Alternative steel selection and its effect on design and testing of tanks to BS 7777

ICS 23.020.40; 77.140.30

Committees responsible for this Published Document

The preparation of this Published Document was entrusted to Technical Committee PVE/15, Site built tanks for the petroleum industry, upon which the following bodies were represented:

Aluminium Federation
British Chemical Engineering Contractors' Association
British Compressed Gases Association
BG Technology
Concrete Society
Energy Industries Council
Engineering Equipment and Materials Users' Association
HSE
Independent Tank Storage Association
Institution of Mechanical Engineers
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UK Steel Association
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This Published Document, having been prepared under the direction of the Engineering Sector Committee, was published under the authority of the Standards Committee and comes into effect on 15 May 2000

Amendments issued since publication

Amd. No.	Date	Comments

The following BSI references relate to the work on this standard:
Committee reference PVE/15
Draft for comment 99/10678 DC

ISBN 0 580 33144 X

Contents

Foreword

This Published Document has been prepared by Technical Committee PVE/15, Site built tanks for the petroleum industry.

It should be used in conjunction with BS 7777:1993.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 6, an inside back cover and a back cover.

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Introduction

BS 7777 is the standard for Flat-bottomed, vertical cylindrical storage tanks for low temperature service, used for the storage of refrigerated liquefied gases. The liquid containers are of metallic construction and the material selection is based on initiation resistance to brittle fracture. In view of this, full height hydrostatic testing of the metallic tanks is specified. This preload ensures that all liquid-containing parts of the tank are subject to an overload at a temperature at which the material and welds are ductile, thus causing yielding at stress concentration areas, and giving added safety with respect to brittle fracture initiation resistance.

The criterion for plate material selection in BS 7777, for use at temperatures between −5 °C and −50 °C, is that the Heat Affected Zones (HAZ) of any plate in the tank should have a minimum individual Charpy V-notch impact property of 20 J at the design temperature. For temperatures in the region −100 °C to −196 °C, the criteria for 9 % Ni steels are the use of BS standard material with 27 J average Charpy V-notch at −196 °C and the improved 9 % Ni steels with 100 J at −196 °C.

When using fully ductile austenitic stainless steels for tank construction, there is inherently no risk of brittle fracture.

The basis of selection in this document is that the steel, in addition to initiation resistance, has the capability to arrest brittle fractures that may extend across a horizontal weld seam or associated with a local brittle region of a vertical weld seam. The steels are therefore inherently capable of arresting short cracks that may extend across a horizontal weld seam or associated with a vertical weld seam. Preloading at a higher temperature has no beneficial effect on the crack arresting characteristics and therefore this Published Document only recommends hydrostatic testing as a proof test to ensure the foundations are capable of supporting the design loads.

Ferritic steels supplied to the specification of this Published Document may be used for:

— the tank or inner tanks of single containment tanks illustrated in Figure 1 of BS 7777-1;

— the inner and outer tanks of double and full containment tanks illustrated in Figures 2 a) and 3 a) of BS 7777-1;

— the inner tanks of double and full containment tanks illustrated in Figures 2 b), 2 c), 3 b) and 3 c) of BS 7777-1;

Nil-Ductility Transition Temperature (NDTT) values, used as a proxy for the Crack Arrest Temperature (CAT), are recommended in order to ensure suitable crack arrest properties. Background data can be found in Bibliography references [1], [2], [3], [4], [5] and [6].

1 Scope

This Published Document gives recommendations for an alternative basis of material selection for ferritic steels for use in low temperature storage tanks for the storage of refrigerated liquefied gases to that specified in BS 7777.

This Published Document does not apply to refrigerated ammonia tanks, since other factors affecting the material selection to resist stress corrosion cracking could be at variance with the recommendations of this Published Document.

2 Normative references

The following normative standards contain provisions which, through reference in this text, constitute provisions of this Published Document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the publication referred to applies.

BS 7777 (all parts), *Flat-bottomed, vertical, cylindrical storage tanks for low temperature service.*

BS EN 10028-1, *Specification for flat products made of steels for pressure purposes — Part 1: General requirements.*

BS EN 10028-4, *Specification for flat products made of steels for pressure purposes — Part 4: Nickel alloy steels with specified low temperature properties.*

ASTM E208, *Test method for conducting drop weight test to determine Nill-Ductillity Transition temperature of ferritic steels.*[1)]

3 Materials

3.1 Steel plate

3.1.1 *Material specifications*

There are no industrial, national or international standards for ferritic steels in which toughness requirements are specified for crack arrest capability. A number of proprietary steels have been developed for which some test data have been provided, and these are summarized in Table 1 with the related references.

[1)] Available from BSI, 389 Chiswick High Road, London W4 4AL.

It is essential, therefore, that purchasers and manufacturers satisfy themselves that the proposed suppliers of steel with crack arrest properties have the necessary expertise to produce the steel and provide adequate evidence that all necessary properties can be achieved in production. Where possible, such evidence should be based upon actual production data but, because of the stage of development of these steels, such evidence might have to be based upon trial production only. In such cases, it is recommended that material property data be based on a minimum of two casts of steel of at least 250 tonnes each.

Ferritic steels should be in accordance with BS EN 10028-1 and -4, amended and supplemented by **3.1.2** to **3.1.5**. Suitable steel grades and their properties are given in Table 1.

3.1.2 *Steelmaking process*

The tank manufacturer should obtain from the steelmaker full details of the proposed steelmaking process, together with details of the final supply condition. However, all steels should be produced by a basic oxygen process and vacuum degassed, and also should be fully killed and made to fine grain practice.

In order to provide the crack arrest toughness properties required, it is likely, but not mandatory, that these steels will be produced by either a thermo-mechanical controlled process (TMCP), or by Quenching and Tempering (Q & T). In either case, the steelmaker should identify the essential details of the process including temperatures and holding times for any heat treatments.

3.1.3 *Chemical composition*

The tank manufacturer should obtain from the steelmaker the composition limits of the elements specified in EN 10028-4, together with those elements, as agreed between the purchaser, the manufacturer and the steelmaker, which are likely to affect the final properties of the steel. For actual production, the chemical composition, as measured by the ladle analysis, should be reported. Requirements for the product analysis and for carbon equivalent limits should be agreed between the purchaser, the manufacturer and the steelmaker.

3.1.4 *Mechanical properties*

The tank manufacturer should obtain from the steelmaker the minimum yield, tensile strength and the minimum elongation and these should have been achieved in the mechanical tests on each plate as specified in BS EN 10028-1. Charpy V-notch impact testing should be undertaken in accordance with BS EN 10028-1, and meet the requirements of Table 2.

3.1.5 *Dropweight testing (crack arrest properties of parent plate and HAZ)*

3.1.5.1 The steelmaker should provide evidence, either from previous production or from trial production test plates as specified in **3.1.5.2**, that the proposed steel has a NDTT as specified in Table 3, based on dropweight testing in accordance with ASTM E208. Tests should be undertaken on a plate thickness able to represent all the thicknesses of plates to be used in the construction of the tank shell or bottom annular plates. Each plate of a particular thickness which is tested may then qualify other plates of thicknesses to 70 % of that thickness. The plate of maximum thickness should be tested first. (For example if a tank is constructed of plates ranging in thickness from 24 mm to 6 mm, tests at 24 mm, 16.8 mm, 11.8 mm and 8.3 mm would qualify all of the plates).

3.1.5.2 A minimum of four test coupons should be taken from each plate to be tested, two from each end of the plate, and butt welded along the edges of the coupons transverse to the final rolling direction to make a minimum of two welded coupons. The welding procedure should follow that given in BS 7777-2:1993, annex A. Specimens conforming to ASTM E208 should be cut from these welded coupons for dropweight testing to establish the NDTT for both the parent plate and the heat affected zone (HAZ). The specimen type is dependent upon plate thickness as given in Table 4.

Specimens for HAZ testing should be taken transverse to the test weld and the notch in the brittle weld bead cut within ± 1 mm of the fusion line.

In cases where the test weld is produced from high nickel filler material, the high nickel of the test weld will dilute the brittle weld bead. Therefore, the notch in the brittle weld bead should be placed above the fusion line first approached by the brittle weld bead (see Figure 1).

3.2 Weld metals

Welding consumables should be selected such that the welding procedure test plates specified in BS 7777 should meet the Charpy V-notch impact test requirements of Table 2. In addition, dropweight test specimens in accordance with **3.1.5** should be taken from each procedure test plate to establish the NDTT. The specimens should be taken transverse to the weld and the notch in the brittle weld bead cut within 1 mm of the centre of the test weld.

In cases where the test weld is produced from austenitic high nickel filler material, there is no need for dropweight testing.

4 Design and manufacture

4.1 General

The tank should be designed, manufactured and tested in accordance with BS 7777, except for the material selection, which should be in accordance with clause **3** of this Published Document, and the hydrostatic testing, which should be in accordance with **4.2**, **4.3** and **4.4**.

4.2 Single containment tanks

For single containment tanks manufactured from steels other than 9 % Ni steel or austenitic stainless steel, for use at temperatures warmer than −105 °C, full height hydrostatic testing in accordance with BS 7777-1:1993, **7.2.5**, or BS 7777-2:1993, **12.1**, is necessary.

For single containment tanks manufactured from 9 % Ni steel or austenitic stainless steel, it is not necessary to carry out full height hydrostatic testing, provided the design temperature is not colder than −196 °C. When using such materials, the water level need only be sufficient to impose a stress in the bottom tier equivalent to 1.25 times the design stress arising from product hydrostatic loading.

For single containment tanks conforming to BS 7777-4, manufactured from 9 % Ni steel in accordance with this Published Document, with a thickness less than 12 mm, or austenitic stainless steel, then an overload during hydrostatic testing is not necessary. Hydrostatic testing should be in accordance with BS 7777-4.

4.3 Inner tanks of double and full containment tanks

For the inner tanks of double and full containment tanks manufactured from steels specified in this Published Document, a full height hydrostatic test is unnecessary.

A hydrostatic test with a water level sufficient to impose a stress in the bottom tier equivalent to 1.25 times the design stress arising from product hydraulic loading should be carried out.

4.4 Outer tanks of double and full containment tanks

For the outer tanks of double and full containment tanks manufactured from steels specified in this Published Document, hydrostatic testing is unnecessary. Equally, where steels specified in this Published Document are used for the lower tiers only of outer containers, there should be no need to carry out a hydrostatic test. However, increased non-destructive examination should be carried out on all surfaces of welds greater than 15 mm thick by magnetic particle crack detection or dye penetrant crack detection.

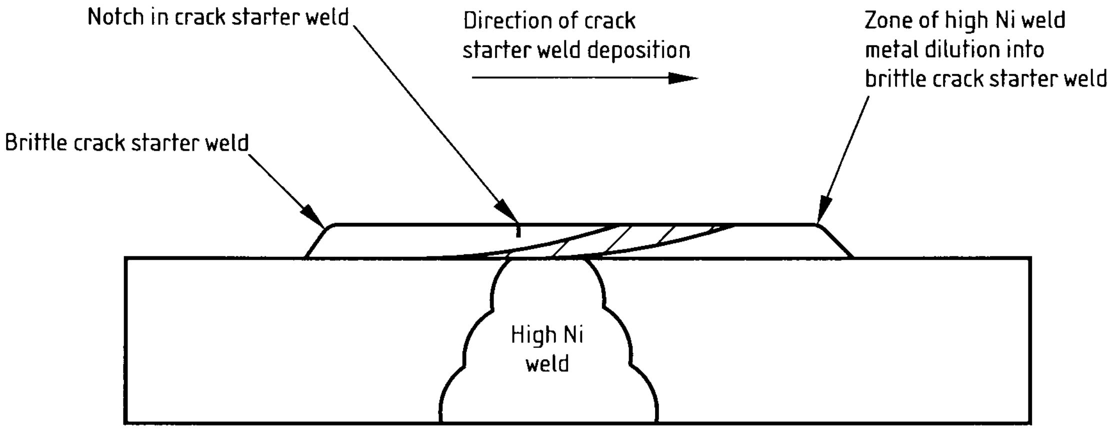

Figure 1 — Schematic longitudinal section through HAZ dropweight test specimen with high Ni weld metal

Table 1 — Suitable steels

Typical stored product	Boiling point °C	Approx. liquid SG	Suitable steel grades (Not lower than NDTT + 40 °C)	Plate thickness mm	NDTT °C	Min. design temp[a] °C	Bib. ref.
n-butane	−0.5	0.60	C-Mn TMCP	35	−55	−15	[7]
iso -	−12.0	0.60	0.15 % Ni C-Mn Q & T Gr 33B	38	−55	−15	[8]
butane			0.15 % Ni C-Mn Q & T Gr37	38	−65	−25	[8]
			C-Mn TMCP	35	−70	−30	[7]
			0.2 % Ni C-Mn TMCP	35	−70	−30	[9]
			0.25 % Ni C-Mn TMCP Gr33B	38	−70	−30	[8]
Propane	−44.5	0.59	0.25 % Ni C-Mn TMCP Gr 33B	18	−95	−55	[8]
			0.25 % Ni C-Mn TMCP Gr 33B	30	−95	−55	[8]
			0.6 % Ni C-Mn TMCP	40	−100	−60	[7]
			1.5 % Ni TMCP	20	−105	−65	[9]
Propylene	−48	0.61	3.5 % Ni Q & T	25	−105	−65	[10]
			2.5 % Ni TMCP	34	−110	−70	[7]
			3.5 % Ni Q & T	15	−115	−75	[8]
			3.5 % Ni Q & T	15	−115	−75	[10]
			3.5 % Ni Q & T	25	−120	−80	[7]
			2.5 % Ni TMCP	10	−120	−80	[8]
			3.5 % Ni Q & T	25	−120	−80	[8]
			2.5 % Ni TMCP	25	−125	−85	[7]
			2.5 % Ni TMCP	50	−125	−85	[8]
Ethane	−88.6	0.55	2.5 % Ni TMCP	20	−130	−90	[8]
			2.5 % Ni TMCP	34	−130	−90	[8]
Ethylene	−104.0	0.57	2.5 % Ni TMCP	6	−145	−105	[8]
			2.5 % Ni TMCP	34	−145	−105	[9]
			2.5 % Ni TMCP	15	≤150[b]	≤115	[9]
Methane	−161.5	0.47	9 % Ni NNT	16	≤196[b]	≤161	[11]
			9 % Ni Q & T	16	≤196[b]	≤161	[11]
			9 % Ni Q & T		≤196[b]	≤161	[12]

[a] Based on T_{min} = NDTT + 40 °C.

[b] "No-break" at temperature indicated, NDTT at least $T - 5$ °C, possibly lower.

Table 2 — Longitudinal Charpy V-notch impact test requirements

Steel type	Test energy of plate[a,b]	Test temperature for 120 J[c] °C	Test energy of weld metal
C-Mn (TMCP)	27 J at −50 °C -ΔT[d]	−20	50 J at −50 °C
Low Ni (TMCP or Q & T)	27 J at −80 °C -ΔT[d]	−50	50 J at −80 °C
9 % Ni steels	100 J at −196 °C[e]	Not required	75 J at −196 °C

[a] Energy value is the minimum average of three specimens, with only one single value less than the value specified and with no single value less than 75 % of the value specified.

[b] For steel thickness less than 11 mm, 10 mm × 5 mm sub-size specimens should be used, and should demonstrate 70 % of the values specified in this table. For 9 % Ni steels, the value for 10 mm × 5 mm sub-size specimens should be 50 % of the value specified in this table.

[c] Impact testing should be carried out on each plate to demonstrate the required impact value. In addition, testing at a frequency of one test of three specimens per 40 tonnes batch should be carried out to demonstrate 120 J at the temperature specified. The definition of plate and batch are given in EN 10025.

[d] Reference should be made to annex A of BS 7777-2.

[e] For horizontal welds in 9 % Ni steels, the weld metal requirement need only be 50 J at −196 °C.

Table 3 — Required nil-ductility transition temperatures and minimum test temperatures for no-break results

Product	Assumed design temperature[a] °C	Nil-ductility transition temperature °C	Minimum testing temperature for two no-break results °C
Butane	−10	−50	−45
Propane/Propylene	−50	−90	−85
Ethane/Ethylene	−105	−145	−140
Methane (LNG)	−165	N/A[b]	−196 [c]

[a] This temperature and the associated NDTT can be used for material selection provided that the specified design temperature is not more than 5 °C colder than this assumed value.

[b] Testing below −196 °C is considered impractical.

[c] Two no-break results at −196 °C ascertain a NDTT of at least −201 °C and, with CAT = NDTT + 400 °C [5], [6], gives a minimum CAT of −161 °C. With the boiling point of LNG being only 0.5 °C lower (−161.5 °C), and the conservatism of the CAT = NDTT + 40 °C relation, this is considered a sufficient requirement to specify crack arrest.

Table 4 — Dropweight specimen type

Plate thickness[a] mm	Specimen type[b]
$16 \le t < 19$	P-3
$19 \le t$	P-2

[a] For plates less than 16 mm thick, the P-3 specimen should be used, but the deflection stop distance specified in ASTM E208 should be increased as follows:

$$\text{Deflection stop distance (in mm)} = \frac{30.25 - \text{specimen thickness}}{7.5}$$

[b] See ASTM E208.

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