THE DEVELOPMENT OF WELD PROCEDURES FOR X80 PIPELINES IN THE UK

Neil A. Millwood

5G Orbital Ltd, Loughborough, UK.

Keywords: Grade X80 Steel, Mechanised GMAW Welding, Pipelines

Abstract

An extensive programme of development work was undertaken prior to the implementation of the first grade X80 pipeline in the UK in the year 2000. Since that time over 900 km of DN1200 grade X80 pipelines have been installed in the UK and a wealth of experience has been gained. This paper chronicles some of the historical background and describes the weld procedure requirements for girth welding of X80 pipelines.

Disclaimer

The views and opinions expressed in this paper are held by the author, and do not necessarily represent those held by National Grid or any other organisation.

Historical Context & Drivers for Large Diameter High Strength Steel Pipelines

The late 1980s and 1990s saw a steady rise in the demand for natural gas. This was brought about largely by the fashion for building gas-fired power stations which helped government commitments to the Climate Change Levy. Other factors such as the deregulation of the UK energy market and two offshore interconnector pipelines – one from continental Europe to Bacton[1] and the other from Scotland to Northern Ireland[2] – only served to increase the need for transportation of natural gas.

At the time, it was recognised that the increased volume of natural gas could be transported either by operating the existing pipelines at higher pressures (often called uprating) or building new larger diameter and higher strength pipelines. These options were not, of course, mutually exclusive.

Large diameter, high strength steels were originally considered for an east coast high pressure pipeline project in the mid 1990s. In the UK at this time the highest grade used was X65 (L450MB) and the largest pipe size, with the exception of a short section of storage main in South Wales, was DN1050. There was some experience of X80 (L555MB) pipelines in Europe and Canada and some pipe manufacturers were offering large diameter grade X80 on a production basis. The concept behind the project was to install a DN1200 pipeline from Bishop Auckland to Wisbech, to take advantage of gas produced by the Elgin-Franklin development which would be brought ashore at Teesside. The pipeline would be 300 km long, pass through

[1] Interconnector Pipeline from Zeebrugge to Bacton, DN1000, 206 km. Commissioned 1998.
[2] SNIP pipeline from Stranraer to Larne, DN600. Commissioned 1996.

four counties and include some 300 crossings. The plan was to have the pipeline installed and operating by 1998. However, the project was halted at the end of 1996 when the government announced the offshore option of bringing the gas from Elgin-Franklin to Bacton[3] instead.

The Technical Working Group examined the following areas:

- Materials selection
- Design parameters
- Statutory requirements
- Optimum life-cycle costs
- Construction issues

The initial considerations for a potential X80[4] pipeline were as follows:

- Track record of X80 pipelines in Europe and elsewhere
- Suppliers of linepipe and fittings
- Coverage in codes and standards
- Relevant safety issues

Standard and heavy wall pipe thicknesses for pressure containment were worked out for grade X65 & X80 at 85 bar & 90 bar respectively. Grade X70 was discounted as being too close to X65. Techno-economic studies showed a cost advantage of using grade X80 at higher pressure (90 bar). A separate study by independent consultants identified the main issues with grade X80 and estimated a 22.7% cost saving with X80 over X65.

An extensive research and development programme was carried out by BG Technology (subsequently renamed Advantica) to establish the suitability of large diameter, grade X80 linepipe. At around the same time development work was also being carried out on grade X100 (690 N/mm^2 specification minimum yield) linepipe. However grade X100 was not favoured by Transco as concept studies showed that this would only be an economic choice at pressures that were unlikely to be feasible in the UK.

Since that time the 'shape' or landscape of gas supply and demand in the UK has changed dramatically and therefore the requirement for a 5th Feeder has ebbed away. Notable changes have been (i) the increased usage of large diameter pipelines for 'linepacking' (storage), (ii) the supply of gas from Norway through the Langeled Pipeline, and (iii) the construction of liquefied natural gas receiving terminals at Milford Haven and Isle of Grain.

---

[3] SEAL pipeline

[4] The term 'X80' is used colloquially in this paper. Where particular reference is made to a specification, or product form, the full designation will be used.

Main Issues

The main issues associated with large diameter high strength steels at the time were identified by the Technical Working Group and external consultants as follows:

- Materials availability
  - Linepipe
  - Bends
  - Fittings
- Materials properties
  - Yield-to-tensile ratio
  - Damage tolerance
  - Charpy impact toughness
  - Ductile fracture propagation
  - Seam weld toughness
- Fittings
  - Transitioning
- Construction
  - Weldability, weld procedures, preheat requirements etc.
  - Field bending
- Operation
  - Ductile fracture control
  - Mechanical damage tolerance
  - Risk implications
  - Repair and hot tapping
- Specifications
  - X80 was not covered by national standards and codes such as IGE/TD/1 [1], nor in company specifications.

Concurrent with the desire to use grade X80 steel, there was an emphasis on using 18 metre lengths instead of the more traditional 12.2 metre lengths. The advantages of using longer lengths were principally fewer field girth welds and more usable pipe length during cold field bending. However, the disadvantages were transportation and logistical challenges as well as fewer mills with the capacity to manufacture the longer joint lengths.

Development Prior to Implementation

An extensive amount of development was carried out prior to implementation of grade X80, and is summarised in bullet-point format below:

- Feasibility studies
- R&T evaluation
  - Parent pipe and seam weld properties
  - SMAW welding trials – cellulosic, and basic low hydrogen
  - GMAW welding trials – CRC-Evans mechanised gas metal arc welding
  - Consideration of girth weld defect acceptance criteria and inspection techniques
  - Cold field bending trials
  - Evaluation of induction bends

    - Damage tolerance – ring tension & full-scale burst tests
    - Hydrogen embrittlement – laboratory scale tests
    - Risk assessment – ALARP[5]
    - Hot tap welding trials – on 20" and 48" pipes
- Specification supplements
- Weldability trials
- Procedure qualification
- Consistency trials

This paper focuses on the specification requirements and welding of grade X80 pipelines. It draws mostly on the experiences in the UK, but recognises the significant contribution of other organisations and projects worldwide.

Welding Procedures

On a cross-country pipeline construction project it is normal practice to qualify a range of weld procedures to cover the various sequences, materials, wall thicknesses, type of fittings and geographical terrains likely to be encountered. Usually, the procedures can be grouped as follows:

- Mainline pipe-to-pipe welding
- Fabrication welding of pipe-to-fittings, and pipe-to-pipe transition welds
- Tie-in welding (usually pipe-to-pipe)

During the development stage, the main question to be answered was: 'would it be possible to use conventional welding techniques for X80 girth welding?' Weld procedure development work was carried out using manual (cellulosic and basic low hydrogen) consumables, mechanised flux-cored arc welding and mechanised gas metal arc welding. Table I shows the scope of application of each of the weld procedures.

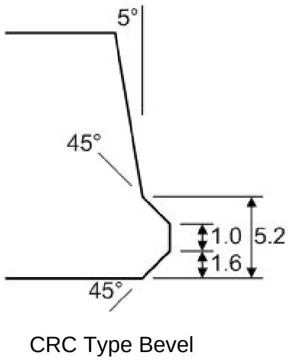
Table I. Matrix of Weld Procedures Available for Cross-Country Pipeline Construction

	Procedure type	**Mainline**	**Fabrication**	**Tie-ins**
1	Mechanised gas metal arc welding	Yes	–	–
2a	Stovepiping: Cellulosic root & hot pass, Basic low hydrogen fill & cap	Yes	–	–
2b	Dollymix: Cellulosic root & hot pass, Basic low hydrogen fill & cap	–	Yes	Yes
3	Low hydrogen SMAW all passes	–	Yes	Yes
4	Hybrid: SMAW root & hot pass, vertical-up mechanised FCAW fill & cap	Yes	Yes	Yes

[5] ALARP = as low as reasonably possible

Mechanised Gas Metal Arc Welding

Mechanised gas metal arc welding (GMAW) is well proven for offshore pipeline construction and for large diameter onshore pipeline construction. Development work was carried out using single torch CRC-Evans equipment, and subsequent to that the majority of the X80 pipelines in the UK have been welded with that process. A typical joint design, weld macro section and parameters are shown in Figure 1 and Table II. The Saturnax dual torch system offered by Serimax has been used on one X80 pipeline project in the UK and a hybrid mechanised flux-cored system has been used on one project.



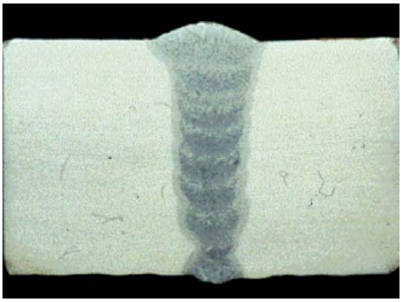


Figure 1. Typical bevel and weld macro-section for a CRC mechanised GMAW girth weld.

Table II. Typical Weld Parameters for a CRC Mechanised GMAW Girth Weld

Pass	**Process & equipment**	**Wire & Gas**	**Arc energy (kJ/mm)**
Root	GMAW with internal welding machine	Thyssen K-Nova (0.9 mm) 80% Ar – 20% CO_2	0.4
Hot pass	Single torch GMAW	Thyssen NiMo80 (0.9 mm) 100% CO_2	0.3
Fill	Single torch GMAW	Thyssen NiMo80 (0.9 mm) 100% CO_2	0.7
Cap	Single torch GMAW	Thyssen NiMo80 (0.9 mm) 80% Ar – 20% CO_2	0.9

Around the time of the first X80 pipeline construction project in the UK there was also a lot of interest in automated ultrasonic testing (AUT) for inspection of girth welds. This method of inspection had already been well established for offshore pipeline construction, but had not gained general acceptance for onshore pipeline construction. The main reason for not adopting AUT was that manual welding was/is still a mainstay of construction practice and this type of welding is less amenable to AUT inspection. The converse to this is that mechanised GMAW girth welds are well suited to inspection by AUT. This is due to the precision bevel used with mechanised GMAW and because the most common type of defect (i.e. lack of sidewall fusion) is planar and therefore more easily detected by AUT.

Mechanised GMAW is suitable for mainline pipe-to-pipe welding, i.e. when it is possible to run an internal line-up clamp inside the pipe and when it is possible to bevel the pipe ends. The contractor's choice of when to use mechanised GMAW will depend on the length of the pipeline project, the terrain and the number of crossings to be completed. In general terms, mechanised GMAW becomes economic when the pipeline length is greater than 50 km. In the UK, pipeline projects tend to be quite short and there also tends to be a large number of crossings.

Shielded Metal Arc Welding

Manual 'stovepipe' vertical-down welding with a cellulosic coated electrode has been used for many years in the pipeline industry. With experienced welders a fast, reliable root bead can be deposited. The process is versatile, well suited for site work and has the additional advantage that the factory applied 'API bevel' can be used. Early X80 development work showed that an all-cellulosic weld would not guarantee the required level of strength overmatching. Added to that, the large diameter pipes would increase the risk of hydrogen assisted cold cracking because of (i) the increase in the physical loading on the root pass ligament, (ii) the increased difficulty in maintaining the correct minimum preheat around the full circumference of the weld, and (iii) the inevitable increase in time between the start of the root pass and the start of the hot pass.

A 'dollymix' procedure, i.e. with a vertical-up root pass and vertical-down hot pass, fill and cap passes, is often used for pipe-to-fitting welds or transition joints where fit-up conditions may not be ideal or where an internal clamp cannot be used. The vertical-up root pass is slower, but it is more tolerant to hi-lo (misalignment) and variations in root gap and landing edge thickness. In the UK, the National Grid specification for pipeline welding requires low hydrogen consumables to be used for pipe-to-fitting welds on pipe sizes equal to or greater than DN900.

Hillenbrand & Perteneder [2] performed small-scale implant tests on X80 material and showed that a minimum preheat of 100 °C was required for avoidance of hydrogen assisted cold cracking. Complementary full-scale testing showed that a minimum preheat of 50-60 °C was sufficient. In the UK, there is a requirement to apply a minimum preheat of 100 °C for girth welding on pipe grades of X65 and above.

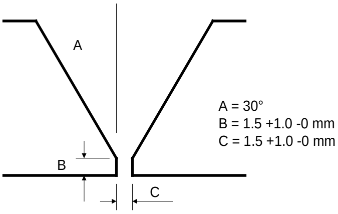
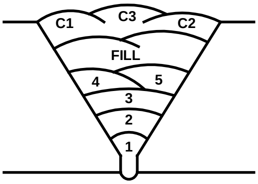
The method of application of preheat is important. Traditionally, propane flame heating with a 'spider' arrangement, Figure 2, is used as it is simple and relatively cheap. More recently, induction heating coils, Figure 3, have gained in popularity for preheating of pipe ends prior to fit-up and welding. The configuration of the coil winding can also be altered such that the heating band can be attached to the pipe remote from the free end.

Figure 2. Preheating of pipe end with ‘spider’ flame torch arrangement.

Figure 3. Preheating of pipe end with induction heating coil.

In the UK, an all-cellulosic weld on X80 is not permitted. Cellulosic coated electrodes may be used for the root and hot pass only. A popular option for the fill and cap passes is to use a basic low hydrogen vertical-down consumable such as the Bohler Thyssen BVD-100. Typical parameters are given in Table III. Whilst the specification does allow a lower minimum interpass temperature of 80 °C, there have been instances of weld metal cracking in the latter fill passes of this type of weld. This is thought to be due to a build-up of hydrogen (notionally from the root and hot pass) and the high strength weld metal.

Table III. Typical Consumables and Pass Sequence for a ‘Dollymix’ Cellulosic and Low Hydrogen SMAW Girth Weld

<table>
<tr><th>Pass</th><th>Consumable</th><th>Size</th><th>Direction</th></tr>
<tr><td>Root</td><td>E6010</td><td>3.2 mm</td><td>Vertical-up</td></tr>
<tr><td>Hot pass</td><td>E8010-P1</td><td>5.0 mm</td><td>Vertical-down</td></tr>
<tr><td>Fill</td><td>E10018-G</td><td>4.5 mm</td><td>Vertical-down</td></tr>
<tr><td>Cap</td><td>E10018-G</td><td>4.0 mm</td><td>Vertical-down</td></tr>
<tr><td colspan="2">
</td><td colspan="2">
</td></tr>
</table>

Hybrid Welding

An alternative to using SMAW for the fill and cap is mechanised flux-cored arc welding (FCAW). The mechanised form of the process has been preferred over the semi-automatic form since it allows better control of heat input. A number of contractors have invested in FCAW welding ‘bugs’, or heads, which are generally much more rudimentary than mechanised GMAW welding heads, but are robust and reliable. The hybrid procedure is quite versatile and will cope with variations in fit-up and also with transition joints. Another advantage is that the standard 30° API bevel can be used, so bevelling in the field is not required. Typical parameters for a vertical-up rutile wire are given in Table IV.

Table IV. Typical Consumables and Pass Sequence for a ‘Hybrid’ SMAW-FCAW Girth Weld

Pass	Process and Consumable	Size	Direction
Root	SMAW, E6010	3.2/4.0 mm	Vertical-up/down
Hot pass	SMAW, E8010-P1	5.0 mm	Vertical-down
1st Fill pass	SMAW, E10018-G	4.5 mm	Vertical-down
Fill passes	FCAW, A5.29 E111T1 & E81T1	1.2 mm	Vertical-up
Cap			

Some contractors have encountered problems with porosity when welding with the flux-cored process over a cellulosic root and hot pass. This problem can be alleviated by making the hot fill pass with a BVD (Basic Vertical Down) consumable. Generally in the field, the contractor would seek to use one crew for the manual (SMAW) welding and another crew for the mechanised FCAW. As there would probably be a time lapse between the first crew finishing their part of the weld and the second crew arriving, it is important to incorporate a suitable delay time and an acceptable minimum ligament thickness into the procedure. The situation for welding of fittings is slightly different in that the weld needs to be completed in one heat cycle.

Specification Requirements

Prior to the year 2000 and the implementation of X80 pipelines, the National Grid specifications did not cover grade X80 linepipe. So, an important output of the R&D evaluation programme was to define appropriate specification limits.

Tensile Properties

The European specification for linepipe, EN 10208-2 [3], defines the strength in the transverse (hoop) direction, as measured from flattened strap specimens. For grade X80/L555MB the specified minimum yield strength is 555 N/mm^2, at 0.5% total elongation. An upper limit of 675 N/mm^2 is also given, and the specified minimum tensile strength is 625 N/mm^2. Since the X80 pipelines in the UK have all been stress-based designs, there has been no requirement for longitudinal materials property testing.

It is widely accepted that strength overmatching of the girth welds is desirable for weld defect tolerance. What is more difficult, and perhaps controversial, is how to measure all-weld yield strength and to define an appropriate level of overmatching.

The extent of overmatching is usually defined as a percentage over the specified minimum yield strength (SMYS), but as the following examples show, there can be a wide interpretation of overmatching:

- Transverse SMYS + 5% = 583 N/mm^2
- Transverse SMYS + 10% = 610 N/mm^2
- Longitudinal SMYS + 10% = 610 N/mm^2
- Actual yield strength (all pipes) = 675 N/mm^2

Measurement of parent pipe metal yield strength can be problematic since the flattened strap test specimen tends to under-represent the true yield strength. To counter this, manufacturers increase the true strength so that the measured values meet the specified minimum yield strength. The net result is that the level of true overmatching is reduced.

Measuring the true yield strength of weld metal is difficult at the best of times, but it is even more so with a narrow gap girth weld. This is mainly due to the geometry which limits the size of specimen and percentage of the weld thickness that can be sampled. The test specimen can either be orientated parallel to the weld, or transverse to the weld. Most welding standards favour the parallel orientation, but DNV OS-F101 [4] describes a transverse round bar tensile test specimen with a short gauge length made up solely of weld metal. Extension is not measured using a clip gauge; instead reduction of area is measured optically, from which elongation is inferred.

All-weld tensile test specimens taken parallel to the weld direction can either be round bar, or prismatic (rectangular) in cross-section. As the schematic shows, Figure 4, the curvature and wall thickness of the pipe will determine which part of the weld is sampled. The width of the narrow gap weld will limit the diameter, or cross-sectional area of the specimen. Hardness testing may be used to assist the placement of the all-weld tensile specimen, although the author is not sure how effective this is. More normally, the blank is etched to locate the weld position before machining.

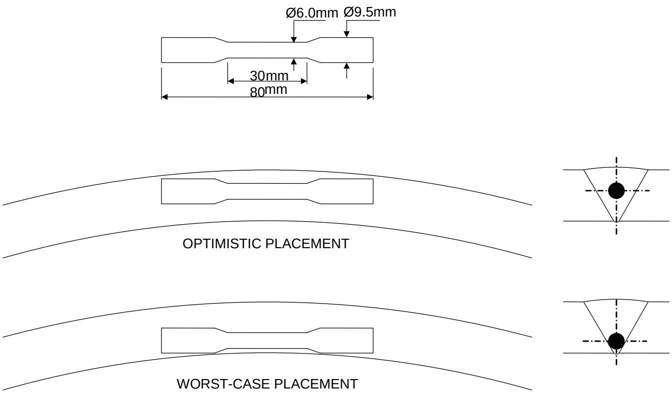


Figure 4. Round bar all-weld tensile testing of girth welds.
(Example shown on DN750 x 20 mm).

In most cases, two round bar tensile specimens, taken from the 3 and 9 o'clock positions around the circumference, and with a maximised diameter, are required. Testing is carried out in accordance with EN ISO 6892-1 [5][6]. Yield strength ($R_{t0.5}$ and $R_{p0.2}$), ultimate tensile strength (R_m) and strength at 0.2% and 0.35% total elongation are measured and recorded. It is considered good practice to include the load-extension or stress-strain curves in the PQR. For high strength applications some users specify a constant low strain rate (circa 0.2 mm/min) until maximum load is attained.

Fracture Toughness

For the majority of C-Mn steel pipelines with wall thickness up to and including 25 mm, minimum design temperature not lower than -10 °C and pipe SMYS not greater than 555 N/mm^2, an impact energy exceeding 30 J minimum individual value and 40 J average value will suffice. For grade X80 in the UK a minimum individual value of 45 J and a minimum average value of 60 J was specified. Typical values obtained for a mechanised GMAW girth weld were 66 – 97 J at -15 °C [6].

Single edge notched bend CTOD[7] specimens with a Bx2B geometry were tested as part of each weld procedure qualification testing programme. No minimum value was specified, and the results were used for information only. The purpose of the testing was to generate some data which might be useful for future fitness-for-purpose calculations.

[6] Formerly EN 10002-1.
[7] CTOD = crack tip opening displacement.

Hardness

Hydrogen assisted cold cracking (HACC) can form after welding due to an unfavourable combination of microstructure, hydrogen concentration and stress concentration. Cracking does not usually occur until the weld has cooled close to ambient temperature and under some conditions may be considerably delayed. Cracks may occur in the heat affected zone or in the weld metal, and may be in several orientations. Older steels had relatively high carbon contents and when cooling rates were sufficiently high there was an increased susceptibility to hydrogen cracking. Over the years, the emphasis has been on promoting slow cooling rates to avoid hard, susceptible microstructures, and to limit the exposure to excessive stresses. The following measures have been instigated primarily to prevent HACC, or at least demonstrate that it is not an issue:

- Application of adequate preheat (as determined by weldability testing)
- Maintenance of minimum interpass temperature
- Balanced sequence of welding (particularly during root pass)
- Restriction on when to lower-off
- Time lapse between start of root pass and start of hot pass
- Minimum number of passes before weld can be cooled to ambient
- The use of full pipe lengths during procedure qualification testing
- Time lapse between completion of welding and inspection (usually only applicable for procedure qualification testing)

Hardness is an indicator of microstructure. It is generally desirable to keep the hardness as low as possible, however the cooling rate in the austenite to ferrite transformation range for pipeline steels can be quite high, (low $t_{8/5}$)[8], leading to the formation of undesirable martensite. There is no unique correlation between HAZ hardness and cracking susceptibility, but it is agreed that higher hardness generally indicates a greater susceptibility to HACC during construction and to other problems such as stress corrosion cracking in service.

The BS 4515 [7] specification limits for grade X80 are summarised in Table V. The limits are of particular relevance to welding processes involving high levels of hydrogen evolution (i.e. cellulosic welding), but the limits can be relaxed for low hydrogen processes and mechanised GMAW. The limits are lower for the root region because of the higher stresses experienced by the root (and hot pass) when lowering-off.

[8] $t_{8/5}$ = time taken to cool from 800 °C to 500 °C.

Table V. Maximum Vickers Hardness (HV_{10}) Requirements for Non-Sour Service Girth Welds Showing Changes Permitted for Grade X80

Position of indent	**SMAW (Cellulosic)**	**Manual & Semi-automatic (Low hydrogen)**	**Mechanised GMAW**
Weld, root	275	275	275
Weld, cap	275	275 → 300 X80	275 → 300 X80
HAZ, root	275	325 → 350 BS4515	350
HAZ, cap	325	325 → 350 BS4515	350

Düren & Niederhoff [8] performed bead-on-plate tests on a series of plate compositions, and over a range of $t_{8/5}$ cooling rates to generate a series of regression equations to predict maximum HAZ hardness. The equation shown below is relevant to medium $t_{8/5}$ values and cooling rates which produced microstructures with a mix of martensite and bainite[9].

$$HV_X = 2019 \cdot \left[C(1 - 0.5 \cdot \log(t_{8/5}) + 0.3 \cdot \left(\frac{Si}{11} + \frac{Mn}{8} + \frac{Cu}{9} + \frac{Cr}{5} + \frac{Ni}{17} + \frac{Mo}{6} + \frac{V}{3} \right) \right] + 66 \cdot (1 - 0.8 \cdot \log(t_{8/5}) \quad (1)$$

Figure 5 shows the predicted maximum HAZ hardness versus $t_{8/5}$ for some typical modern grade X80 linepipe steels, Table VI. Work by Hudson [9] and Militzer [10] showed that for mechanised GMAW welds a $t_{8/5}$ time of 2 – 6 seconds is typical.

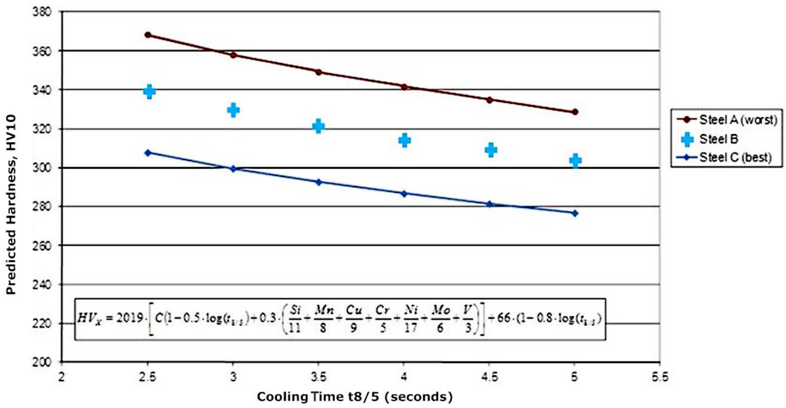


Figure 5. Predicted maximum HAZ hardness for selected grade X80 pipes. Using the regression formula developed by Düren and Niederhoff [8].

---

[9] Separate regression equations were developed for 100% martensite and 100% bainite.

Table VI. Compositions (wt%) of some X80 Steels; for Prediction of Maximum HAZ Hardness

Steel	**C**	**Si**	**Mn**	**Cu**	**Cr**	**Ni**	**Mo**	**V**	**Nb**	**Al**	**CE_{IIW}**
A	0.08	0.33	1.92	0.03	0.07	0.03	0.22	-	0.05	0.04	0.46
B	0.06	0.35	1.93	0.02	0.04	0.04	0.17	0.002	0.05	0.04	0.43
C	0.05	0.20	1.87	0.01	0.01	0.26	0.18	-	0.04	-	0.42

Examples of high hardness have been observed in the cap HAZ of thick wall grade X80 pipes welded using single wire mechanised GMAW. Dual torch mechanised GMAW with a ‘split cap’ can alleviate high cap hardnesses since the weave width is less and the effective heat input (per wire) can be increased.

Defect Acceptance Limits

Most pipeline girth welding specifications use ‘workmanship’ based defect acceptance criteria. These are not directly related to the actual service conditions of the pipeline, but are based on the performance of a good welder and also to some extent on the capability of radiographic inspection techniques. These methods have worked well on conventional materials, and when properly applied produce a high quality pipeline. However, there is limited experience with using these criteria for high strength linepipe such as X80. As there is no theoretical basis for the workmanship criteria, their application to X80, where the stresses will be higher, involves some uncertainty.

A related issue is that the construction of large diameter pipelines has coincided with a move to replace radiographic inspection of the girth welds with automatic ultrasonic inspection (AUT). This has been for reasons of improved productivity and safety by eliminating ionising radiation and chemicals used in processing the radiographs. AUT provides information on the through wall height of the defects, which makes it well suited to a ‘fitness for purpose’ approach.

Fitness for purpose criteria relate the defect acceptance limits to the service conditions and the material properties. Thus the acceptance criteria can be related to the material grade and the properties of the weldment. A simple set of defect acceptance criteria were developed for material up to X70 by the EPRG in 1996 [11]. Full details are given in this reference, but key points are that they assume the pipe may be stressed up to yield in the axial direction and require an average Charpy impact energy for the weldment of 40 J. They also require the weld metal to overmatch the parent metal strength. As noted above, the guidelines were extended to cover X80 for the St Fergus to Aberdeen pipeline in conjunction with development work for the use of AUT [6]. Subsequent work by EPRG [12] has confirmed that the guidelines can be used for X80, although the yield to tensile ratio of the parent pipe is restricted to a maximum of 0.90[10]. This restriction applies to all pipe grades, but will be easier to achieve in the lower strength X65 than in X80. Similarly, the requirement for overmatching weld metal will be easier to achieve in X65

[10] This restriction applies to properties measured in the longitudinal direction, not transverse.

than in X80, although it should be noted that most workmanship defect acceptance criteria also require overmatching.

Overall, the use of X65 is likely to be beneficial to the use of fitness for purpose weld defect acceptance criteria compared with X80, as it will be easier to achieve requirements such as weld metal overmatching and to meet limits on the parent metal yield to tensile ratio.

Implementation

As mentioned earlier, up until 1996 the largest pipeline diameter in use in the national transmission system was DN1050 and a material grade X65. Sensibly, a phased implementation strategy was adopted for DN1200 X80 pipelines, as follows:

- Large diameter DN1200 grade X65 – Peters Green to South Mimms
- Large diameter DN1200 grade X80 distribution line – Drointon to Sutton on the Hill
- Large diameter grade X80 high pressure transmission pipeline 94 bar design pressure – St Fergus to Aberdeen

Since then several projects have been constructed in the UK using large diameter grade X80, with a cumulative length of almost 900 km, Table VII. Development work has continued during this time, for example fitness for purpose acceptance criteria for girth welds based on the EPRG Weld Defect Guidelines were developed during the St Fergus to Aberdeen project in conjunction with the introduction of automatic ultrasonic testing [6].

Table VII. Summary of Grade X80 Pipelines in the UK

Date	**Project**	**WT (mm)**	**Length (km)**
2000	Drointon to Sutton on the Hill	15.9 / 19.1	25
2001	St Fergus to Aberdeen	15.1 / 21.8	72
2001	Hatton to Silk Willoughby	15.1 / 21.8	45
2002	Cambridge to Matching Green	14.3 / 20.6	46
2003	Bacton to Kings Lynn	14.3 / 20.6	68
2004	Aberdeen to Loch Side	15.9 / 22.9	50
2006	Ganstead to Asselby	14.3 / 20.6	53
2006/7	Pannal to Nether Kellet	14.3 / 20.6	90
2006/7	Milford Haven to Aberdulais	15.9 / 22.9	128
2007	Felindre to Brecon	15.9 / 22.9	86
2007	Brecon to Tirley	15.9 / 22.9	107
2008	Easington to Ganstead	14.3 / 20.6	30
2008	Asselby to Aberford	14.3 / 20.6	33
2008	Aberford to Pannal	14.3 / 20.6	30
2010	Easington to Paull	14.3 / 20.6	26

References

1. IGE/TD/1: “Recommendations on Transmission and Distribution Practice: Steel Pipelines for High Pressure Gas Transmission,” (London, UK: Institution of Gas Engineers and Managers, Edition 3 1993, Edition 4 2001, Edition 5 2008).

2. H.G. Hillenbrand et al., “Procedures, Considerations for Welding X-80 Linepipe Established,” *Oil & Gas Journal*, (September 15, 1997).

3. EN 10208-2: “Steel Pipes for Pipelines for Combustible Fluids – Technical Delivery Conditions. Part 2: Pipes of Requirement Class B” (London, UK: British Standards Institution, 2009).

4. DNV OS-F101: “Submarine Pipeline Systems” (Oslo, NO: Det Norske Veritas, 2010).

5. EN ISO 6892-1: “Metallic Materials. Tensile Testing. Method of Test at Ambient Temperature” (London, UK: British Standards Institution, 2009).

6. R.M. Andrews and L.L. Morgan, “Integration of Automated Ultrasonic Testing and Engineering Critical Assessment for Pipeline Girth Weld Defect Acceptance,” *Proceedings of Fourth International Conference on Pipeline Technology*, Ostende, Belgium, (9-13 May 2004). (Beaconsfield, UK: Scientific Surveys, 2004), 2, 655-667.

7. BS 4515-1: “Specification for Welding of Steel Pipelines on Land and Offshore. Part 1: Carbon and Carbon Manganese Steel Pipelines” (London, UK: British Standards Institution, 2009).

8. C.F. Düren and K.A. Niederhoff, “Hardness in the Heat Affected Zone of Pipeline Girth Welds,” *Proceedings of 3rd International Conference on Welding and Performance of Pipelines*, London, (18-21 November 1986).

9. M.G. Hudson, “Welding of X100 Linepipe” (Ph.D. thesis, Cranfield University, UK, 2004).

10. W.J. Poole, M. Militzer and F. Fazeli, “Microstructure Evolution in the HAZ of Girth Welds in Linepipe Steels for the Arctic,” *Proceedings of the 8th International Pipeline Conference*, Calgary, Alberta, Canada (27 September – 1 October 2010). (New York, NY: ASME, 2010).

11. G. Knauf and P. Hopkins, “The European Pipeline Research Group (EPRG) Guidelines on the Assessment of Defects in Transmission Pipeline Girth Welds,” *3R International – Rohre, Rohrleitungsbau, Rohrleitungstransport* 35 (10/11) (1996), 620-624.

12. R. Denys et al., “The European Pipeline Research Group (EPRG) Tier 2 Guidelines for the Assessment of Defects in Transmission Pipeline Girth Welds,” IPC2010-31640. *Proceedings of the 8th International Pipeline Conference*, Calgary, Alberta, Canada (27 September – 1 October 2010). (New York, NY: ASME, 2010).