

Guidance on PWHT for P1 CMn Steels

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Contents

Foreword	VIII
Acknowledgements.....	VIII
Abbreviations/Acronyms used in this Guide.....	IX
1 Background	1
2 Scope.....	3
2.1 Exclusions.....	3
2.2 Alternative Criteria	3
3 Basis of Design.....	5
3.1 As-Welded Applications	5
3.1.1 As-welded residual Stress	5
3.1.2 Applied Stress	5
3.1.3 Minimum Flaw Size.....	5
3.1.4 Fracture Toughness.....	6
3.1.5 Application	6
3.2 Charpy Impact Exemption Curves	7
3.3 PWHT Applications.....	7
4 Application Methods.....	9
4.1 Method A – Determine the MDMT.....	9
4.2 Method B – Define maximum as-welded thickness against fixed Charpy test temperature depression values	11
5 Additional Impact Energy Benefit.....	13
APPENDIX A Direct Calculation of temperature depression.....	14
APPENDIX B Impact test exemption curves: SI Units	15
B.1 SMYS=30ksi (207MPa).....	16
B.2 SMYS=35ksi (241MPa).....	17
B.3 SMYS=40ksi (276MPa).....	18
B.4 SMYS=50ksi (345MPa).....	19
B.5 SMYS=60ksi (414MPa).....	20

APPENDIX C Impact test exemption curves: US Customary Units	21
C.1 SMYS=30ksi (207MPa)	22
C.2 SMYS=35ksi (241MPa)	23
C.3 SMYS=40ksi (276MPa)	24
C.4 SMYS=50ksi (345MPa)	25
C.5 SMYS=60ksi (414MPa)	26
APPENDIX D Impact tested curves: SI Units	27
D.1 SMYS=30ksi (207MPa)	28
D.2 SMYS=35ksi (241MPa)	29
D.3 SMYS=40ksi (276MPa)	30
D.4 SMYS=50ksi (345MPa)	31
D.5 SMYS=60ksi (414MPa)	32
APPENDIX E Impact tested curves: US Customary Units.....	33
E.1 SMYS=30ksi (207MPa)	34
E.2 SMYS=35ksi (241MPa)	35
E.3 SMYS=40ksi (276MPa)	36
E.4 SMYS=50ksi (345MPa)	37
E.5 SMYS=60ksi (414MPa)	38
APPENDIX F Worked examples.....	39
F.1 Example A: Impact test exemption	39
F.2 Worked Example B: Impact tested material	40
F.3 Example C: Sub size specimen.....	42
F.4 Example D: Sub size specimen	44
References	46
Bibliography.....	47

List of Figures

Figure 1:	MDT Vs CVN Impact test temperature.....	2
Figure B-1:	Impact test exemption – 207MPa (30ksi) yield – as welded.	16
Figure B-2:	Impact test exemption – 207MPa (30ksi) yield – PWHT.	16
Figure B-3:	Impact test exemption – 241MPa (35ksi) yield – as welded.	17
Figure B-4:	Impact test exemption – 241MPa (35ksi) yield – PWHT.	17
Figure B-5:	Impact test exemption – 276MPa (40ksi) yield – as-welded.....	18
Figure B-6:	Impact test exemption – 276MPa (40ksi) yield – PWHT.	18
Figure B-7:	Impact test exemption – 345MPa (50ksi) yield – as welded.	19
Figure B-8:	Impact test exemption – 345MPa (50ksi) yield – PWHT.	19
Figure B-9:	Impact test exemption – 414MPa (60ksi) yield – as welded.	20
Figure B-10:	Impact test exemption – 414MPa (60ksi) yield – PWHT.	20
Figure C-1:	Impact test exemption – 30ksi (207MPa) yield – as welded.	22
Figure C-2:	Impact test exemption – 30ksi (207MPa) yield – PWHT.	22
Figure C-3:	Impact test exemption – 35ksi (241MPa) yield – as welded.	23
Figure C-4:	Impact test exemption – 35ksi (241MPa) yield – PWHT.	23
Figure C-5:	Impact test exemption – 40ksi (276MPa) yield – as-welded.....	24
Figure C-6:	Impact test exemption – 40ksi (276MPa) yield – PWHT.	24
Figure C-7:	Impact test exemption – 50ksi (345MPa) yield – as welded.	25
Figure C-8:	Impact test exemption – 50ksi (345MPa) yield – PWHT.	25
Figure C-9:	Impact test exemption – 60ksi (414MPa) yield – as welded.	26
Figure C-10:	Impact test exemption – 60ksi (414MPa) yield – PWHT.	26
Figure D-1:	Impact tested curve – 207MPa (30ksi) yield – as welded.....	28
Figure D-2:	Impact tested curve – 207MPa (30ksi) yield – PWHT.....	28
Figure D-3:	Impact tested curve – 241MPa (35ksi) yield – as welded.....	29
Figure D-4:	Impact tested curve – 241MPa (35ksi) yield – PWHT.....	29
Figure D-5:	Impact tested curve – 276MPa (40ksi) yield – as welded.....	30
Figure D-6:	Impact tested curve – 276MPa (40ksi) yield – PWHT.....	30
Figure D-7:	Impact tested curve – 345MPa (50ksi) yield – as welded.....	31
Figure D-8:	Impact tested curve – 345MPa (50ksi) yield – PWHT.....	31
Figure D-9:	Impact tested curve – 414MPa (60ksi) yield – as welded.....	32
Figure D-10:	Impact tested curve – 414MPa (60ksi) yield – PWHT.....	32
Figure E-1:	Impact tested curve – 30ksi (207MPa) yield – as welded.....	34
Figure E-2:	Impact tested curve – 30ksi (207MPa) yield – PWHT.....	34
Figure E-3:	Impact tested curve – 35ksi (241MPa) yield – as welded.....	35
Figure E-4:	Impact tested curve – 35ksi (241MPa) yield – PWHT.....	35
Figure E-5:	Impact tested curve – 40ksi (276MPa) yield – as welded.....	36
Figure E-6:	Impact tested curve – 40ksi (276MPa) yield – PWHT.....	36
Figure E-7:	Impact tested curve – 50ksi (345MPa) yield – as welded.....	37
Figure E-8:	Impact tested curve – 50ksi (345MPa) yield – PWHT.....	37

Figure E-9: Impact tested curve – 60ksi (414MPa) yield – as welded.....	38
Figure E-10: Impact tested curve – 60ksi (414MPa) yield – PWHT.....	38

List of Tables

Table 1: Charpy Temperature Depression vs. Control Thickness (US Customary Units).....	9
Table 2: Charpy Temperature Depression vs. Control Thickness (SI Units)	10
Table 3: Maximum As-Welded Control Thickness [in] vs Charpy Temperature Depression (US Customary Units).....	11
Table 4: Maximum As-Welded Thickness [mm] vs Charpy Temperature Depression (SI Units)	12

Foreword

The ASME Code for Pressure Piping, B31.3-2014⁽¹⁾, and later versions, are different from the 2012 and earlier editions⁽²⁾ with regard to rules for post-weld heat treatment (PWHT). Specifically, there is no longer a defined thickness threshold for P1 (CMn) steels above which PWHT is required. EEMUA member companies identified a concern of brittle fracture associated with the relaxation of the pre-2014 edition PWHT thickness thresholds⁽³⁾. They were concerned that there was no suitable industry standard guidance available to assist designers in determining whether PWHT should be required.

The aim of this publication is to provide guidance to designers of piping systems on the threshold thickness for PWHT of P1 steels. Guidance is also provided on the benefit of PWHT of P1 steels when selected for low temperature applications.

Acknowledgements

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Abbreviations/Acronyms used in this Guide

a	crack depth
c	half crack length
CMn	Carbon / Carbon-Manganese
ECA	Engineering Critical Assessment
MDMT	Minimum Design Metal Temperature, same as 'Design Minimum Temperature' as defined by ASME B31.3 para. 301.3.1
P1	ASME Steel P-No 1 (steel grouping)
PWHT	Post Weld Heat Treatment
SMYS	Specified Minimum Yield Stress
s	Specified Minimum Yield Stress
t	Control Thickness, as defined by ASME B31.3 para. 331.1.3
T _{CV}	Charpy Impact Reference Temperature (to achieve 27J minimum average)
T _{DEP}	Charpy Impact Test Temperature Depression (expressed as a positive number where it corresponds to a lower required Charpy test temperature than the MDMT)
x	Steel Thickness Parameter, $x = (1/t)^{0.25}$ for control thickness (t) in inches $x = (25.4/t)^{0.25}$ for control thickness (t) in mm

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1 Background

The susceptibility of CMn steels to low-temperature brittle fracture has been observed since the early 1900's. Current industry knowledge recognises that there are a number of factors which increase this susceptibility. These include:

- low temperature
- low material toughness
- large wall thickness
- high applied and/or residual tensile stresses
- the presence of flaws in the weld or base metal

Whilst the underlying mechanisms were not fully understood until the development of fracture mechanics principles into mature technology in the 1960s, specifications were developed to counter these risks, including the ASME Boiler and Pressure Vessel Code in 1914 and the forerunner to ASME B31.3, the American Tentative Standard Code for Pressure Piping in 1935.

These design codes specified PWHT for CMn steels above certain thickness thresholds to avoid brittle fracture along with Charpy impact test requirements for steels and weld procedures. The 2012 edition of ASME B31.3⁽²⁾ and earlier editions set this threshold at 0.75 inch (equated to 19mm or 20mm depending on edition).

The 2014 edition of ASME B31.3⁽¹⁾, and later editions, waived this requirement subject to two constraints: multiple layer welding for steel thickness > 5mm, and a minimum preheat of 95°C (200°F) prior to welding steel thickness > 25mm (1 in). EEMUA members⁽³⁾ and others⁽⁴⁾ raised concerns about the technical justification for these changes.

Other design codes for pressure vessels and pipework, eg. PD5500, EN ISO 13445, & EN ISO 13480 followed similar principles and included relationships between Charpy impact test temperature, minimum design temperature and material thickness in a series of design curves for as-welded and PWHT applications. These design curves showed a common trend: as the material thickness is increased, the margin between the minimum design temperature and the (normally lower) Charpy impact test temperature also increases. This relationship is illustrated schematically in Figure 1.

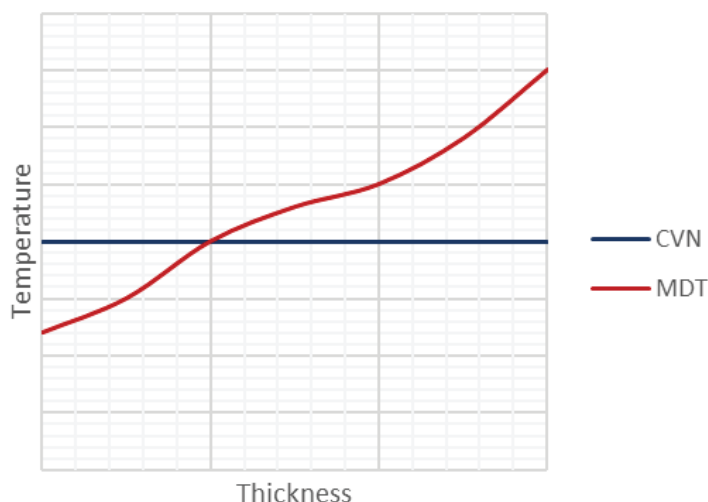


Figure 1: MDT Vs CVN Impact test temperature

The requirements of ASME B31.3 were often supplemented by end users, including EEMUA publication 153 which included a detailed appendix outlining *“Requirements for Carbon, Carbon Manganese and some low Alloy Steel Piping for Applications below 0°C”*. This appendix was based on the requirements of BS 5500:1994 which necessitated several changes to material specifications and design rules which were also covered in the publication. EEMUA 153 was withdrawn in 2010.

The removal of mandatory PWHT for P1 steels thicker than 0.75 inch prompted EEMUA to develop this publication 235.

Adoption of design curves from other codes for use on pipework designed to ASME B31.3 was considered problematic because of the different underlying design assumptions. Therefore, EEMUA commissioned fracture mechanics work to be carried out by Equity Engineering Group Inc. to create a new set of design curves for P1 steels based on ASME B31.3 and API 579⁽⁵⁾. This work provides the technical justification for the guidance contained in this publication.

This publication meets the intent of the ASME B31.3 code, when the obligations of the designer and owner, as described in B31.3 para. 300 (c) (3), are met.

2 Scope

This publication applies to design of new P1 pipework when also designed in accordance with ASME B31.3.

2.1 Exclusions

The guidance in this publication does not apply to:

- Severe cyclic service
- Mechanical and/or thermal shock loading
- Hydrogen-charged service
- Materials outside the thickness and SMYS ranges used in this publication
- Any materials that are not P1 group steels

2.2 Alternative Criteria

The guidance in this publication is the result of a generic ECA⁽⁶⁾. The method is based, amongst other things, on statistical fracture toughness correlations with the results of Charpy Impact testing according to the Master Curve approach which is the current best industry practice.

This publication uses a particular set of underlying assumptions. If the results are found to be unacceptable, then alternative routes based on specific ECA may be considered. Such calculations should be based on directly measured fracture toughness data, e.g. by CTOD testing, J testing etc. These alternative criteria are in line with the principles of ASME B31P, Appendix E.

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3 Basis of Design

3.1 As-Welded Applications

A fracture mechanics assessment⁽⁶⁾ has been conducted to prepare low temperature design curves for 30ksi, 35ksi, 40ksi, 50ksi, and 60ksi SMYS P1 steels.

In order to complete this assessment, a number of assumptions have to be made. These assumptions are included in the following sections.

3.1.1 As-welded Residual Stress

The as-welded residual stress has been assumed to be equal to the steel SMYS plus an additional 10ksi to allow for the actual yield stress being higher than the specified minimum.

3.1.2 Applied Stress

The primary membrane stress used was set equal to $2/3$ SMYS

3.1.3 Minimum Flaw Size

The crack depth, a , is 20% of the control thickness, t , subject to a minimum of 2 mm and a maximum of 20mm. The crack length, $2c$, is equal to six times the crack depth. This flaw size is shown in equation (1) and (2).

$$a = \min \left[\max \left(\frac{t}{5}, 2 \text{ mm} \right), 20 \text{ mm} \right] \quad (1)$$

$$c = 3a \quad (2)$$

The design curves were initially based on an assumed reference surface-breaking flaw size equivalent to that used in ASME VIII-1 and VIII-2⁽⁷⁾ as shown in equations (3) and (4)

$$a = \min \left[\frac{t}{4}, 25 \text{ mm} \right] \quad (3)$$

$$c = 3a \quad (4)$$

However, it was apparent that the resulting guidance would be significantly more conservative than the threshold in pre-2014 editions of ASME B31.3. Given the long term successful use and lack of failure evidence, it was not considered necessary to increase the level of conservatism and the smaller flaw size was selected as the basis for this publication. It is considered that this flaw size can be reliably detected using existing NDE techniques. It is not required or anticipated that additional NDE above code requirements are necessary to use this publication.

The flaw depth was limited to a minimum of 2mm to account for minimum detectable defect sizes using conventional NDE techniques. This approach is consistent with BS 7910, Annex T⁽⁸⁾. The maximum flaw depth was limited at the same material thickness cut-off of 4 inch (100mm).

3.1.4 Fracture Toughness

The fracture toughness used in the analysis was derived using the Master Curve approach (see WRC bulletin 562⁽⁹⁾). This correlation relies on knowing the 27J (20 ft-lb.) transition temperature for the parent materials and weld joint. For practical purposes, it need only be established that the material(s) and weld procedure are tested at this reference temperature or lower and achieve 27J (20 ft-lb.) minimum average. Alternatively, the transition temperature may be estimated using the ASME B31.3 material designations for non-impact-tested materials.

The Impact Test Exemption curves and the Impact tested curves were generated for a series of material yield stresses and thicknesses and are presented in APPENDIX B/C and APPENDIX D/E respectively.

3.1.5 Application

It was noted that the constraints on the minimum defect size resulted in the 0.25in (6.35mm) and 0.5in (12.7mm) curves being very close together. The 0.25in (6.35mm) curve was therefore removed from the guidance and all thicknesses below 0.5in (12.7mm) should be treated as equal to this thickness.

Examination of the design curves shows that for any material thickness and specified minimum yield stress, the curve can be defined as a depression (T_{DEP}) in the Charpy impact test reference temperature (T_{CV}) from the MDMT as shown in equation (5). These values are shown in Table 1 and Table 2.

$$MDMT = T_{cv} + T_{DEP} \quad (5)$$

For specification purposes it may be useful to define As-Welded/PWHT thickness thresholds against fixed Charpy test temperature depression values. Examples can be seen in Table 3 and Table 4.

It was noted that Charpy impact testing at the MDMT is conservative up to the following thicknesses for as-welded steels.

- 1.00in (25.4mm) for 30ksi (207MPa) SMYS
- 0.84in (21.4mm) for 35ksi (241MPa) SMYS
- 0.72in (18.3mm) for 40ksi (276MPa) SMYS
- 0.55in (14.0mm) for 50ksi (345MPa) SMYS
- 0.44in (11.2mm) for 60ksi (414MPa) SMYS

3.2 Charpy Impact Exemption Curves¹

For non-impact tested material and weld joints, modified versions of the ASME exemption curves were produced applying the assumptions outlined above and using the following assumed reference temperatures from WRC Bulletin 562⁽⁹⁾.

- $T_{CV} = 28.5^{\circ}\text{C}$ (81.7°F) for ASME Exemption Curve A
- $T_{CV} = 7.3^{\circ}\text{C}$ (43.7°F) for ASME Exemption Curve B
- $T_{CV} = -13.8^{\circ}\text{C}$ (5.7°F) for ASME Exemption Curve C
- $T_{CV} = -28.2^{\circ}\text{C}$ (-20.3°F) for ASME Exemption Curve D

These values of T_{CV} may be used as the assumed Charpy reference temperatures for non-impact steels when using the ASME B31.3 A-D exemption curve designations alongside the guidance in this publication.

3.3 PWHT Applications

Design curves were also generated for PWHT steels using the same assumptions and methodology, except using reduced residual stress of $0.3 \times (\text{SMYS} + 10\text{ksi})$. As expected, these curves demonstrate the significant benefit of post-weld heat treatment. It was noted that Charpy impact testing at the MDMT is conservative up to the following thresholds for PWHT steels.

- 3.0in (76.2mm) for 30ksi (207MPa) SMYS
- 2.5in (63.5mm) for 35ksi (241MPa) SMYS
- 2.25in (57.2mm) for 40ksi (276MPa) SMYS
- 1.5in (38.1mm) for 50ksi (345MPa) SMYS
- 1.25in (31.8mm) for 60ksi (414MPa) SMYS

¹ The reference temperatures are consistent with those shown in WRC Bulletin 562. The Fahrenheit and Celsius reference temperatures were obtained by separate SI and USC calculations. The slight difference reflects the rounding involved in these calculations. The Fahrenheit and Celsius values are not a direct temperature conversion.

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4 Application Methods

4.1 Method A – Determine the MDMT

Assuming that both parent materials and weld metal all achieve a minimum average 27J (20 ft-lb) at a Charpy impact test temperature T_{CV} , the MDMT is given by equation (5). T_{DEP} is obtained from Table 1 or Table 2.

Table 1: Charpy Temperature Depression vs. Control Thickness (US Customary Units)

T_{DEP} [°F]	Steel SMYS				
Thickness [in]	30ksi	35ksi	40ksi	50ksi	60ksi
≤ 0.5	-74	-53	-36	-9	12
0.55	-63	-43	-27	0	20
0.60	-54	-34	-18	8	28
0.65	-45	-26	-10	15	35
0.70	-37	-19	-3	22	41
0.75	-30	-12	4	28	47
0.80	-23	-5	10	34	53
0.85	-17	1	15	39	58
0.90	-11	6	21	44	63
0.95	-5	11	26	49	68
1.0	0	16	30	53	72
1.1	9	25	39	62	80
1.2	17	33	47	69	87
1.3	25	40	54	76	94
1.4	32	47	60	82	100
1.5	38	53	66	88	105
1.6	44	59	71	93	110
1.7	49	64	77	98	115
1.8	54	69	81	102	120
1.9	59	73	86	107	124
2.0	63	77	90	111	128
2.2	71	85	97	118	135
2.4	78	92	104	125	142
2.6	85	98	110	131	147
2.8	90	104	116	136	153
3.0	96	109	121	141	158
3.2	101	114	126	146	163
3.4	105	119	131	150	167
3.6	110	123	135	155	171
3.8	113	127	139	158	175
4.0	117	130	142	162	178

Table 2: Charpy Temperature Depression vs. Control Thickness (SI Units)

T_{DEP} [°C]	Steel SMYS				
Thickness [mm]	207MPa	241MPa	276MPa	345MPa	414MPa
<=12.7	-41	-30	-20	-5	7
13	-40	-28	-19	-4	8
14	-35	-24	-15	0	11
15	-31	-20	-11	3	15
16	-27	-16	-7	7	18
17	-23	-13	-4	10	21
18	-20	-10	-1	13	24
19	-17	-7	2	15	26
20	-14	-4	5	18	29
22	-8	1	10	23	33
24	-3	6	14	27	37
26	1	10	18	31	41
28	5	14	22	34	44
30	9	18	25	38	48
32	12	21	28	41	51
34	15	24	31	43	53
36	18	27	34	46	56
38	21	29	37	49	58
40	24	32	39	51	61
45	29	37	44	56	66
50	34	42	49	61	70
55	39	46	53	65	74
60	43	50	57	69	78
65	46	54	61	72	81
70	50	57	64	75	84
75	53	60	67	78	87
80	55	63	69	81	90
85	58	65	72	83	92
90	60	68	74	85	94
95	62	70	76	87	96
100	64	72	78	89	98

Intermediate values may be interpolated or the next highest SMYS and thickness in the table may be used.

Caution should be used when making use of negative values (shown in the light blue shading and italics) which may infringe other code or standard requirements. It should be noted that temperature depressions (shown in the grey shaded cells) exceeding 50°C (90°F) have limited useful application. This is an intrinsic material limitation; designers should be careful not to specify Charpy test temperatures below the practical limits for P1 steels (~ -50°C, -58°F).

Example 1

Given a 345MPa SMYS steel, 20mm thick, that is impact tested to achieve 27J (20 ft-lb) minimum average at -46°C.

Then the minimum as-welded MDMT = $-46^{\circ}\text{C} + 18^{\circ}\text{C} = -28^{\circ}\text{C}$

Example 2

Given a 241MPa SMYS steel, 32mm thick, and a MDMT of -20°C

Then the maximum Charpy impact test temperature for as-welded applications is $-20^{\circ}\text{C} - 21^{\circ}\text{C} = -41^{\circ}\text{C}$

4.2 Method B - Define maximum as-welded thickness against fixed Charpy test temperature depression values

For a given material SMYS, the maximum as-welded control thickness for a given Charpy impact temperature depression, based on 27J (20ft-lb) minimum average, is as shown in Table 3 and Table 4.

Table 3: Maximum As-Welded Control Thickness [in] vs Charpy Temperature Depression (US Customary Units)

	Material SMYS				
Charpy Temp Depression [°F]	30ksi	35ksi	40ksi	50ksi	60ksi
0	1.002	0.844	0.722	0.552	0.439
10	1.110	0.936	0.802	0.616	0.491
20	1.233	1.041	0.893	0.687	0.549
30	1.373	1.160	0.966	0.767	0.615
40	1.533	1.295	1.113	0.858	0.689
50	1.717	1.450	1.246	0.962	0.773
60	1.928	1.627	1.398	1.080	0.869
70	2.172	1.831	1.573	1.215	0.978
80	2.455	2.066	1.773	1.369	1.102
90	2.785	2.339	2.005	1.546	1.244

Table 4: Maximum As-Welded Thickness [mm] vs Charpy Temperature Depression (SI Units)

Charpy Temp Depression [°C]	Material SMYS				
	207MPa	241MPa	276MPa	345MPa	414MPa
0	25.5	21.4	18.3	14.0	11.2
5	27.9	23.5	20.2	15.5	12.3
10	30.7	25.9	22.2	17.1	13.6
15	33.8	28.5	24.5	18.8	15.1
20	37.3	31.5	27.0	20.8	16.7
25	41.2	34.8	29.9	23.1	18.5
30	45.7	38.6	33.1	25.6	20.6
35	50.7	42.8	36.8	28.4	22.9
40	56.5	47.6	40.9	31.6	25.4
45	63.1	53.1	45.6	35.2	28.3
50	70.7	59.4	50.9	39.3	31.6

Intermediate values may be interpolated or the next highest SMYS and lower thickness in the table may be used.

The first two lines for the 60ksi (414MPa) steel indicate thicknesses below the nominal threshold of 0.5in (12.7mm) in the Method A approach. This is permissible when using Method B.

Example 3

Given that the MDMT is -20°C for a 345MPa SMYS steel and the Charpy impact requirements are 27J (20ft-lb) minimum average at -50°C.

Then there is a 30°C temperature depression and the maximum as-welded thickness is 25.6mm

5 Additional Impact Energy Benefit

As this guidance is based on the Master Curve approach a small benefit, ie. reduction in T_{DEP} (and consequently MDMT) of 6°C (10.8°F), may be used if all materials and weld procedures are impact tested to achieve 40J (29.5ft-lb) minimum average.

APPENDIX A Direct Calculation of temperature depression

The required temperature depression [$^{\circ}\text{C}$] may be calculated using equation (6).

$$T_{\text{DEP}} = Ax^2 + Bx + C \quad (6)$$

Where:

x = steel thickness parameter

$x = (1/t)^{0.25}$ for t in inches

$x = (25.4/t)^{0.25}$ for t in mm

$0.5 \text{ (12.7 mm)} \leq t \leq 4 \text{ (101.6 mm)}$

The intermediate constants, A/B/C are given by equations (7),(8) and (9).

$$A = 3.865E-6s^3 - 4.446E-3s^2 + 1.793s - 202.8 \quad (7)$$

$$B = -5.428E-6s^3 + 6.165E-3s^2 - 2.426s + 42.81 \quad (8)$$

$$C = 2.450E-6s^3 - 2.897E-3s^2 + 1.292s + 66.1 \quad (9)$$

Where:

s = specified minimum yield stress (SMYS) in MPa.

The values used/calculated in the above formulae may be converted to US customary units using

$$s \text{ [MPa]} = s \text{ [ksi]} / 0.145$$

$$T_{\text{DEP}} \text{ [}^{\circ}\text{F]} = T_{\text{DEP}} \text{ [}^{\circ}\text{C]} * 9 / 5$$

Note that T_{DEP} is a relative value so no constant 32° is required in the temperature conversion

APPENDIX B Impact test exemption curves: SI Units

The notes in Fig 323.2.2a also include conditions underlying the material supply of the different curve designations. These notes should be used when assigning material to a given curve designation.

Notes

1. The graphs in this Appendix have been produced within a temperature range of -200°C to 150°C. There are no specific minimum temperature limits for impact tested material in ASME B31.3.
2. Attention is drawn to the cautionary note in section 4.1.
3. Attention is drawn to note (5) in Figure 323.2.2A and note (4) of Table 323.2 B31.3. The temperatures quoted are based on experience of piping systems auto refrigerating propylene (-48°C; -55°F) and auto refrigerating ethylene (-104°C; -155°F). The use of this publication at temperatures below (-104°C; -155°F) is not recommended and shall be subject to the agreement of the owner.
4. The graphs in this Appendix have been produced with a minimum thickness of 6.4 mm. Table 1 and Table 2 use a minimum thickness of 12.7 mm. See also section 3.1.5.

B.1 SMYS=30ksi (207MPa)

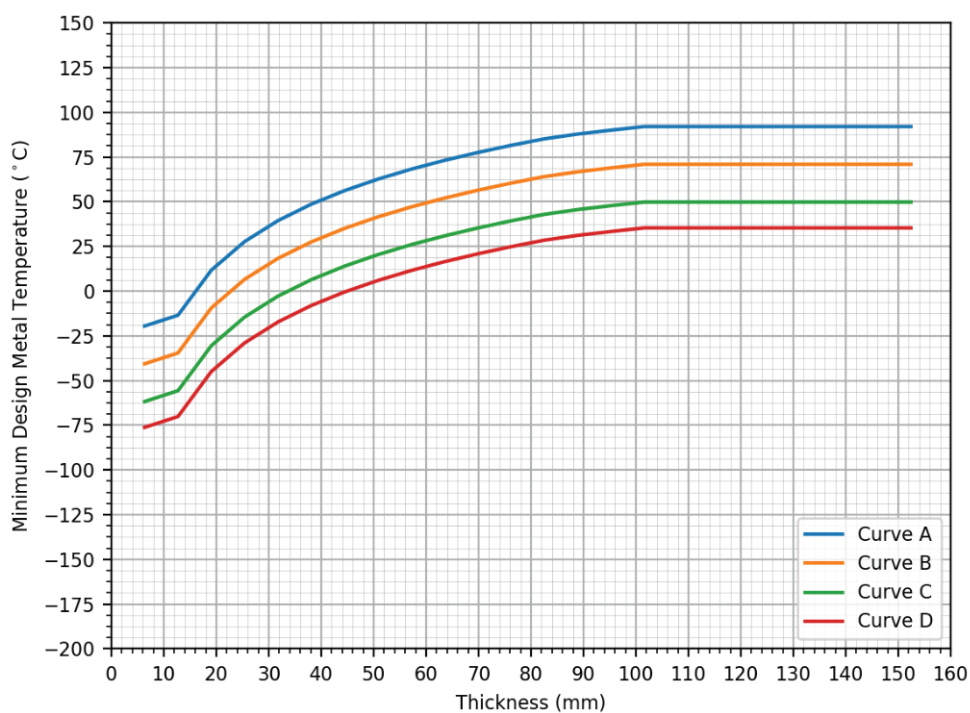


Figure B-1: Impact test exemption – 207MPa (30ksi) yield – as welded.

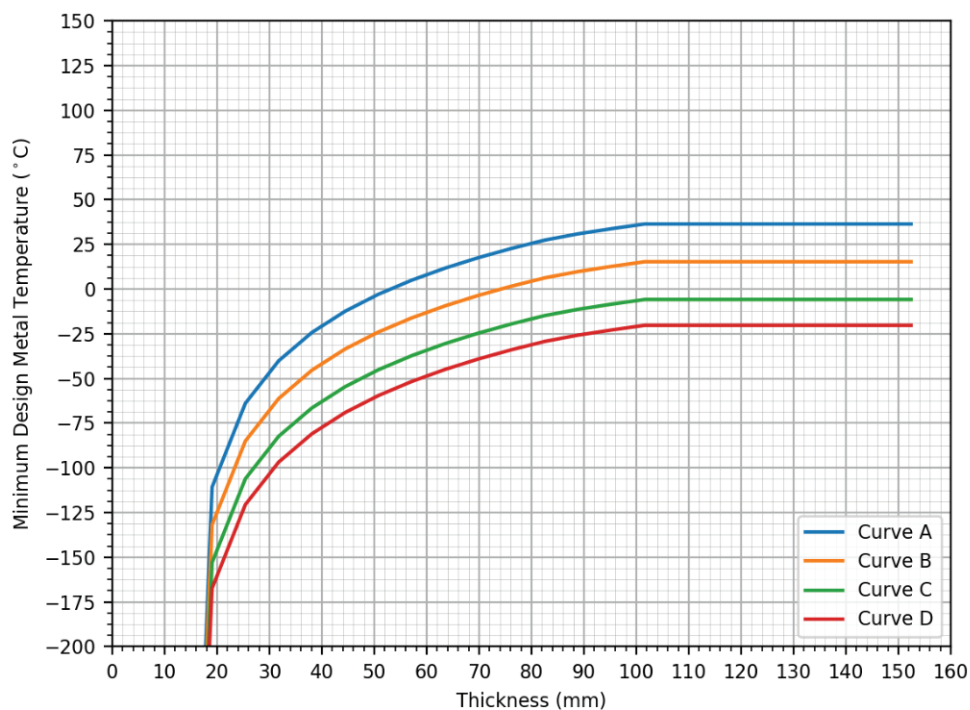


Figure B-2: Impact test exemption – 207MPa (30ksi) yield – PWHT.

B.2 SMYS=35ksi (241MPa)

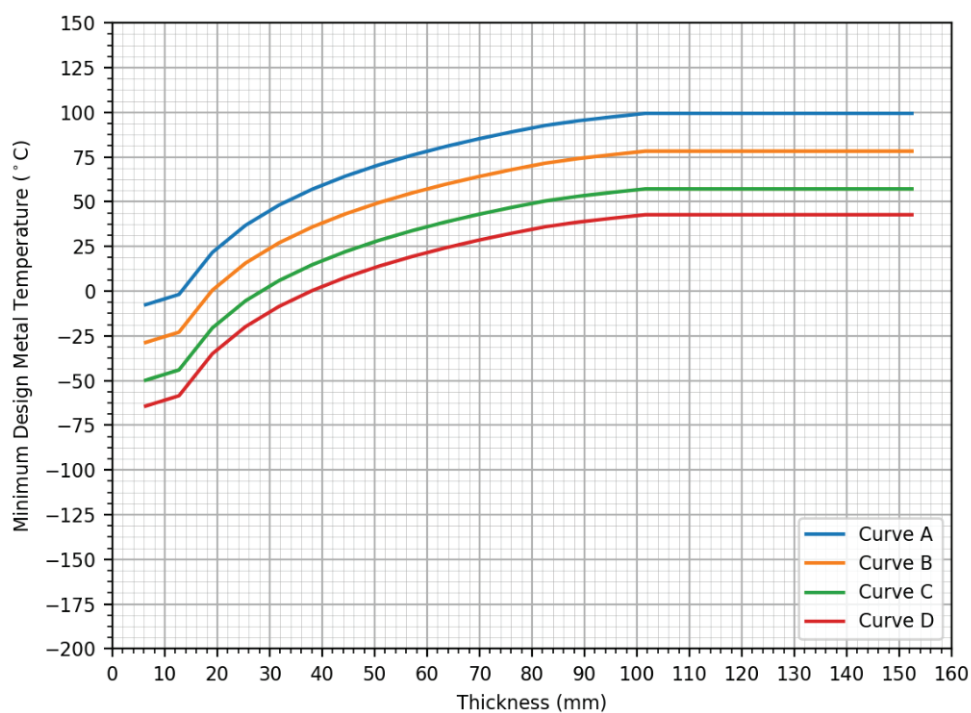


Figure B-3: Impact test exemption – 241MPa (35ksi) yield – as welded.

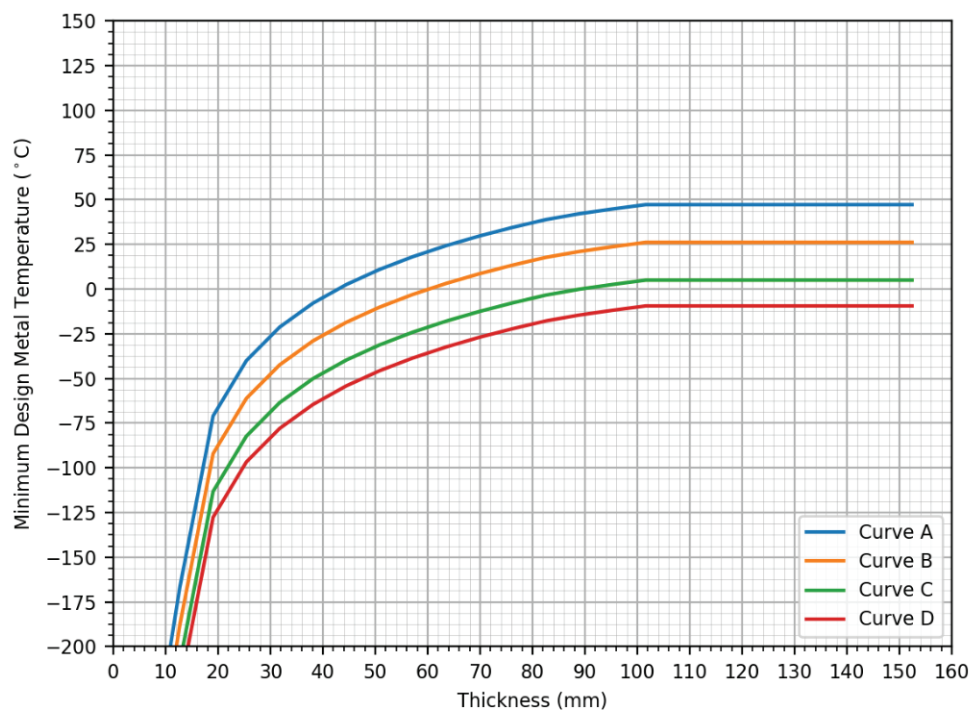


Figure B-4: Impact test exemption – 241MPa (35ksi) yield – PWHT.

B.3 SMYS=40ksi (276MPa)

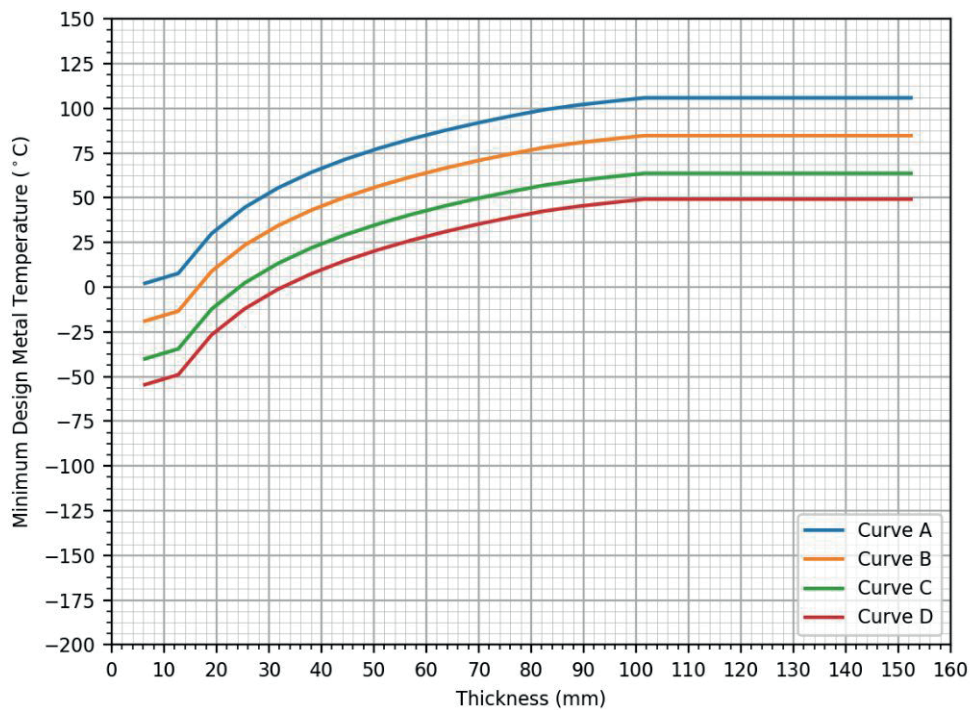


Figure B-5: Impact test exemption – 276MPa (40ksi) yield – as-welded.

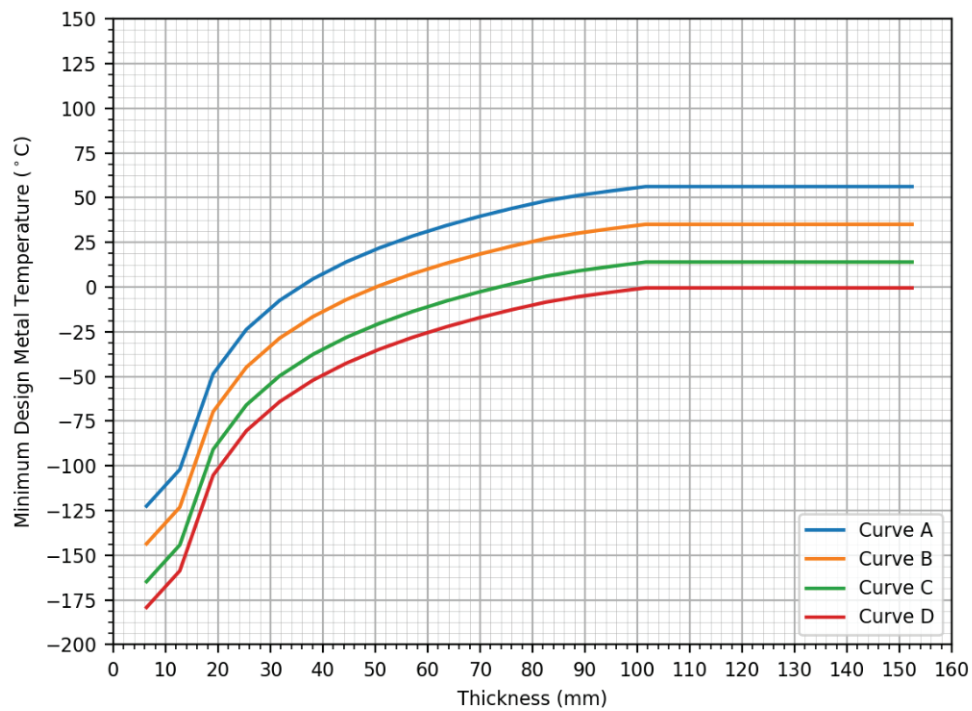


Figure B-6: Impact test exemption – 276MPa (40ksi) yield – PWHT.

B.4 SMYS=50ksi (345MPa)

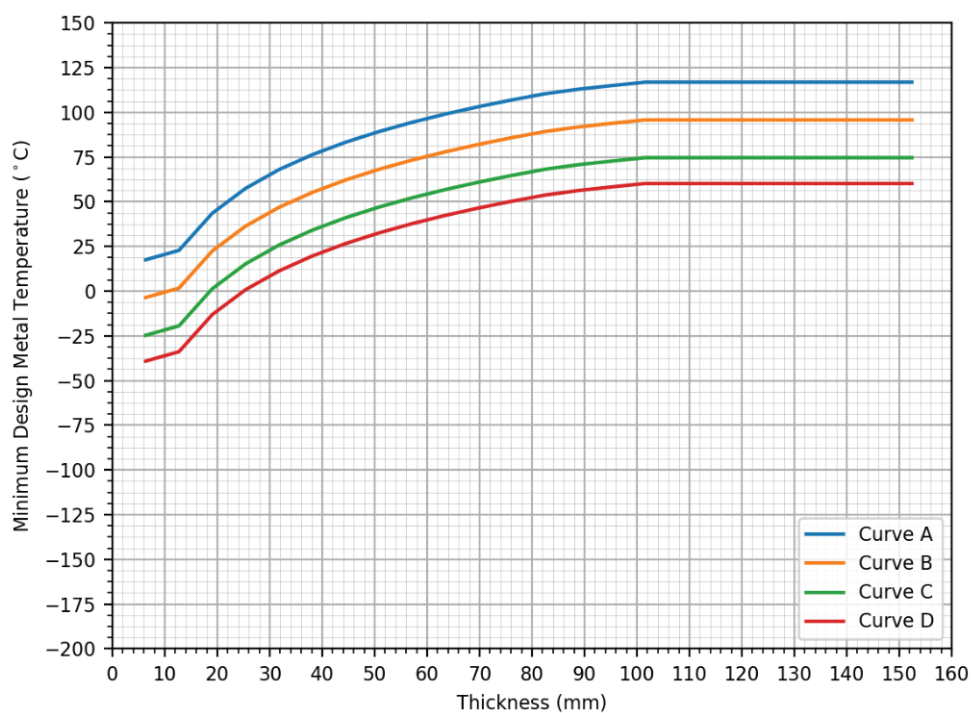


Figure B-7: Impact test exemption – 345MPa (50ksi) yield – as welded.

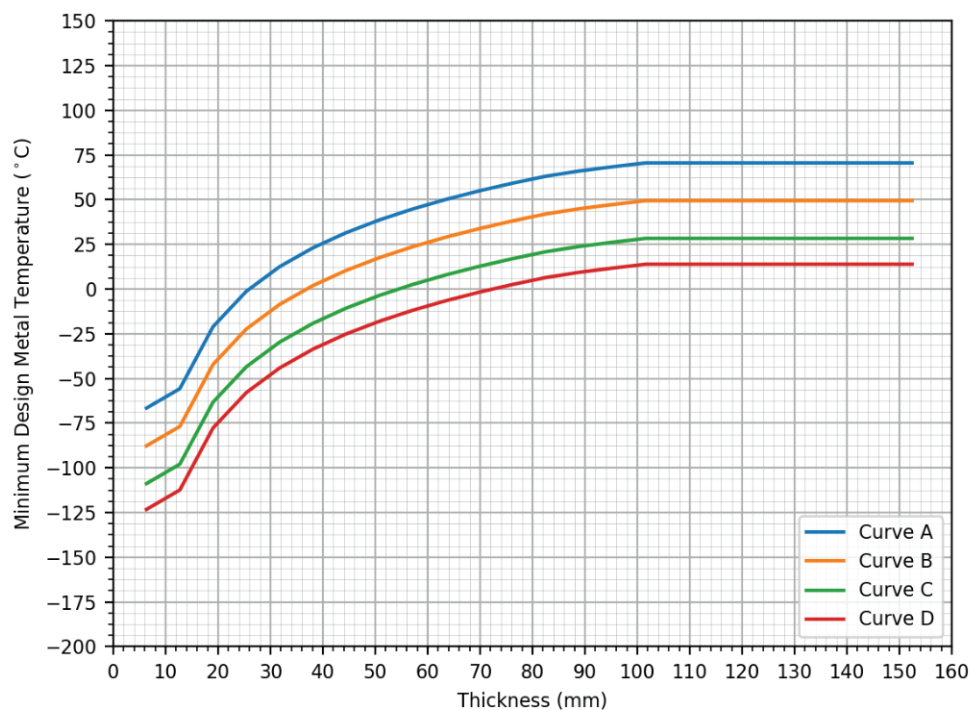
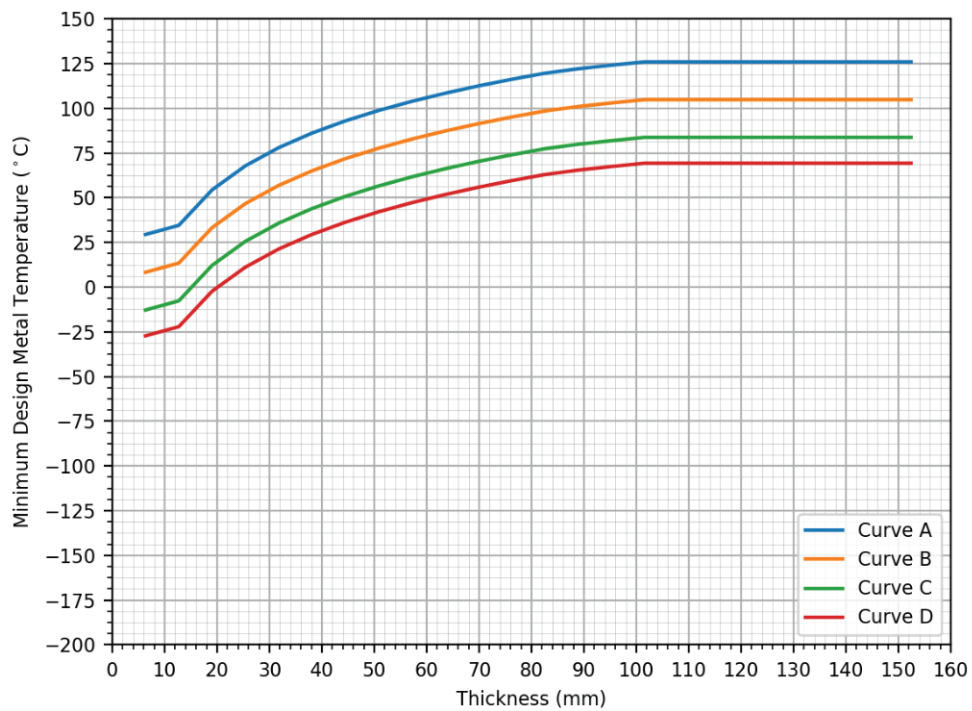
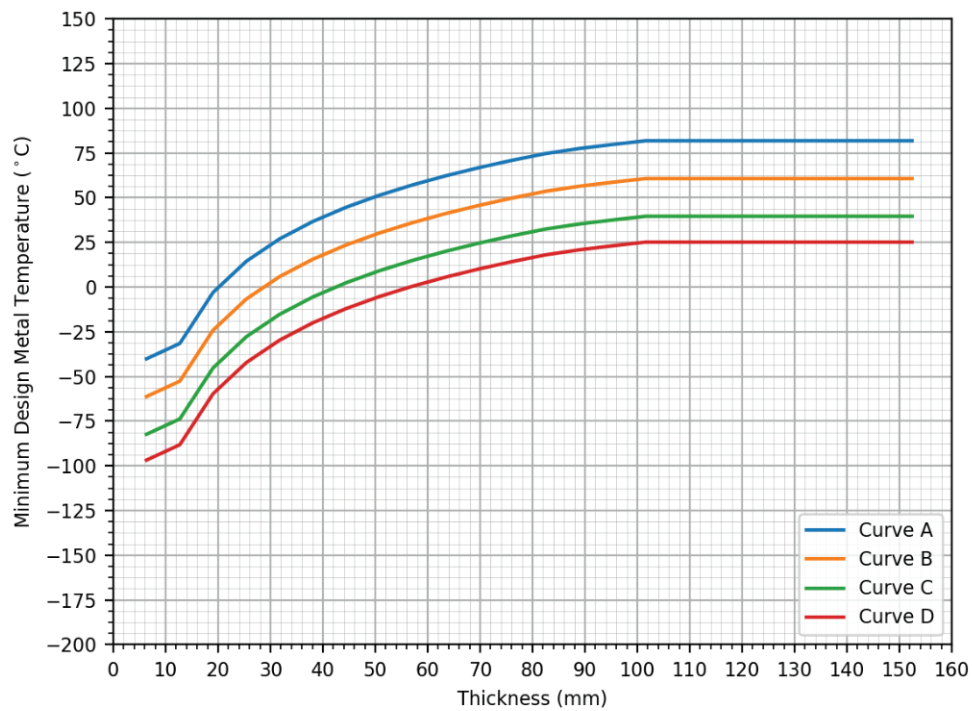


Figure B-8: Impact test exemption – 345MPa (50ksi) yield – PWHT.

B.5 SMYS=60ksi (414MPa)**Figure B-9: Impact test exemption – 414MPa (60ksi) yield – as welded.****Figure B-10: Impact test exemption – 414MPa (60ksi) yield – PWHT.**

APPENDIX C Impact test exemption curves: US Customary Units

The notes in Fig 323.2.2a also include conditions underlying the material supply of the different curve designations. These notes should be used when assigning material to a given curve designation.

Notes

1. The graphs in this Appendix have been produced within a temperature range of -300°F to 300°F. There are no specific minimum temperature limits for impact tested material in ASME B31.3.
2. Attention is drawn to the cautionary note in section 4.1.
3. Attention is drawn to note (5) in Figure 323.2.2A and note (4) of Table 323.2 B31.3. The temperatures quoted are based on experience of piping systems auto refrigerating propylene (-48°C; -55°F) and auto refrigerating ethylene (-104°C; -155°F). The use of this publication at temperatures below (-104°C; -155°F) is not recommended and shall be subject to the agreement of the owner.
4. The graphs in this Appendix have been produced with a minimum thickness of ¼". Table 1 and Table 2 use a minimum thickness of ½". See also section 3.1.5.

C.1 SMYS=30ksi (207MPa)

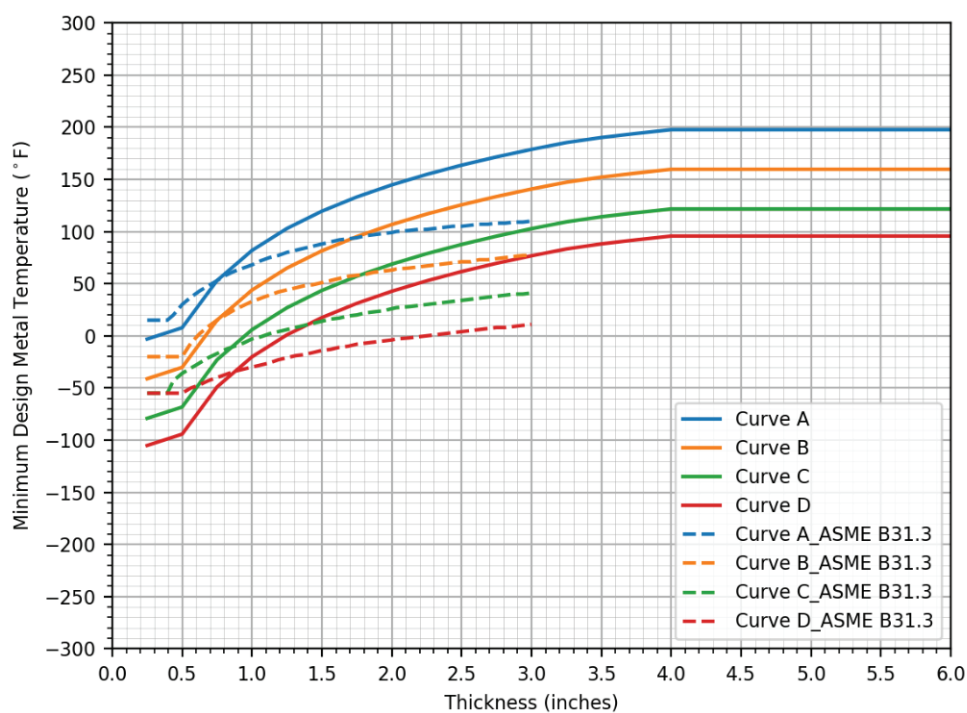


Figure C-1: Impact test exemption – 30ksi (207MPa) yield – as welded.

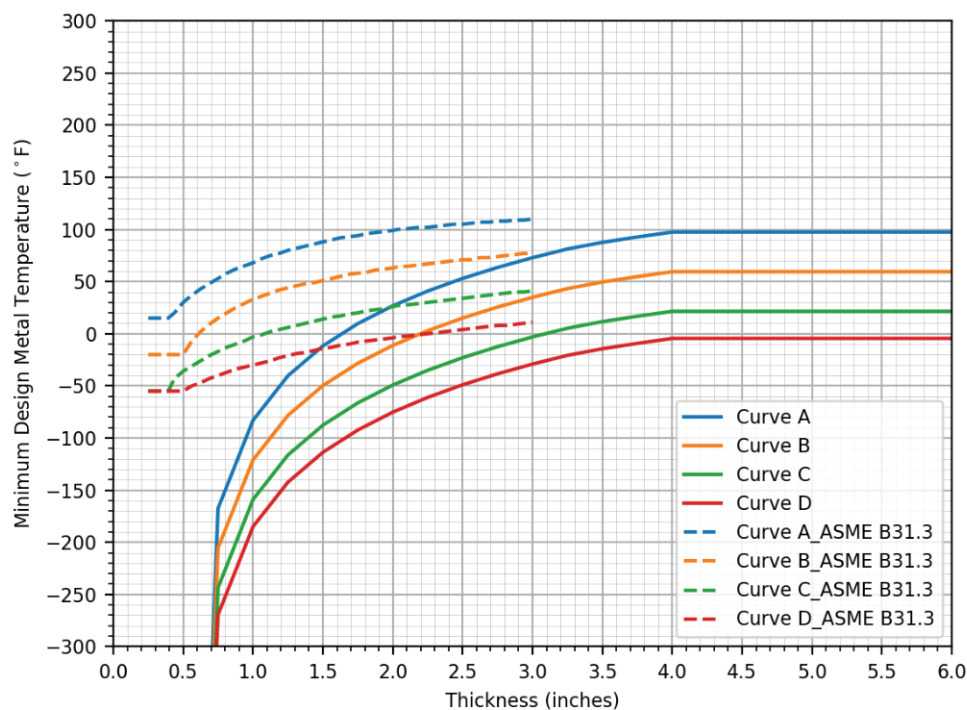


Figure C-2: Impact test exemption – 30ksi (207MPa) yield – PWHT.

C.2 SMYS=35ksi (241MPa)

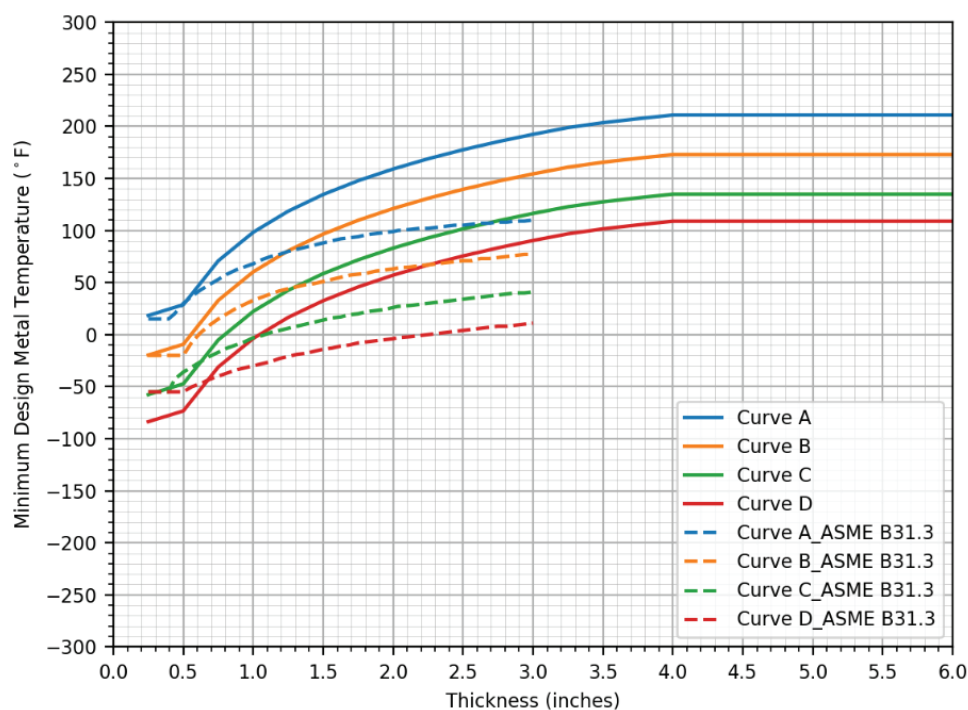


Figure C-3: Impact test exemption – 35ksi (241MPa) yield – as welded.

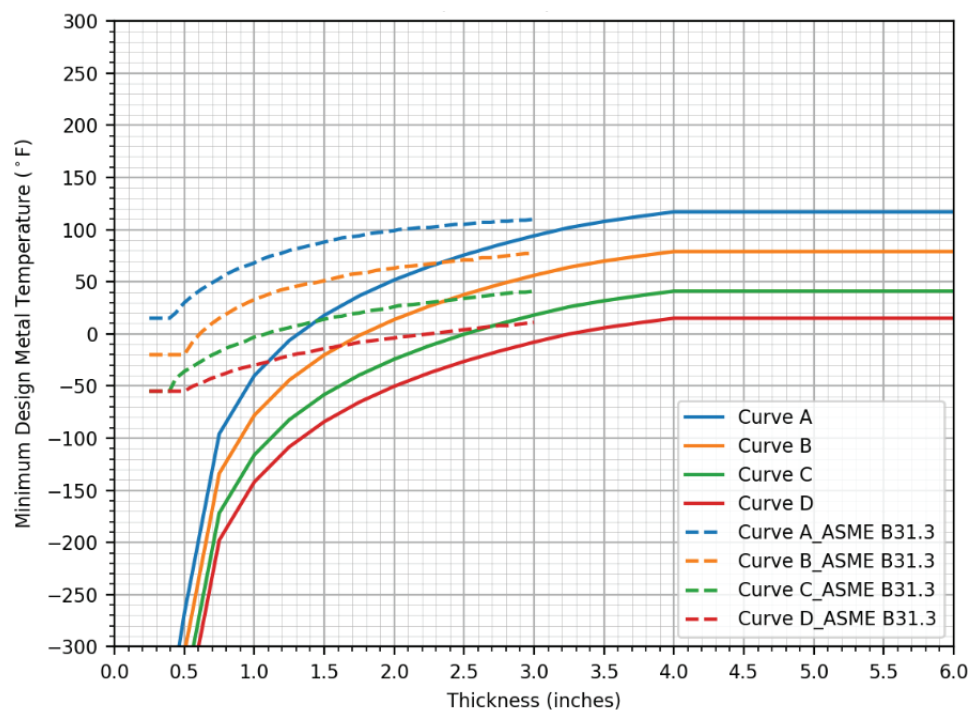


Figure C-4: Impact test exemption – 35ksi (241MPa) yield – PWHT.

C.3 SMYS=40ksi (276MPa)

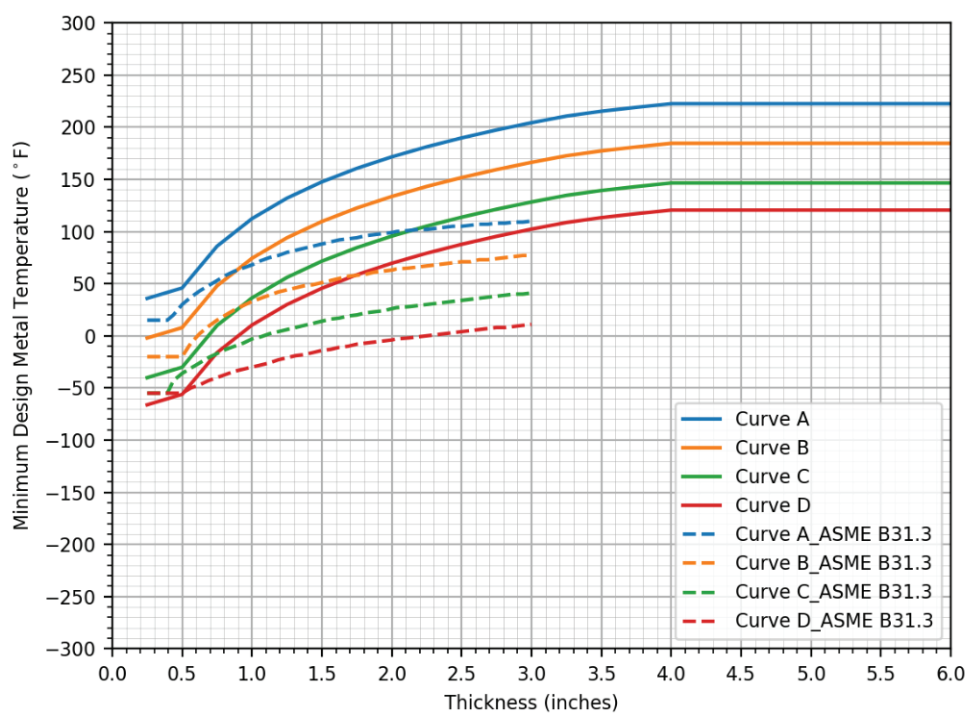


Figure C-5: Impact test exemption – 40ksi (276MPa) yield – as-welded.

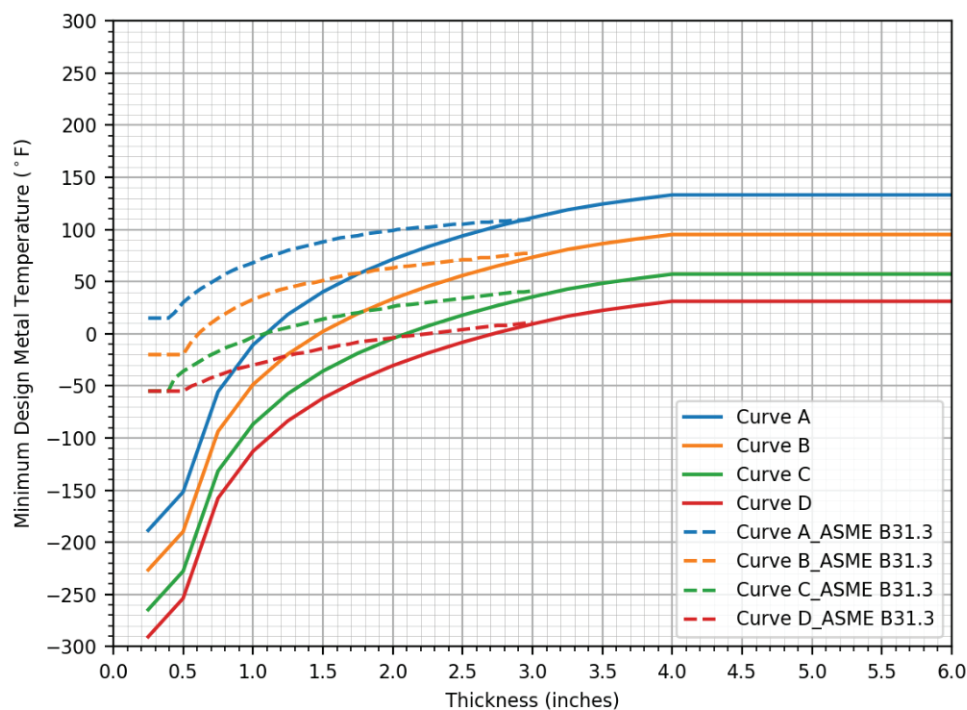


Figure C-6: Impact test exemption – 40ksi (276MPa) yield – PWHT.

C.4 SMYS=50ksi (345MPa)

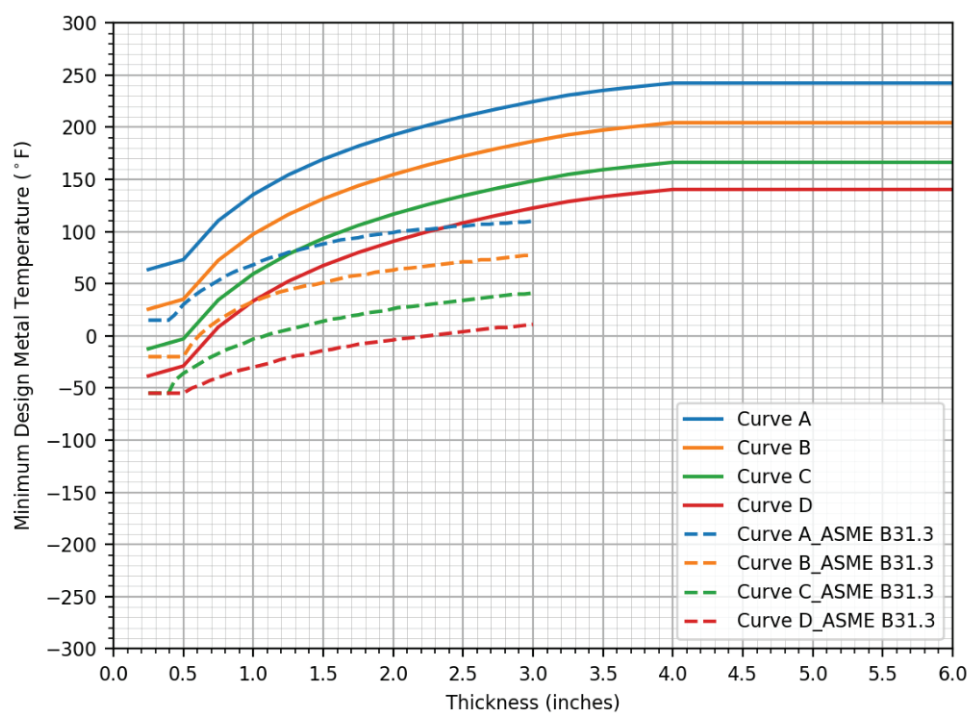


Figure C-7: Impact test exemption – 50ksi (345MPa) yield – as welded.

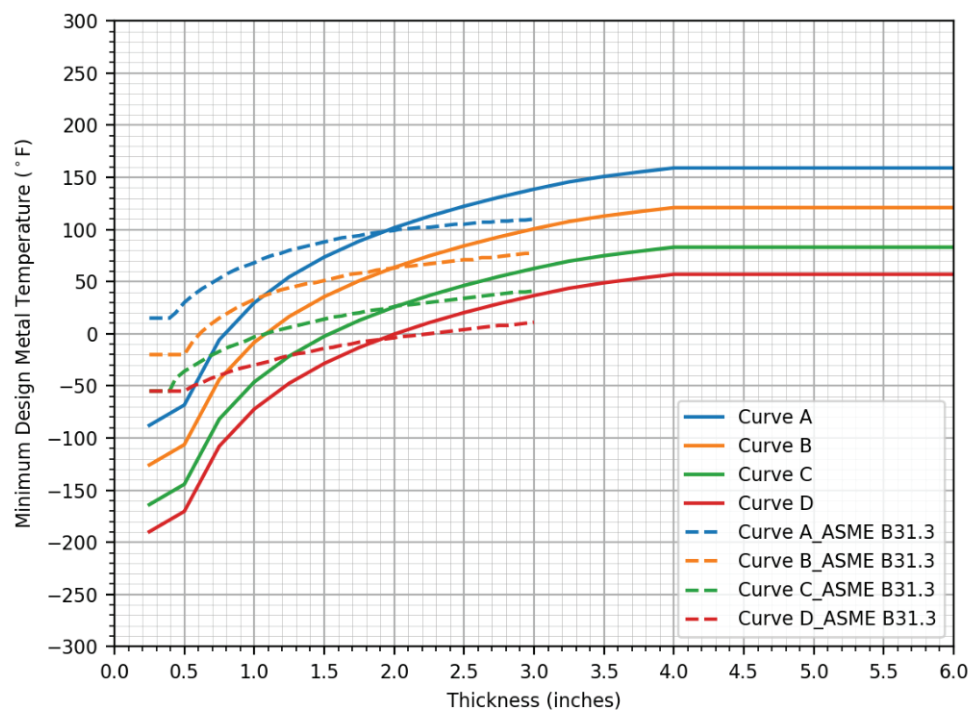


Figure C-8: Impact test exemption – 50ksi (345MPa) yield – PWHT.

C.5 SMYS=60ksi (414MPa)

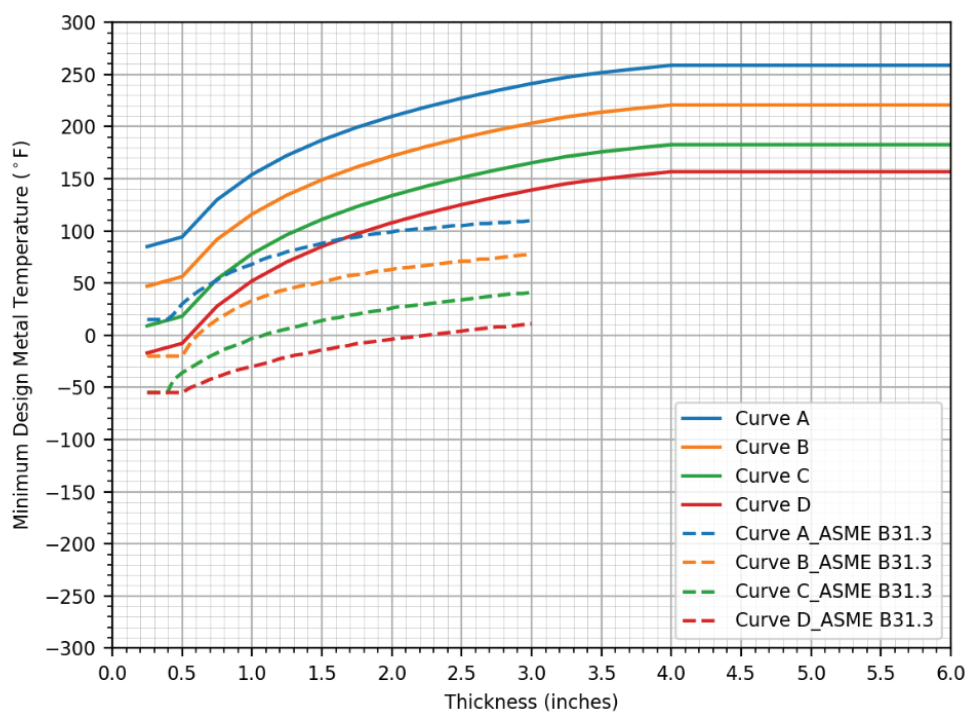


Figure C-9: Impact test exemption – 60ksi (414MPa) yield – as welded.

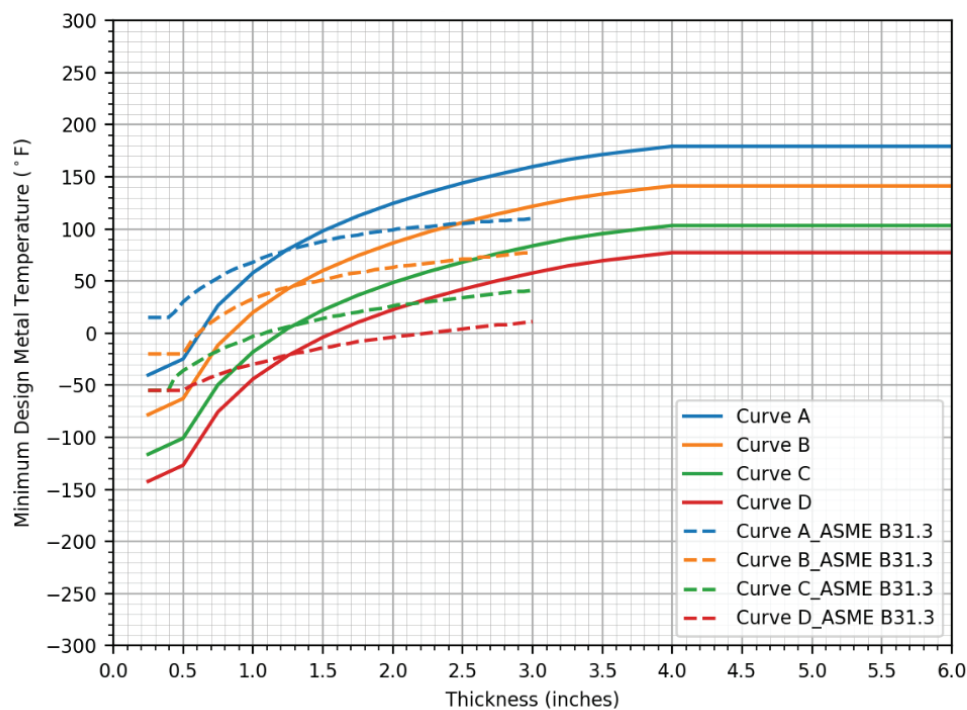


Figure C-10: Impact test exemption – 60ksi (414MPa) yield – PWHT.

APPENDIX D Impact tested curves: SI Units

Notes

1. The graphs in this Appendix have been produced within a temperature range of -200°C to 150°C. There are no specific minimum temperature limits for impact tested material in ASME B31.3.
2. Attention is drawn to the cautionary note in section 4.1.
3. Attention is drawn to note (5) in Figure 323.2.2A and note (4) of Table 323.2 B31.3. The temperatures quoted are based on experience of piping systems auto refrigerating propylene (-48°C; -55°F) and auto refrigerating ethylene (-104°C; -155°F). The use of this publication at temperatures below (-104°C; -155°F) is not recommended and shall be subject to the agreement of the owner.
4. The graphs in this Appendix have been produced with a minimum thickness of 6.4 mm. Table 1 and Table 2 use a minimum thickness of 12.7 mm. See also section 3.1.5.

D.1 SMYS=30ksi (207MPa)

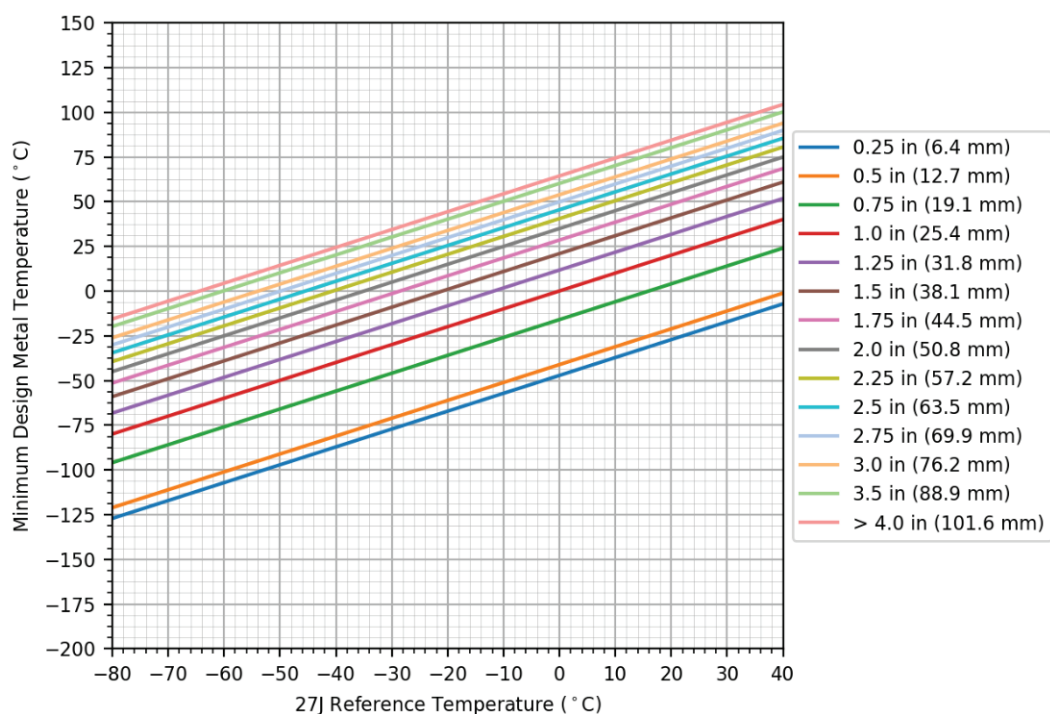


Figure D-1: Impact tested curve – 207MPa (30ksi) yield – as welded.

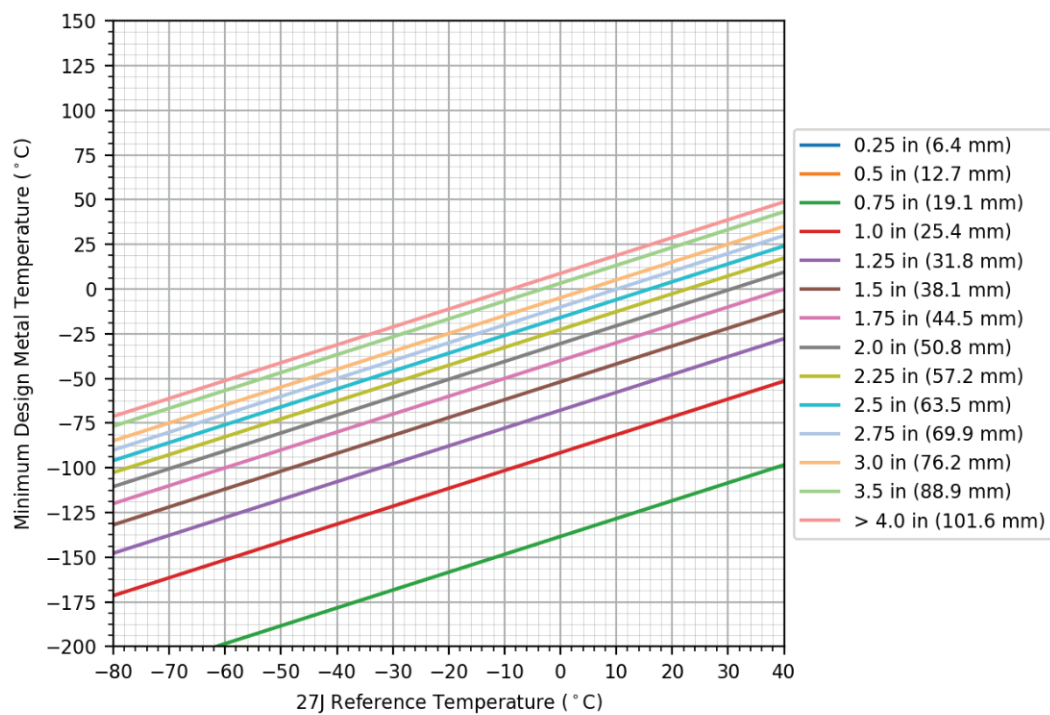


Figure D-2: Impact tested curve – 207MPa (30ksi) yield – PWHT.

D.2 SMYS=35ksi (241MPa)

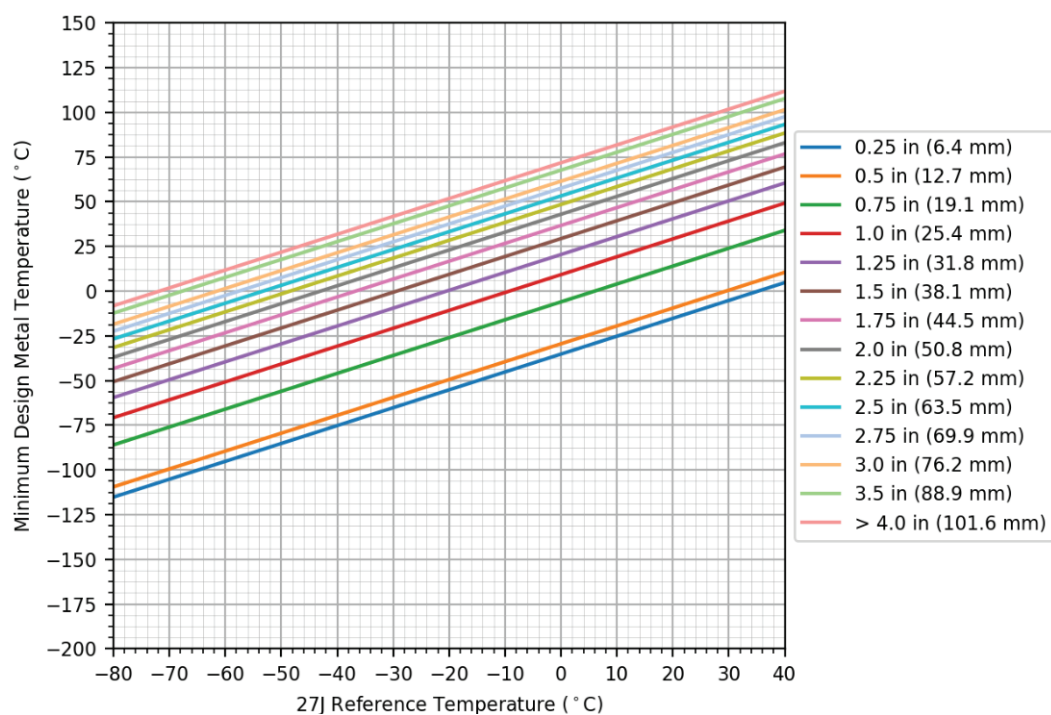


Figure D-3: Impact tested curve – 241MPa (35ksi) yield – as welded.

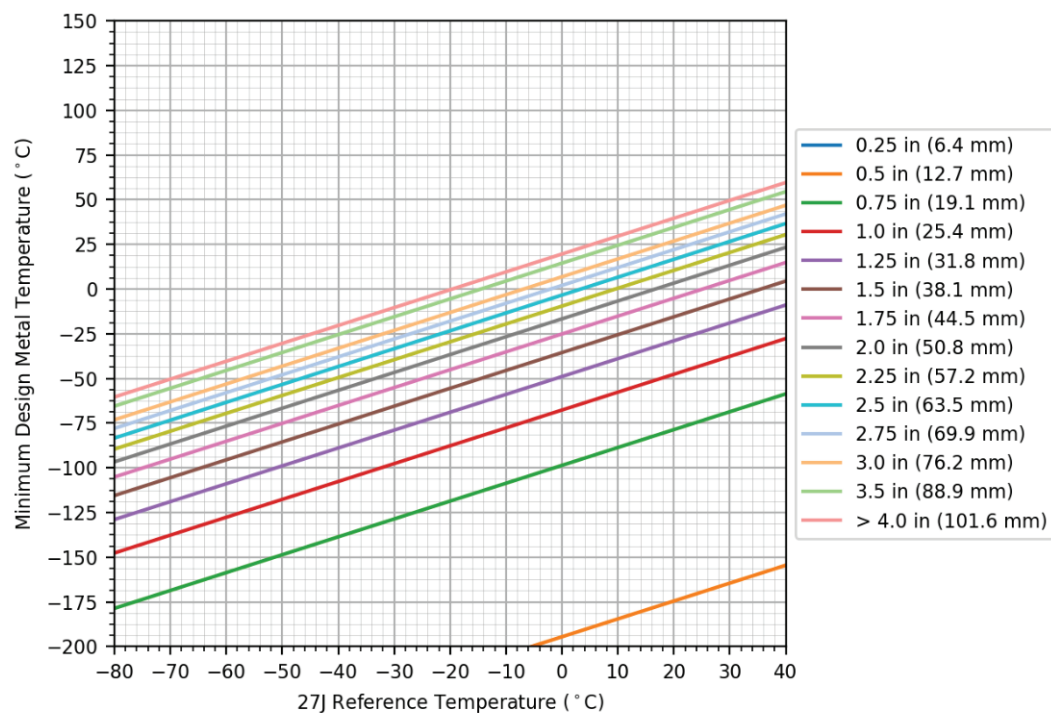


Figure D-4: Impact tested curve – 241MPa (35ksi) yield – PWHT.

D.3 SMYS=40ksi (276MPa)

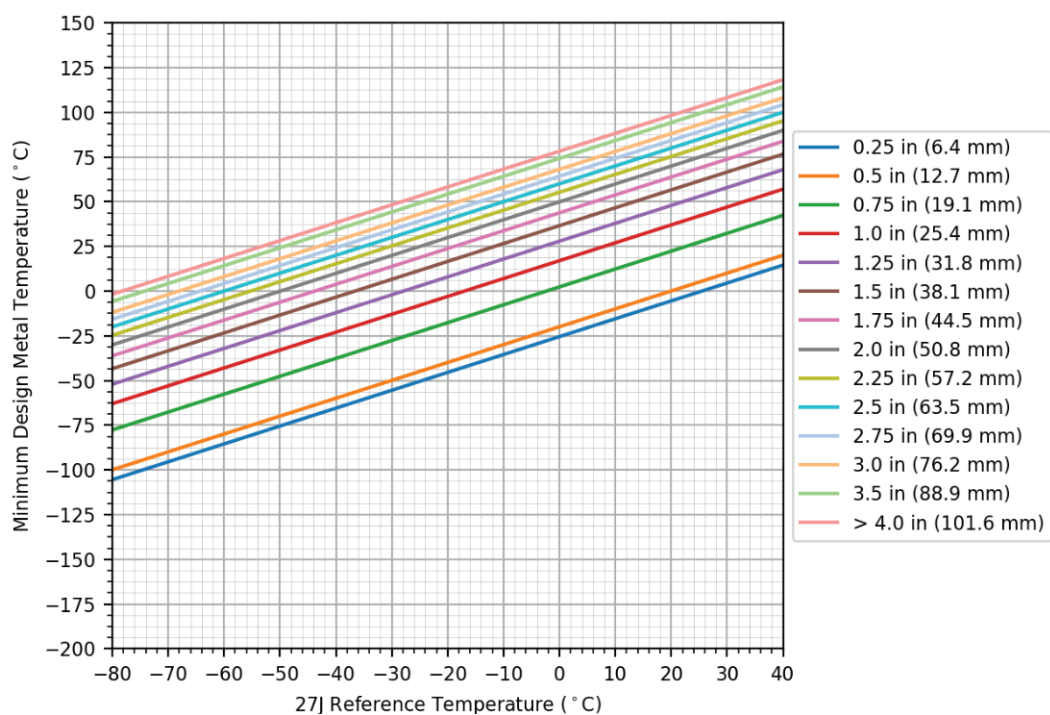


Figure D-5: Impact tested curve – 276MPa (40ksi) yield – as welded.

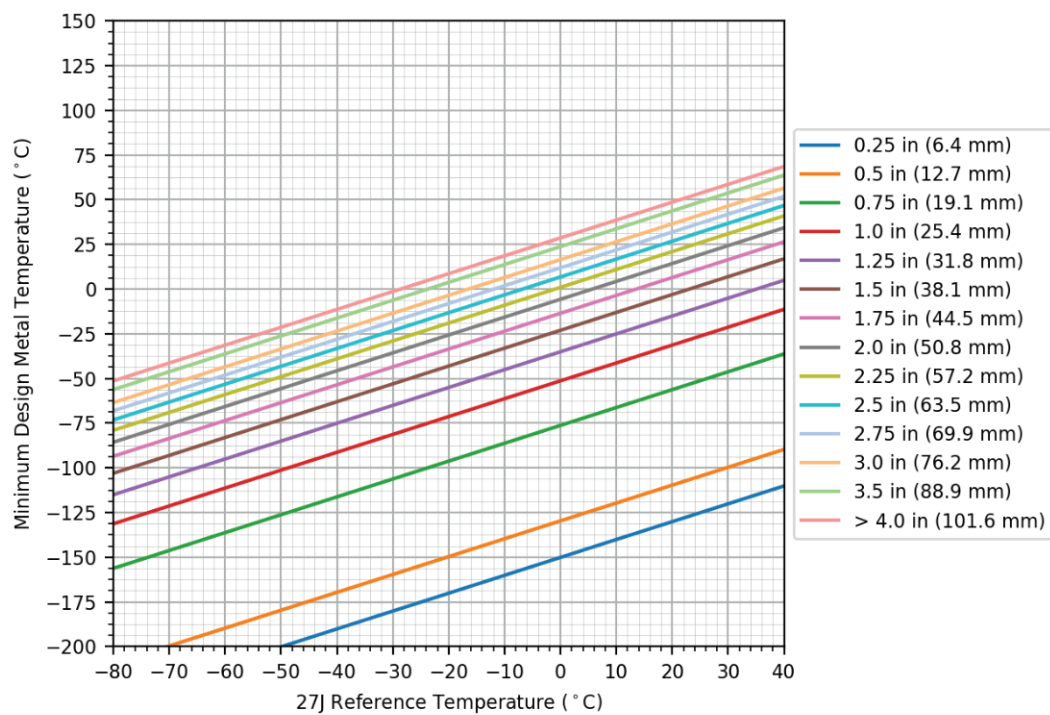


Figure D-6: Impact tested curve – 276MPa (40ksi) yield – PWHT.

D.4 SMYS=50ksi (345MPa)

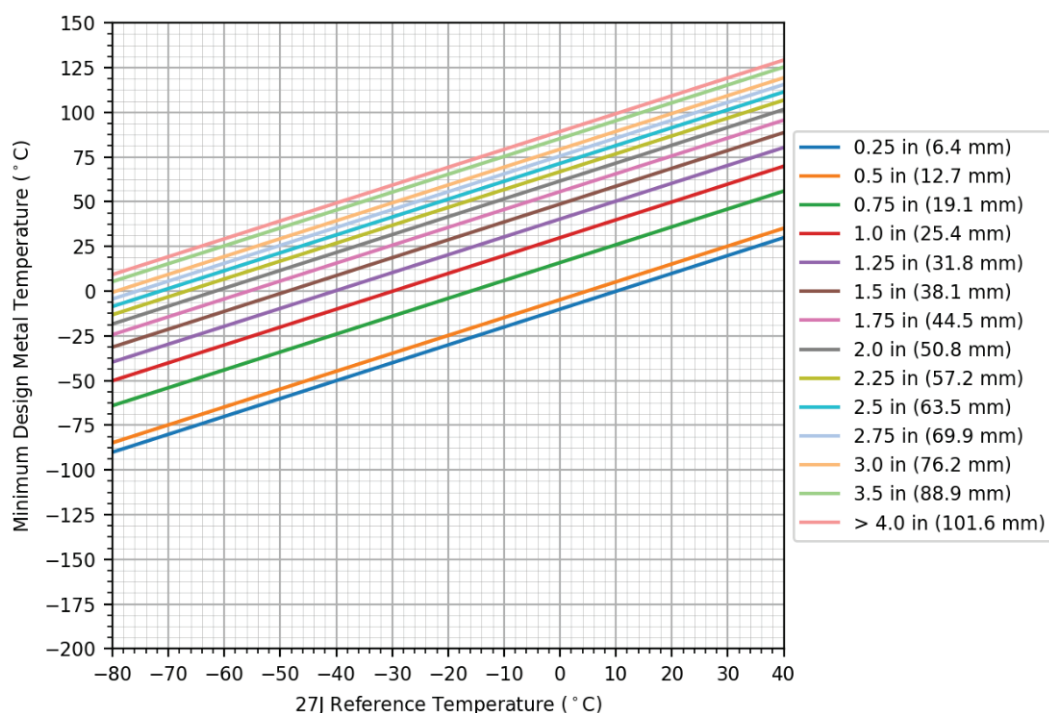


Figure D-7: Impact tested curve – 345MPa (50ksi) yield – as welded.

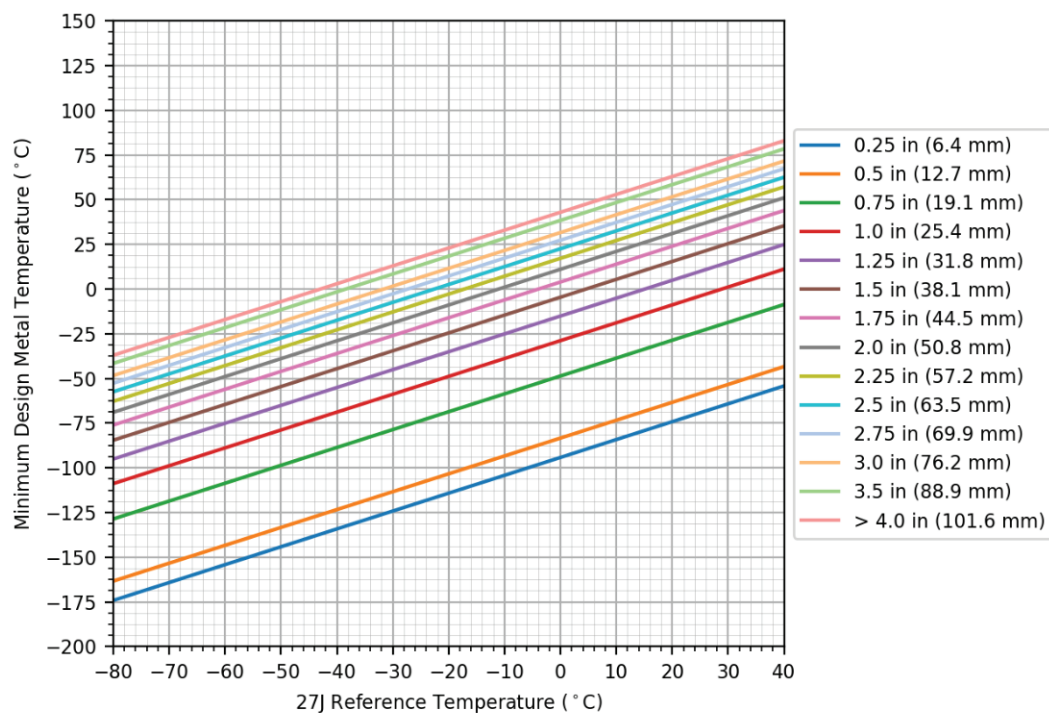


Figure D-8: Impact tested curve – 345MPa (50ksi) yield – PWHT.

D.5 SMYS=60ksi (414MPa)

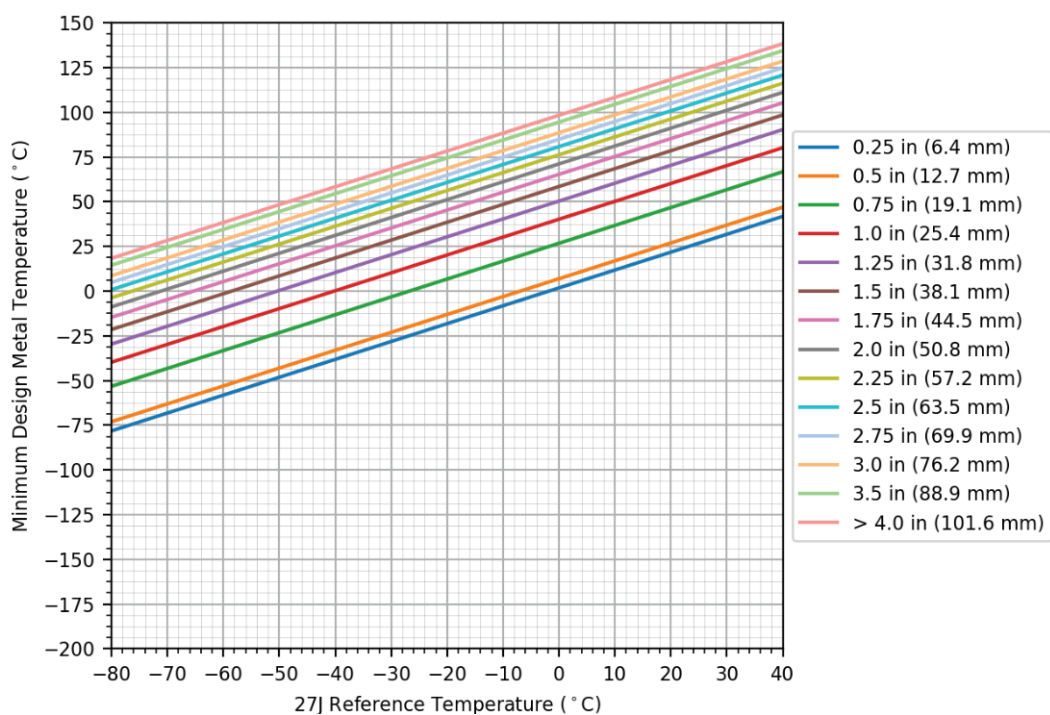


Figure D-9: Impact tested curve – 414MPa (60ksi) yield – as welded.

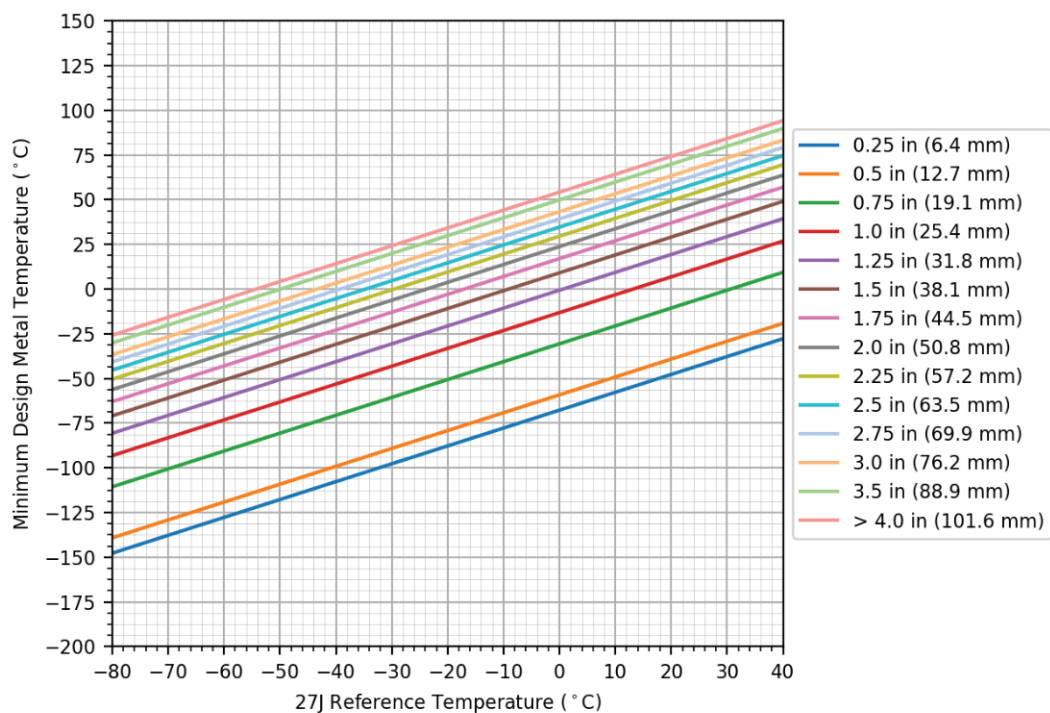


Figure D-10: Impact tested curve – 414MPa (60ksi) yield – PWHT.

APPENDIX E Impact tested curves: US Customary Units

Notes

1. The graphs in this Appendix have been produced within a temperature range of -300°F to 300°F. There are no specific minimum temperature limits for impact tested material in ASME B31.3.
2. Attention is drawn to the cautionary note in section 4.1.
3. Attention is drawn to note (5) in Figure 323.2.2A and note (4) of Table 323.2 B31.3. The temperatures quoted are based on experience of piping systems auto refrigerating propylene (-48°C; -55°F) and auto refrigerating ethylene (-104°C; -155°F). The use of this publication at temperatures below (-104°C; -155°F) is not recommended and shall be subject to the agreement of the owner.
4. The graphs in this Appendix have been produced with a minimum thickness of ¼". Table 1 and Table 2 use a minimum thickness of ½". See also section 3.1.5.

E.1 SMYS=30ksi (207MPa)

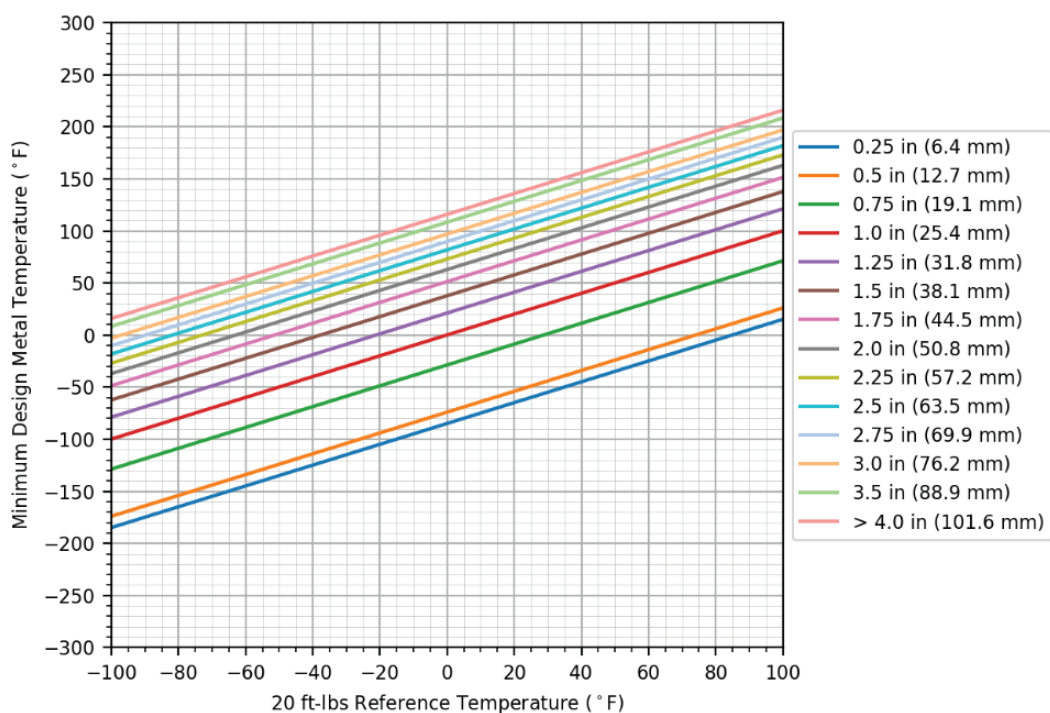


Figure E-1: Impact tested curve – 30ksi (207MPa) yield – as welded.

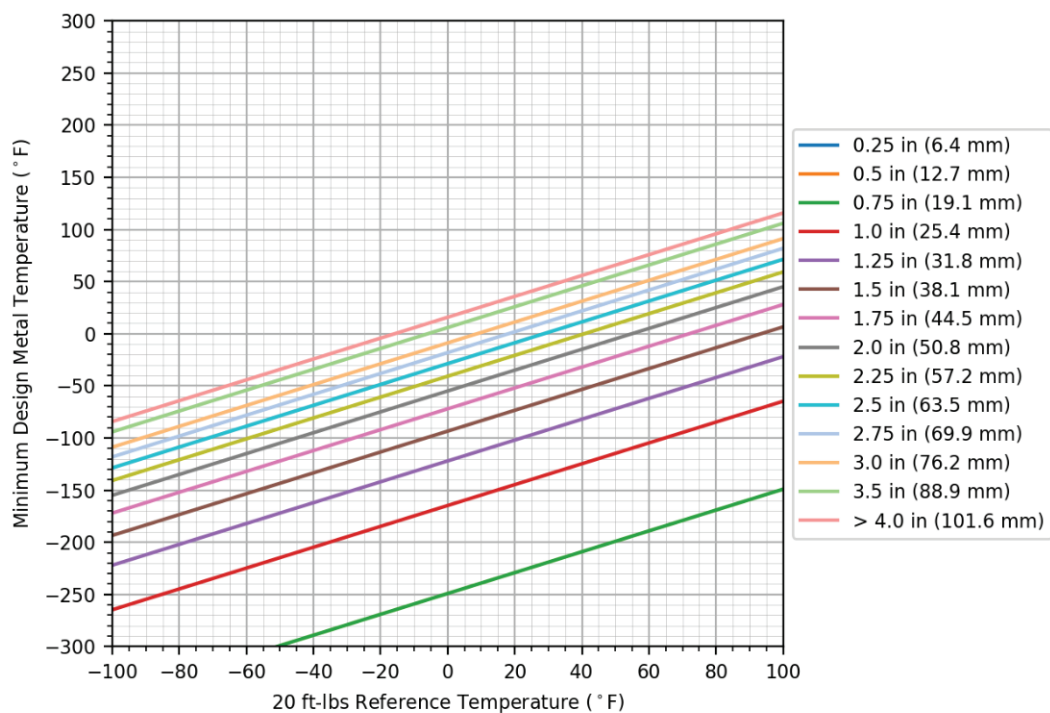


Figure E-2: Impact tested curve – 30ksi (207MPa) yield – PWHT.

E.2 SMYS=35ksi (241MPa)

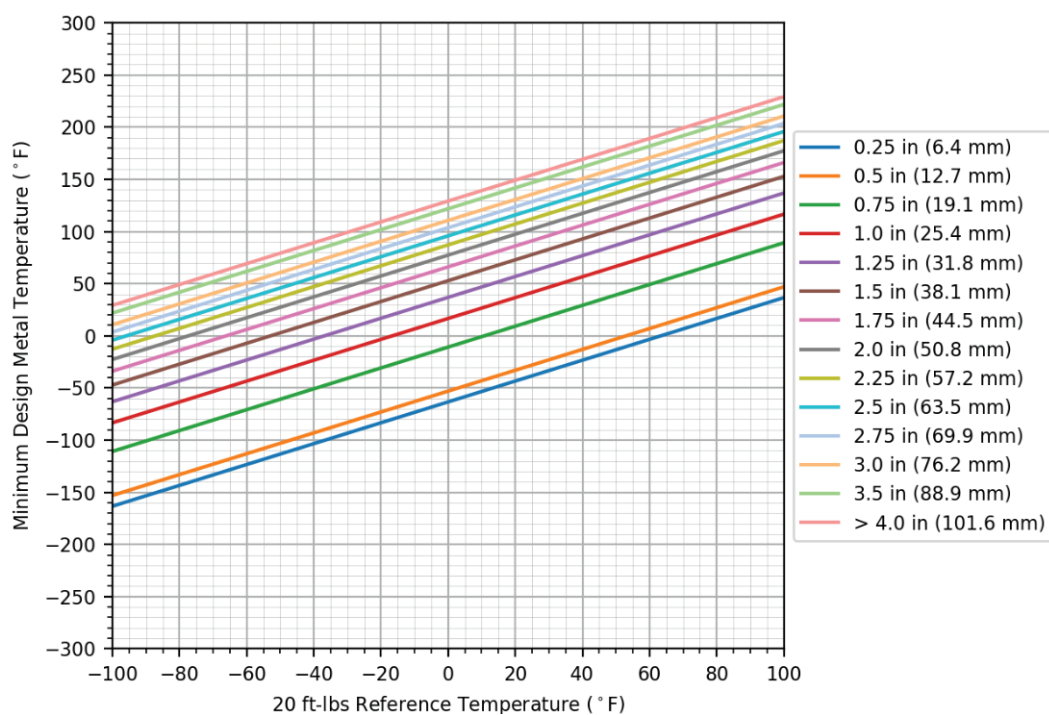


Figure E-3: Impact tested curve – 35ksi (241MPa) yield – as welded.

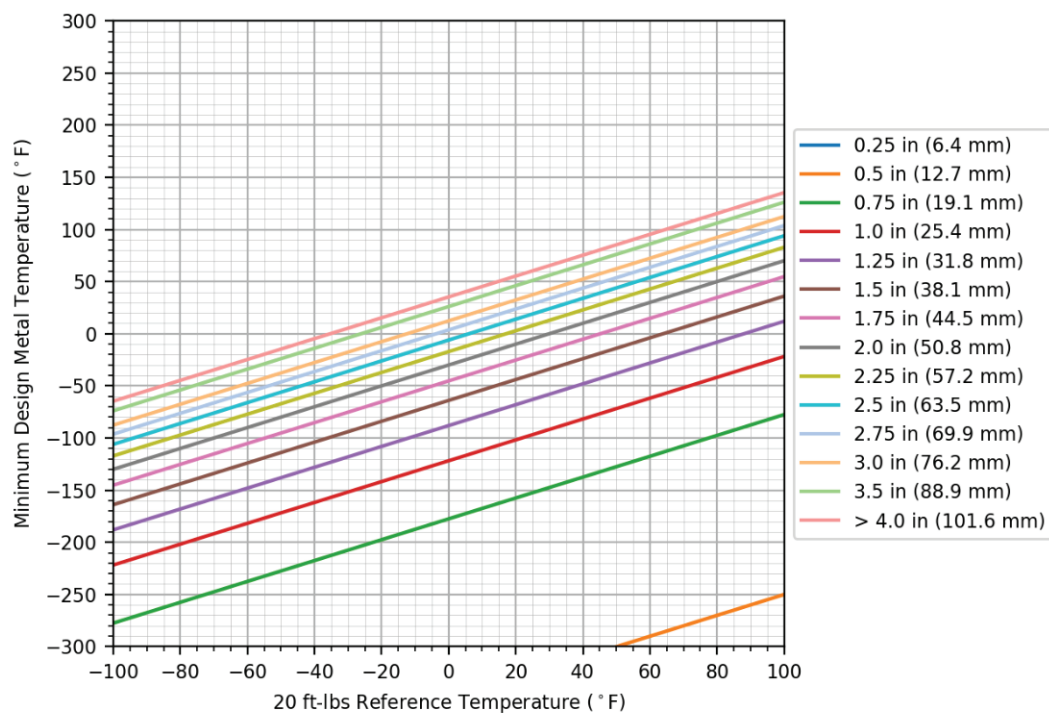


Figure E-4: Impact tested curve – 35ksi (241MPa) yield – PWHT.

E.3 SMYS=40ksi (276MPa)

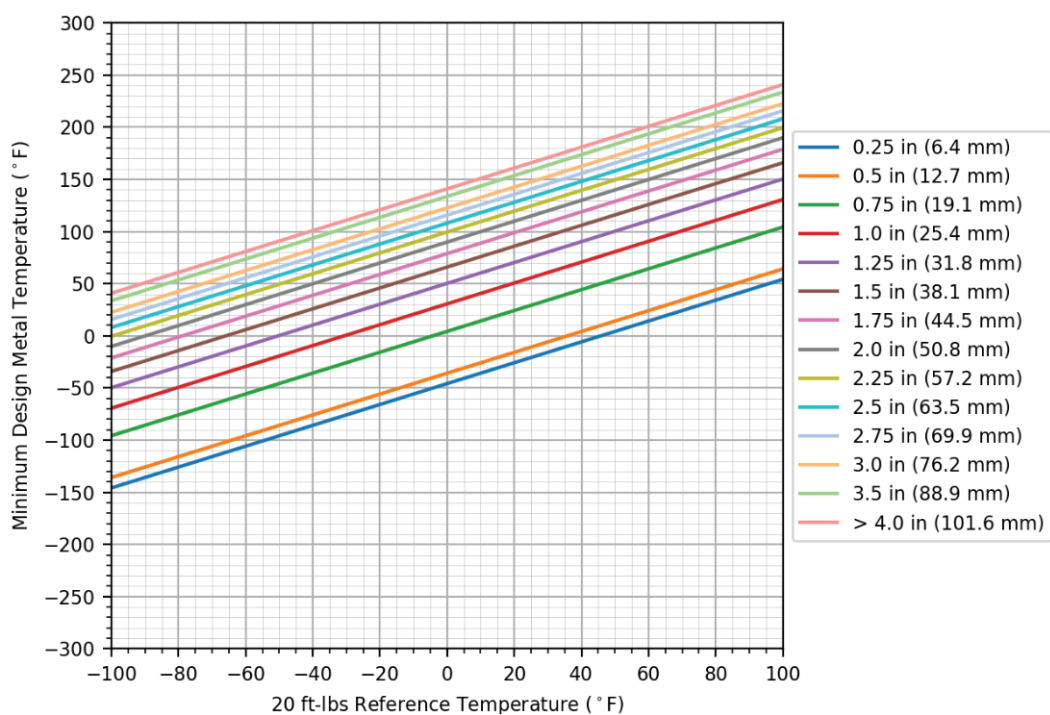


Figure E-5: Impact tested curve – 40ksi (276MPa) yield – as welded.

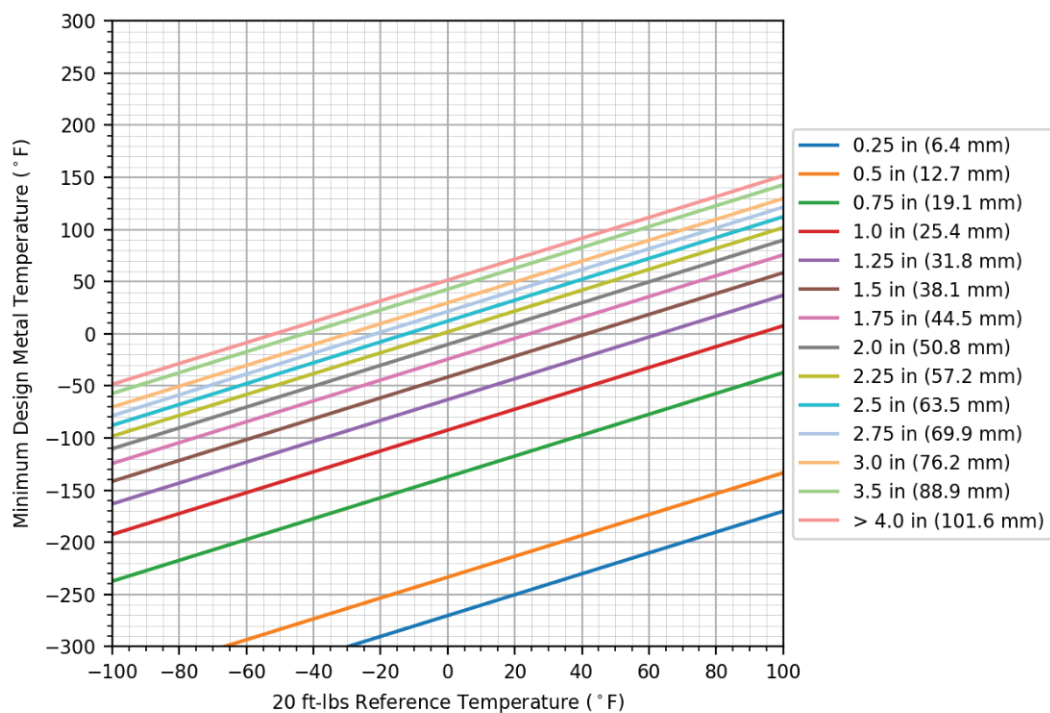


Figure E-6: Impact tested curve – 40ksi (276MPa) yield – PWHT.

E.4 SMYS=50ksi (345MPa)

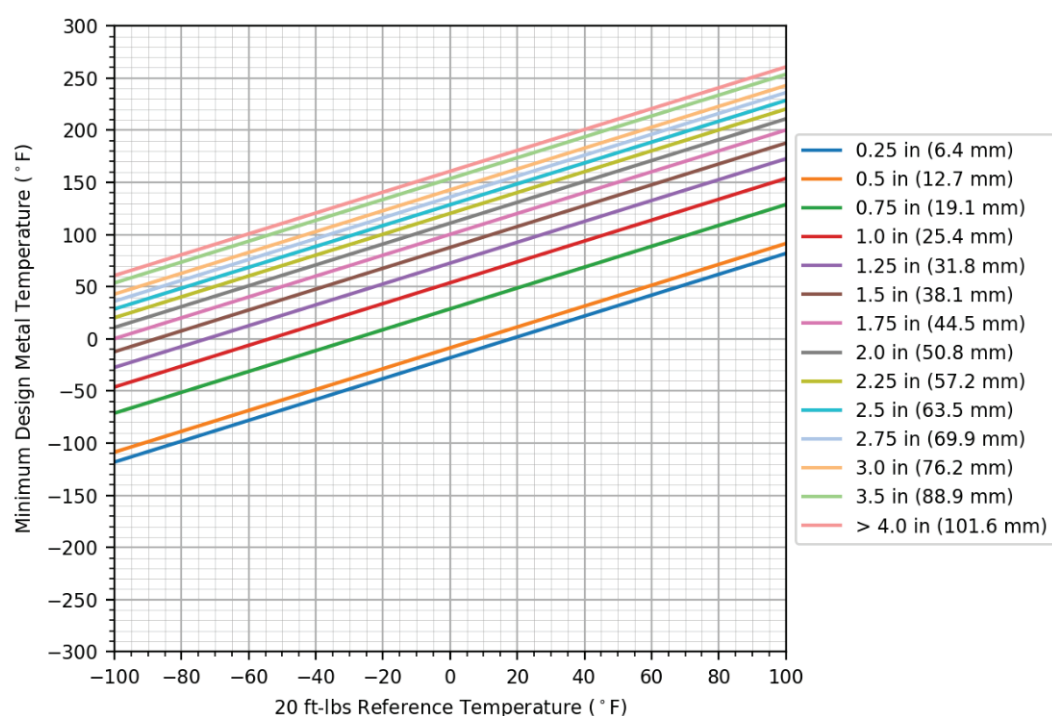


Figure E-7: Impact tested curve – 50ksi (345MPa) yield – as welded.

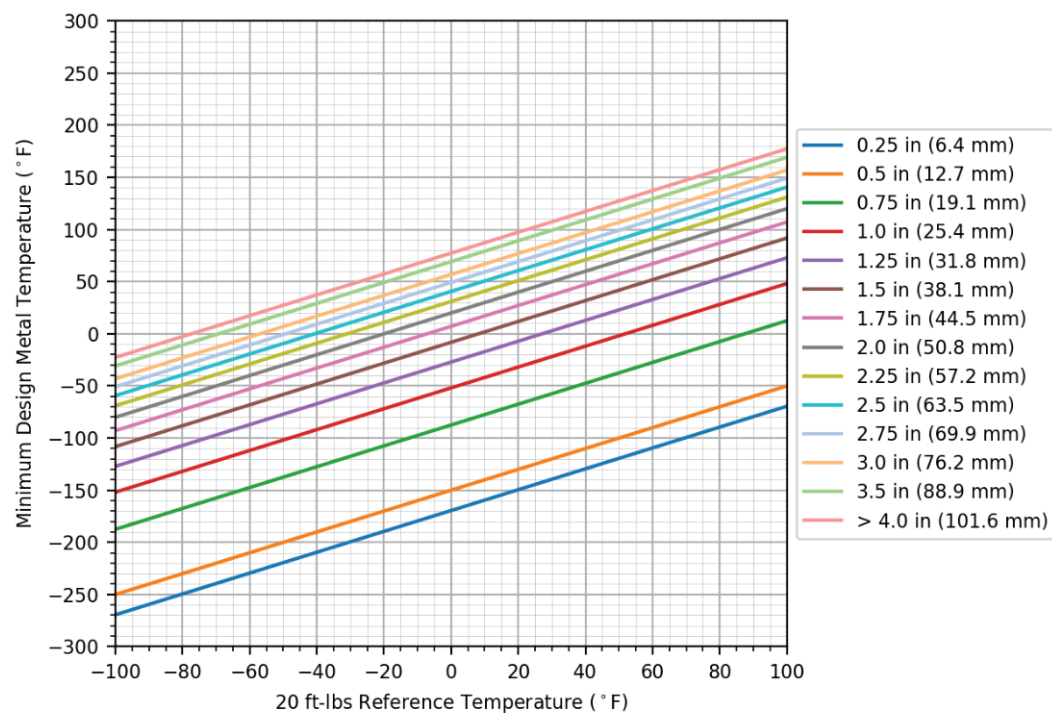


Figure E-8: Impact tested curve – 50ksi (345MPa) yield – PWHT.

E.5 SMYS=60ksi (414MPa)

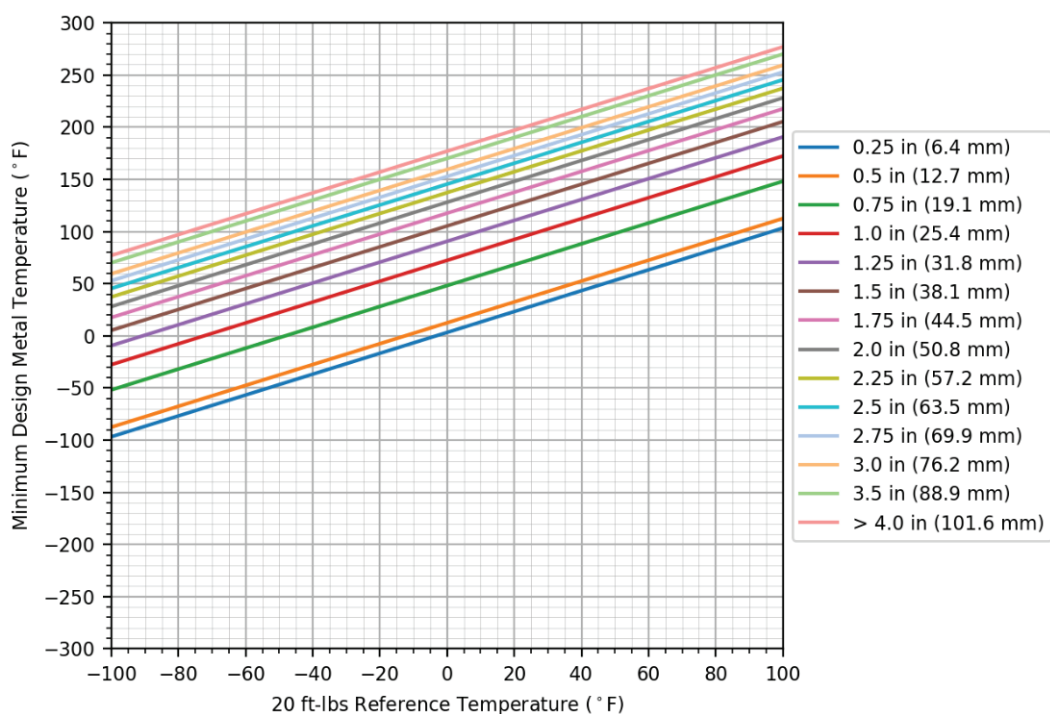


Figure E-9: Impact tested curve – 60ksi (414MPa) yield – as welded.

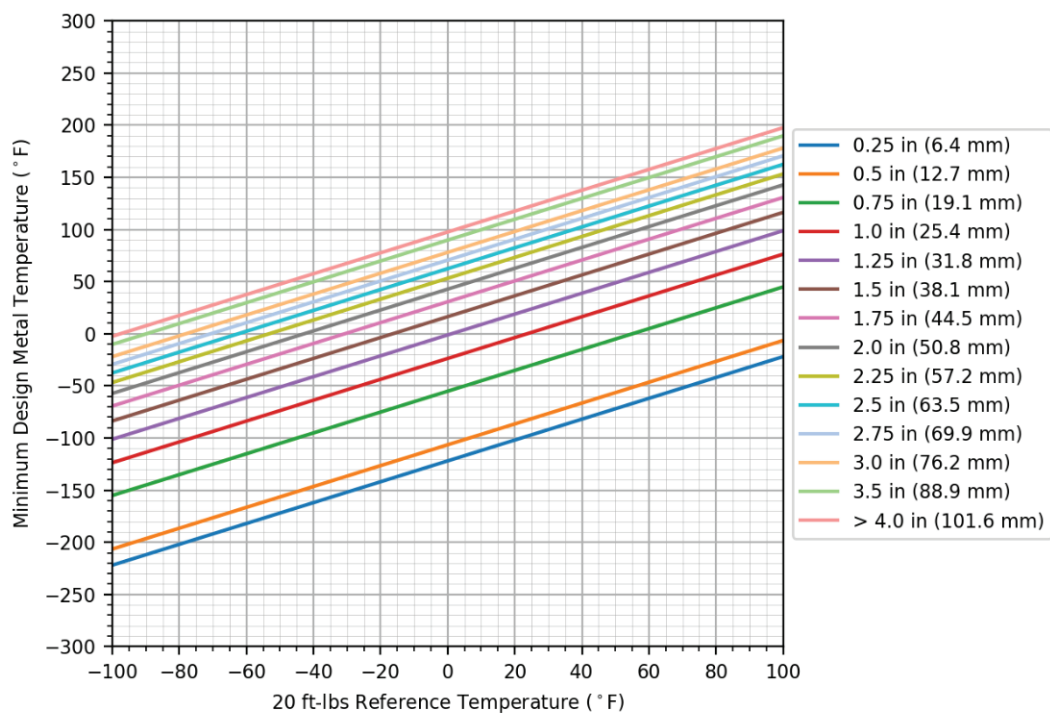


Figure E-10: Impact tested curve – 60ksi (414MPa) yield – PWHT.

APPENDIX F Worked examples

F.1 Example A: Impact test exemption

What is the MDMT of a 10" standard wall A106 pipe without impact testing?

In accordance with ASME B36.10M, the wall thickness of a 10" STD schedule pipe is 9.27mm (0.365").

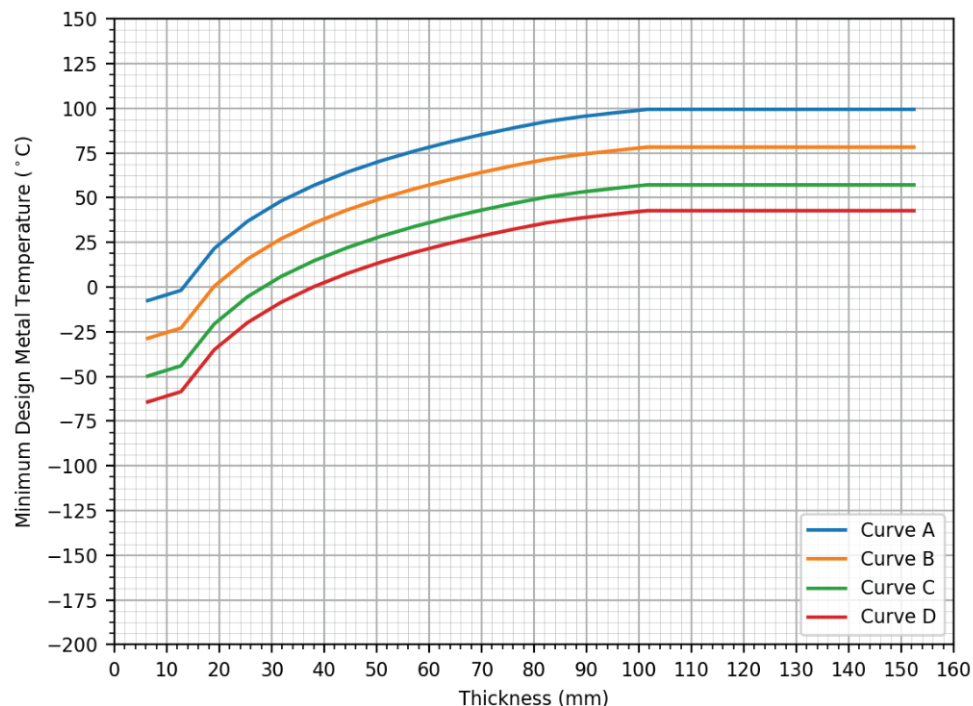
Nominal pipe wall thickness is used.

In accordance with ASME B31.3, the specified minimum yield strength is 241MPa (35 ksi) and the minimum temperature shall be established using Curve B.

Specified minimum yield strength is used to determine which graph in this report is used. ASME B31.3, Appendix A tables are used to assign the material to curve B.

The pipe is in the as-welded condition, therefore use Figure B-3. The MDMT for curve B is -25°C (-13°F). If a minimum thickness of 12.7 mm is used, as per section 3.1.5, then the MDMT is -23°C .

For comparison, -25°C is higher than the ASME B31.3 MDMT of -28.9°C (-20°F).



From section 3.2, for a curve B material, $T_{CV} = 7.3^{\circ}\text{C}$ and using Table 2, $T_{DEP} = -30^{\circ}\text{C}$. The MDMT at which this pipe can be used without impact testing may be calculated using equation (5):

$$\text{MDMT} = 7.3 - 30 = -22.7^{\circ}\text{C}$$

F.2 Worked Example B: Impact tested material

What is the MDMT of a 10" XXS A333 Gr. 6 pipe in the as-welded and the PWHT condition.

In accordance with ASME B36.10M, the wall thickness of a 10" XXS schedule pipe is 25.4mm (1").

Nominal pipe wall thickness is used.

In accordance with ASME B31.3, the specified minimum yield strength is 241MPa (35 ksi).

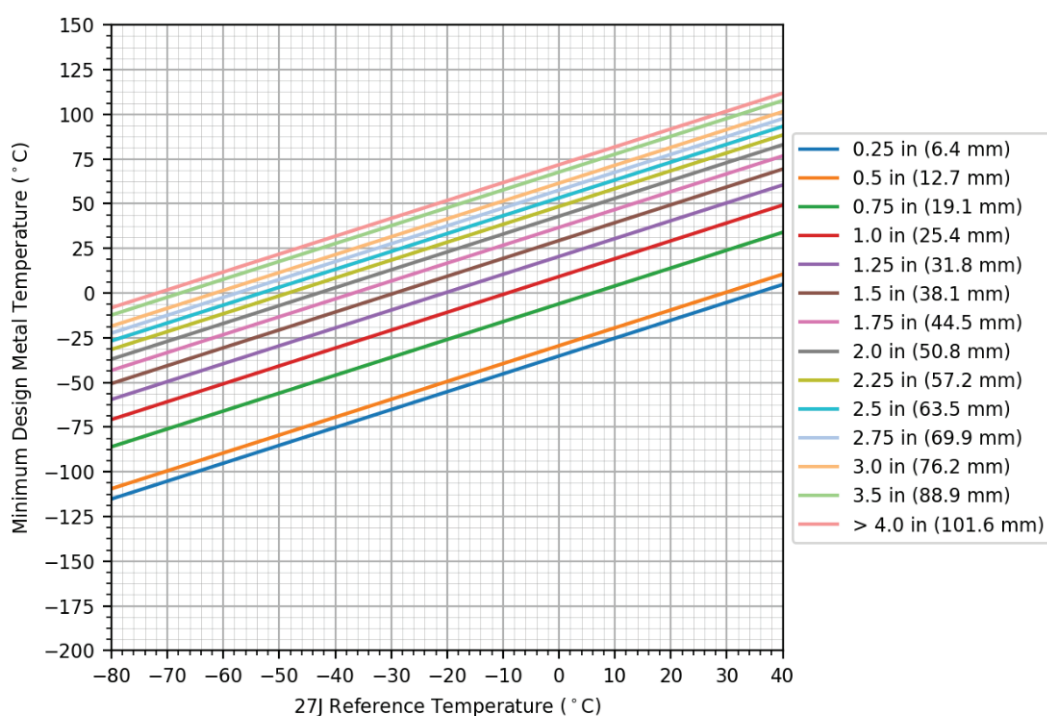
Specified minimum yield strength is used to determine which graph in this report is used.

A333 Gr.6 pipe material has a specified minimum tensile strength of 414MPa (60ksi). Using Table 323.3.5, the minimum required Charpy-V-notch Impact values for an average of 3 specimens is 18J (13ft-lbf). The material specification for A333 Gr. 6 requires that the impact test temperature is -45°C (-50°F) (Table 5). This temperature is consistent with the minimum temperature in ASME B31.3 for this material. The 27J reference temperature may be established using the relationship of 1.5J per 1°C. This conversion may be used in the range 18J to 47J of Charpy V-notch energy. The 27J reference temperature is calculated as:

$$-45 + \frac{(27 - 18)}{1.5} = -45 + 6 = -39^{\circ}\text{C}$$

For pipe in the **as-welded** condition, use Figure D 3. The MDMT for 25.4 mm thickness is -30°C (-22°F).

For comparison, -30°C is higher than the ASME B31.3 MDMT of -45°C (-50°F).

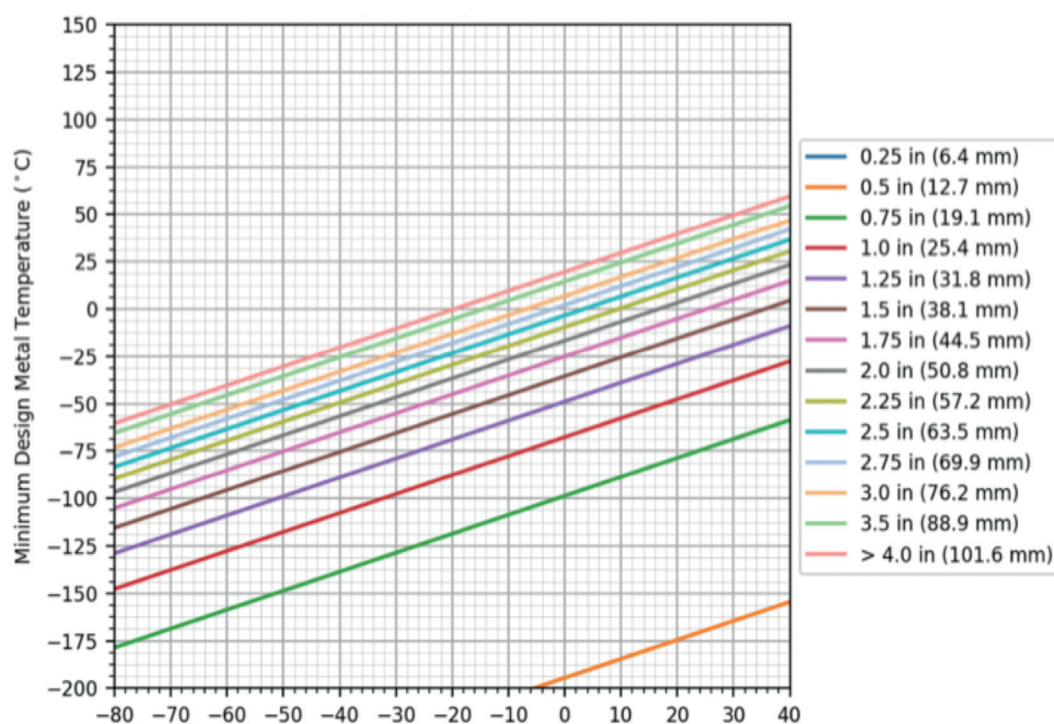


The 27J reference temperature is calculated as -39°C using the methodology outlined above. Using Table 2, $T_{\text{DEP}} = 9^{\circ}\text{C}$. The MDMT at which this pipe can be used in the as welded condition may be calculated using equation (5):

$$\text{MDMT} = -39 + 9 = -30^{\circ}\text{C}$$

For pipe in the **PWHT** condition, use Figure D 4. The MDMT for 25.4 mm pipe is -106°C (-159°F).

For comparison, -106°C is lower than the ASME B31.3 MDMT of -45°C (-50°F).



F.3 Example C: Sub size specimen

A 10" schedule 20 A333 Gr. 6 pipe in the as-welded condition has been tested using a Charpy impact specimen width of 5 mm (½ size bar). What are the minimum required Charpy V-notch impact values and the MDMT?

In accordance with ASME B36.10M, the wall thickness of a 10" schedule 20 pipe is 6.35mm (0.25").

Nominal pipe wall thickness is used.

In accordance with ASME B31.3, the specified minimum yield strength is 241MPa (35 ksi).

Specified minimum yield strength is used to determine which graph in this report is used.

In accordance with ASME B31.3, the specified minimum tensile strength is 414MPa (60ksi).

Specified minimum tensile strength is used to determine minimum the required Charpy V-notch Impact Values.

Using Table 323.3.5, the minimum required Charpy-V-notch Impact values for an average of 3 specimens is 18J (13ft-lbf). The material specification for A333 Gr. 6 requires that the impact test temperature is -45°C (-50°F) (Table 5). This temperature is consistent with the minimum temperature in ASME B31.3 for this material.

Minimum required Charpy V-notch Impact values

Using API 579 and rearranging equation (9F.1), the required impact energy for a 5 mm sub size specimen is:

$$C_{V-ss} = \frac{C_{V-std}}{\left(\frac{t_{std}}{t_{ss}}\right)} = \frac{18}{\left(\frac{10}{5}\right)} = 9J$$

The temperature shift may be calculated by using equation (9F.2) and equation (9F.3):

$$T_{shift} = -51.4 \times \ln \left[2 \left(\frac{t_{ss}}{10} \right)^{0.25} - 1 \right] = -51.4 \times \ln \left[2 \left(\frac{5}{10} \right)^{0.25} - 1 \right] = 20^{\circ}\text{C}$$

$$TT_{ss} = TT_{std} - T_{shift} = -45 - 20 = -65^{\circ}\text{C}$$

The Charpy V-notch impact values required are an average of 9J at -65°C.

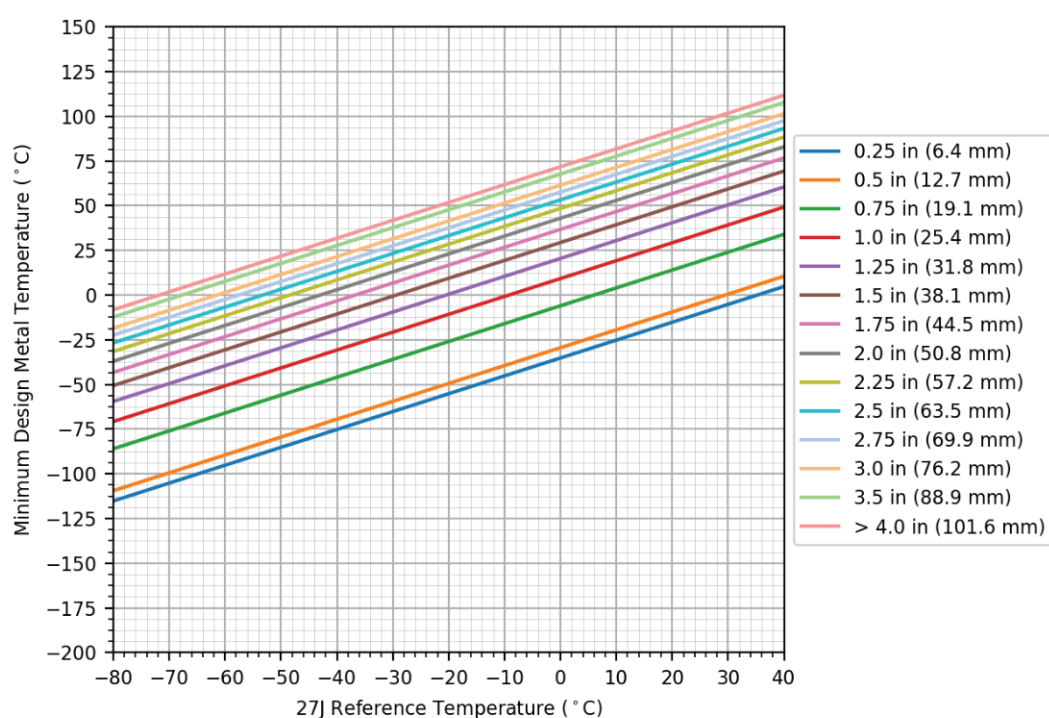
This is equivalent to an average of 18J at -45°C for a full-size specimen.

MDMT

The 27J reference temperature may be established using the relationship of 1.5J per 1°C. This conversion may be used in the range 18J to 47J of Charpy V-notch energy. The 27J reference temperature is calculated as:

$$-45 + \frac{(27 - 18)}{1.5} = -45 + 6 = -39^{\circ}\text{C}$$

For pipe in the as-welded condition, use Figure D 3 with a 27J reference temperature of -39°C. If a minimum thickness of 12.7 mm is used, as per section 3.1.5, then the MDMT is -69°C.



For comparison, -69°C is lower than the ASME B31.3 MDMT of -45°C (-50°F).

F.4 Example D: Sub size specimen

A 10" schedule 20 A333 Gr. 6 pipe in the as-welded condition has been tested using a Charpy impact specimen width of 5 mm (½ size bar). The test results are in accordance with the requirements of A333. What is the MDMT?

In accordance with ASME B36.10M, the wall thickness of a 10" schedule 20 pipe is 6.35mm (0.25").

Nominal pipe wall thickness is used.

In accordance with SA-333 (2017) specification, the minimum impact requirements for a 10x5 mm specimen is 9J (Table 3) and the impact temperature is -45°C (Table 4). In accordance with the impact testing requirements for sub size specimens, the temperature reduction is 11°C (Table 6). The test requirements for a 10x5 mm standard size specimen are 9J at -56°C.

Equivalent Charpy V-notch Impact values

Using equation (9F.1) from API 579 the required impact energy for a 10x10 mm specimen is:

$$C_{V-std} = C_{V-ss} \left(\frac{t_{std}}{t_{ss}} \right) = 9 \frac{10}{5} = 18J$$

The temperature shift may be calculated by using equation (9F.2) and equation (9F.3):

$$T_{shift} = -51.4 \times \ln \left[2 \left(\frac{t_{ss}}{10} \right)^{0.25} - 1 \right] = -51.4 \times \ln \left[2 \left(\frac{5}{10} \right)^{0.25} - 1 \right] = 20^{\circ}\text{C}$$

$$TT_{ss} = TT_{std} - T_{shift} = -56 + 20 = -36^{\circ}\text{C}$$

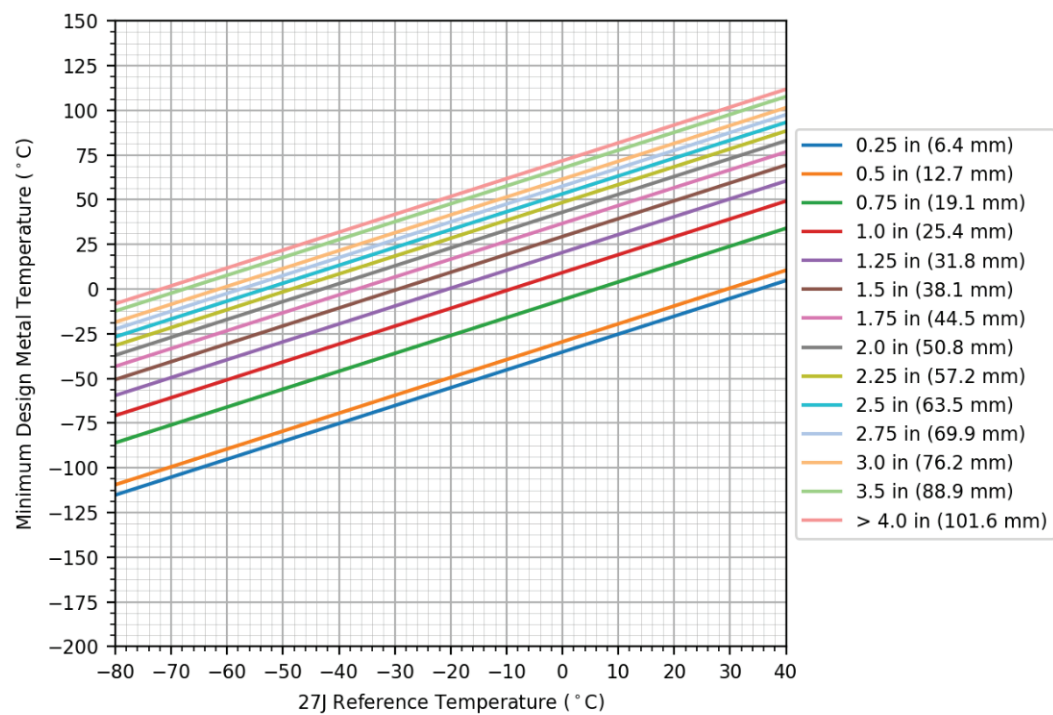
The equivalent full size Charpy V-notch impact values are 18J at -36°C.

MDMT

The 27J reference temperature may be established using the relationship of 1.5J per 1°C. This conversion may be used in the range 18J to 47J of Charpy V-notch energy. The 27J reference temperature is calculated as:

$$-36 + \frac{(27 - 18)}{1.5} = -36 + 6 = -30^{\circ}\text{C}$$

For pipe in the as-welded condition, use Figure D 3 with a 27J reference temperature of -30°C. If a minimum thickness of 12.7 mm is used, as per section 3.1.5, then the MDMT is -60°C.



For comparison, -60°C is lower than the ASME B31.3 MDMT of -45°C (-50°F).

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