which there are few additional requirements and a minimum level of absorbed Charpy energy could be assumed for the steels concerned. A greater limiting thickness could then be accommodated if additional requirements were met. This is the approach adopted in PD 5500 (Ref. 26), where the additional requirement is a minimum Charpy impact toughness (of ≥ 27J at –20°C) for the higher level of limiting thickness of 40 mm. More extensive requirements for the same limiting thickness are imposed in Stoomwezen (Ref. 21). These are C ≤0.23%, IIW CE ≤0.45, R_e ≤370 N/mm^2, both C_v ≥ 27 J at –50°C and C_v ≥ 31 J at 0°C for the base steel, and C_v ≥ 31 J at 0°C for the weld metal. It will be noted that the codes do not mention explicitly as-welded HAZ toughness, even though this factor would probably be limiting if HAZ fracture toughness were to be measured and a detailed engineering critical assessment were to be carried out.

This present study has demonstrated that code classifications and material groupings do not provide avenues for a uniform approach across all the codes, at least for C and C-Mn steels, for the omission of PWHT following welding. PD 5500:2000 (Ref. 26) provides an Appendix that can be used to justify exemption from PWHT. The justification is based on a design reference temperature calculation. However, it appears that this philosophy has been adopted only in this pressure vessel code, and the approach may not gain wide acceptance in codes for other applications. A material properties, rather than code-based, approach might be more widely acceptable. What appears to be required is a knowledge base of weldment impact value/fracture toughness properties for welds deposited with known welding parameters. It may then be possible for codes to include HAZ toughness requirement for weldments.

Conclusions

Code requirements for permitting as-welded construction without PWHT have been reviewed for C and C-Mn steels and some low-alloy steels, and the requirements of different codes have been compared. The conclusions are as follows:

1) U.S. and UK code requirements are generally similar in the limiting thickness of C and C-Mn steels (including ASME P1 steels) beyond which PWHT is required for pressure vessels, piping, and storage tanks, at ~32 mm. However, differences in the chemical compositions of U.S. and UK steels influence PWHT requirements. The major exceptions in this area are ASME B31.1 and B31.3 (limiting thickness 19 mm). However, general structural codes, such as BS 5400 for bridges, BS 5950 for buildings, and EEMUA 158 for offshore structures, permit significantly higher thicknesses in the as-welded condition, linked to increasing Charpy energy requirements.

2) For low-alloy steels containing ≤1.5%Cr and ≤0.5%Mo (including ASME P4 groups 1 and 2 steels), and also for 2.25%Cr-1%Mo steels (including ASME P5 group 1 steels), there are some strong similarities between the BS 2633 requirements and those of ASME VIII and ASME B31.1 and B31.3. The general trends are for the permitted thickness without PWHT to decrease with increasing alloy content of steels and/or for increased preheat to be required, together with reductions in maximum carbon level permitted.

3) In view of the differences that exist in the chemical compositions of broadly comparable U.S. and UK steels and the lack of consistent requirements for Charpy test properties (as far as ASME and CEN are concerned), alignment by material grouping for C-Mn steels is not universally possible as a basis for exemption from PWHT.

4) Since the development of the earliest codes, steel-making technology has changed significantly, steel toughness levels have generally improved substantially, and (at least within Europe) steel specifications commonly incorporate impact toughness requirements. It is therefore likely that limiting thicknesses could be increased, and thus PWHT omitted.

5) UK code requirements for general structures such as bridges, buildings, and offshore structures permit significantly greater thicknesses to be used in the as-welded condition, linked to Charpy toughness requirements for different grades of steel, based on fracture mechanics analyses. The requirements can be expressed in terms of MDMT – T_{27J} (the temperature difference between the material design minimum temperature and the temperature for 27 J energy absorption in the Charpy test) and the yield strength of the steel, for given assumptions about flaw size and stress level.

Recommendations

1) Where the relevant fabrication codes require that a PWHT be carried out, consideration should be given to carrying out a fracture mechanics assessment, with the agreement of all interested parties, in order to extend the thickness beyond which PWHT is required.

2) Typical Charpy test data should be reviewed and collated in terms of thickness and material type and IIW CE for steels supplied against the various standards summarized in Table 1. Following completion of the review, consideration should be given to the following cases: C- and C-Mn steels that would potentially allow an increase in the ASME B31.1 and B31.3 threshold thickness level for PWHT, and C- and C-Mn steels with <0.25%C, to establish if the BS 1113 and BS 2633 requirements are justified.

3) Consideration should be given to the generation of toughness data for thicknesses >12.5 mm and where Charpy energy requirements are not unduly onerous, to see where the avoidance of PWHT can be justified.

4) Steel producers should be encouraged to extend the practice of dual, or even multiple, certification of steels, so that greater uniformity is achieved in the compositions of steels, thereby facilitating the eventual unification of standards.

5) Consideration should be given to introducing HAZ toughness requirements into fabrication codes.

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