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TECHNICAL CHALLENGES OF HEAVY WALL HFW PIPE PRODUCTION FOR BORD GÁIS ÉIREANN PIPELINE PROJECT

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ABSTRACT

The recently constructed Bord Gáis Éireann, Curraleigh West to Midleton pipeline runs due north from the Midleton compressor station near the city of Cork in Southern Ireland. The 47.5 km, 610mm outside diameter pipeline, comprises over 30 km of 9.5 mm and 17 km of 19.1 mm wall thickness L450MB (X65) grade pipe. The pipe for the project was produced by Corinth Pipeworks (CPW), at its state of the art HFW pipe mill at Thisvi, Greece and represents a first in terms of the quantity of 19.1 mm L450MB (X65) HFW pipe produced by the mill for a specific project.

The paper outlines the engineering approach adopted for the pipeline before describing in detail the production challenges faced by the pipe mill in successfully completing this demanding pipe order. Production of the 9.5 mm wall thickness pipe was not anticipated to present any particular difficulties. However, the principal concern associated with the manufacture of the 19.1 mm pipe was that the combination of wall thickness and strength level was toward the upper end of the commercially supplied wall thickness-strength combinations for HFW produced linepipe, particularly as the actual strength of the starting coil was well above the minimum specified level for L450MB (X65). In addition, to accommodate the demanding drop weight tear test (DWTT) toughness requirement the chemical composition of the 19.1 mm coil strip was above the permitted limits of the parent pipe standard EN 10208-2 [1] for the elements Cu & Ni, and the yield to tensile ratio was also above the 0.87 maximum level required by EN 10208-2 for L450MB (X65) grade pipe. Potential risks were therefore identified prior to production and mitigated by several methods detailed in the paper, including for example; increased initial production test frequency, close monitoring during pipe production, duplicate testing to verify mill results, identification of potential construction issues and weldability testing.

A summary of production experience including statistical data for the production of both 9.5 mm and 19.1 mm pipe is presented. Also covered are the results of a supplementary investigation which makes a further assessment of the influence of the welding and heat treatment cycles on the final pipe properties. The paper concludes by referring to the overall successful construction phase of the project.

INTRODUCTION

Bord Gáis Éireann was founded in 1976 to develop the natural gas industry in Southern Ireland following the discovery of natural gas off the south coast. It is a commercial state body operating in the energy sector and is majority owned by the Irish government, with 3.27% owned by the employees. The company employs just over 1,000 staff and is headquartered in Cork City, Ireland. Originally a gas transmission company, it took over the towns' gas companies in Dublin, Cork, Limerick and other urban centres during the 1980s. Since 1995, the gas market in Ireland has been gradually opened to competition, with full market opening down to residential level occurring in 2007.

Today, Bord Gáis Éireann is a leading energy provider, serving c. 640,000 gas users in 152 population centres in Ireland. It owns and operates 13,150km of gas pipelines, including two sub-sea interconnectors with Scotland from where Ireland gets over 93% of its gas supplies. Bord Gáis Éireann has both transmission pipeline and gas supply / distribution businesses in Northern Ireland. It is constructing a 445 MW gas-fired power station at Whitegate in Co. Cork, operates 218 MW of wind generation and is developing gas-fired peaking plants and wind farms in various locations throughout the country.

The recently constructed Curraleigh West to Midleton pipeline runs due north from the Midleton compressor station near the city of Cork to an above ground installation at Curraleigh West. The 47.5 km, 610mm outside diameter (OD) pipeline, comprises over 30 km of 9.5 mm and 17 km of 19.1 mm wall thickness L450MB (X65) grade pipe. The pipe for the project was produced by Corinth Pipeworks (CPW), at its state of the art high frequency welded (HFW) pipe mill at Thisvi, Greece and represents a first in terms of the quantity of 19.1 mm L450MB (X65) HFW pipe produced by the mill for a specific project. The purpose of this paper is to describe the approach taken to address the potential technical challenges associated & anticipated with the project pipe order and how BGE supported by MACAW Engineering worked together with CPW to ensure a successful outcome to the project.

PIPELINE ENGINEERING APPROACH

The pipeline design pressure is 85bar. The pipeline routing is shown in Figure 1 and Figure 2 below. The pipeline traverses two national roads, four regional roads and approximately forty local roads. There are four major river crossings (Blackwater, Bride, Araglin and Dungourney) and a further twelve water courses along the length of the pipeline. There were 112 way leaves along the route of the pipeline. Pipe of both 12 m & 18 m nominal length was utilised. Pipe was internally coated with epoxy flow coat. The external coating was predominantly three layer polyethylene although some pipe was coated with 3 layer polypropylene and concrete coating was also utilised to provide negative buoyancy for a small quantity of pipe.

Approximately one hundred and fifty 5D radius induction bends with angles of 45º, 22.5º & 11.25º were procured for the project. The induction bends were supplied by Mannesmann, Germany and were manufactured from SAWL pipe starting material of 20.5 mm nominal thickness for the heavy wall pipe and 11.0 mm nominal thickness for the light wall pipe, the increased thickness to allow for the torus factor and also anticipated thinning on the extrados.

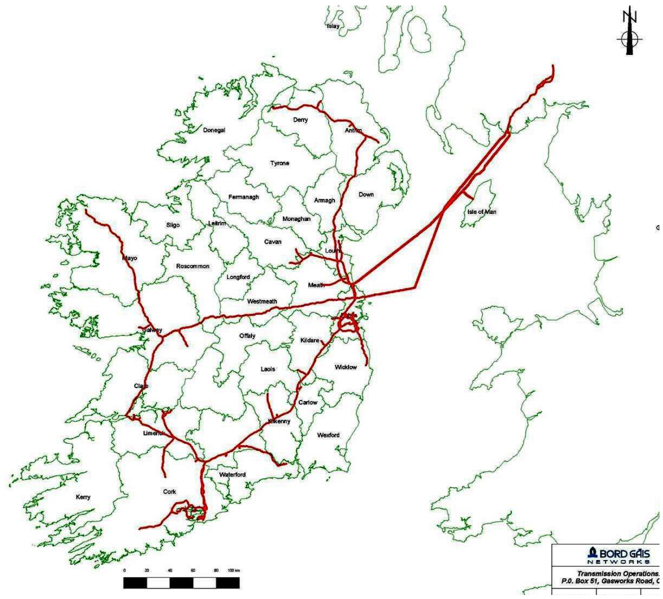


Figure 1: Bord Gáis Éireann transmission pipeline network

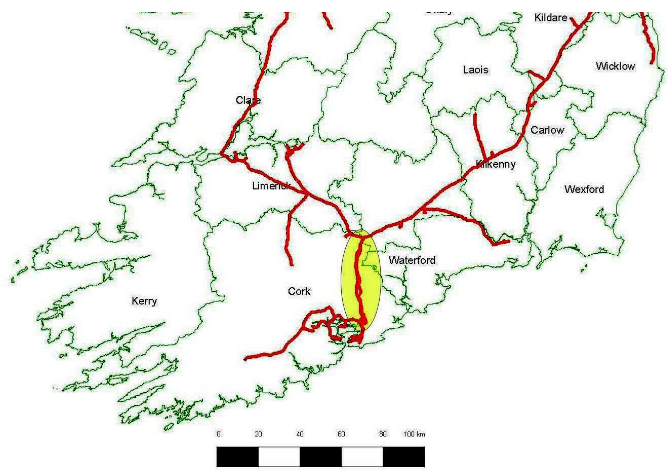


Figure 2: Regional map showing pipeline location

PIPE PRODUCTION

Corinth Pipeworks was selected to supply pipe for the project following a successful independent audit of its HFW pipe mill, initiated by Bord Gáis Éireann in 2007. The audit identified CPW as capable of producing 610 mm OD x 20 mm wall thickness pipe and of also producing grades up to X80. The audit report noted a reliable approach to quality and found associated QA/QC procedures consistent with expectations. There were no non conformances identified.

The CPW plant is located in the industrial area of Thisvi, in the prefecture of Viotia and is considered to be one of the most modern steel pipe manufacturing facilities in the world. Full operation of the four mills (HFW, submerged arc welded helical seam (SAWH), Coating and Lining) started in the 2001 / 2002 period. State-of-the-art production equipment is used to manufacture HFW and SAWH pipes to the highest standards for the Oil and Gas Industry. The HFW mill produces pipes from 219 mm to 660 mm OD (the widest product range in Europe), while the "two - step" technology SAWH mill produces pipes from 610 mm to 2540 mm OD. The in-house external and internal coating facilities have established Corinth Pipeworks as a one-stop-shop supplier of the Energy Industry.

Production of the 9.5 mm wall thickness pipe was not anticipated to present any particular difficulties. However, for the 19.1 mm pipe the combination of wall thickness and strength level was toward the upper end of the commercially supplied wall thickness-strength combinations for HFW produced linepipe. In fact in the event, the actual strength of the starting coil was well above the minimum specified level for L450MB (X65). In addition, the chemical composition of the coil strip was above the permitted limits of the pipe standard EN 10208-2 (the basis of the Bord Gáis Éireann pipe specification), for the elements Cu & Ni, and the yield to tensile ratio was anticipated to be up to 0.92 which is above the 0.87 maximum level required by EN 10208-2 for L450MB (X65) grade pipe. Potential risks were therefore identified prior to pipe production and these risks were mitigated by several methods as indicated below.

RISK MITIGATION MEASURES

Recommendations from the pipe mill audit were implemented for the order. These recommendations included:

- Full manufacturing procedure qualification (MPQ) undertaken at the start of production
- Additional production testing to verify weld line Charpy toughness properties.
- Duplicate testing using an independent test laboratory to confirm production test results generated at the EN 17025 accredited pipe mill laboratory.

In addition to the above measures, further precautions were taken as indicated below, primarily relating to the 19.1 mm pipe item.

- Potential impact of high Y/T ratio assessed for the project
- Close monitoring during pipe production
- Identification of potential construction issues
- Weldability testing

Further details relating to the above mitigation measures are discussed in subsequent sections of the paper.

Potential impact of high Y/T ratio

A technical assessment of the impact of high yield to tensile ratio 19.1 mm wall thickness HFW pipe on the design and fitness for purpose of the Curraleigh West to Midleton pipeline was undertaken at an early stage in the project. The findings of the assessment were as follows:

Expert opinion [2, 3] suggests that acceptable Y/T ratios based on round bar tests for pipe of the current wall thickness and grade could be as high as 0.90 if significant longitudinal strains are experienced, or 0.95 if longitudinal strains are less than 0.5%. The anticipated 0.92 Y/T ratio maximum for the CPW 19.1 mm HFW pipe based on flattened strap specimens, was expected to be approximately equivalent to a 0.95 Y/T ratio based on round bar tests. The 0.92 Y/T ratio maximum anticipated for the CPW 19.1 mm HFW pipe is within the 0.93 maximum limit specified by the internationally recognised and applied linepipe specification, API 5L. The CPW 19.1 mm HFW pipe was expected to have good ductility and toughness, conferring good defect tolerance and, combined with the pipe wall thickness, a high damage tolerance. The maximum equivalent stress calculated for the maximum depth of cover, temperature range and assumed construction settlement for the 19.1 mm wall thickness sections of the pipeline was estimated to be 249.6 MPa. The safety factor calculated against the tensile strength at the maximum estimated equivalent stress in the 610 mm dia. x 19.1 mm WT L450 pipe was 1.96 at a Y/T ratio of 0.92. This safety factor is well above the limiting safety factor of 1.49 on tensile strength at a maximum equivalent stress of 0.8 SMYS and a Y/T ratio of 0.84 for the specified material properties, and confirms that the Y/T ratio requirement could be based on stress based design. It was therefore concluded that, subject to the recommendations below, the use of 19.1 mm HFW pipe with a maximum Y/T ratio of 0.92 would be acceptable for the Curraleigh West to Midleton pipeline, with no impact on the pipeline design process or fitness for purpose.

Recommendations from the Y/T study included the following points:

- The need to monitor actual Y/T ratios during MPQ & production testing of the 19.1 mm wall thickness HFW pipe to verify that the 0.92 max limit (based on flattened strap specimens) was not exceeded during production.

- To include transverse round bar tensile testing in the scope of the intended duplicate testing, to confirm that the EPRG recommended limit of 0.95 Y/T based on round bar specimens has not been exceeded. To also include longitudinal flattened strap tensile testing to validate assumptions made in the project specific stress analysis undertaken in the assessment. To select pipe for duplicate testing based on the highest Y/T values occurring in either pipe or coil product form.

- Care should be taken when qualifying welding procedures to ensure that yield strength overmatching of the weld metal compared to the pipe is obtained.

Close monitoring during pipe production

Further to the use of experienced third party inspection during pipe production, additional qualified metallurgical support was engaged by Bord Gáis Éireann in the pipe mill specifically during the bulk of the 19.1 mm wall thickness pipe production in order to ensure that any issues arising could be identified and resolved in an expedient manner. Activities undertaken included the following:

- Production monitoring
- Qualification & production testing witnessing
- Qualification & duplicate test pipe selection
- Selection of casts / heats for weldability test
- Preparation of duplicate testing schedule
- Laboratory testing and reporting procedure review
- Additional test requirements
- Support to inspection personnel

PRODUCTION SUMMARY

General

Pipe manufacturing took place during the Autumn of 2008. The steel coils for the order were sourced from an approved European coil producer. Coils were approximately 35 tonnes in weight. The number of pipes produced per coil ranged from seven to twenty one, dependant on wall thickness (i.e. 9.5 mm or 19.1 mm) and nominal pipe length (i.e. 12 m and 18 m). Heat treatment for both pipe thicknesses was applied on line and involved three sequential steps; localized annealing of the weld seam, water cooling, and a second localized (normalizing) heating cycle. This heat treatment cycle is commonly referred to as “double weld seam normalizing”. The actual annealing & normalizing temperatures applied were somewhat higher for the heavier wall thickness pipe in order to achieve the required through thickness austenitizing of the weld seam region. For the 19.1 mm thickness pipe the combination of heavy wall thickness and actual coil strength level led to an increased number of interruptions and a slower than anticipated production speed. The latter was mainly attributed to the edge miller operation and the fact that the actual exit width must remain within very strict tolerances to achieve a stable forming and welding operation and therefore enhanced finished product quality. Reject rates (on a coil weight basis) were 2.9% for the 9.5 mm and 11.5% for the 19.1 mm. The higher rejection rate for the 19.1 mm is attributed to the shorter production runs coupled with the on line double weld seam normalizing heat treatment cycle utilized.

Production data summary

Typical pipe chemical composition for the project is shown in Table 1. The 9.5 mm pipe is a 0.05 C, 1.5 Mn, low sulphur steel microalloyed with Nb and with a low carbon equivalent value (CEV) i.e. 0.31. The 19.1 mm pipe has a similar composition but with the addition of 0.3 Cu & 0.36 Ni to accommodate the demanding DWTT toughness requirement. As a consequence it has a higher CEV (0.36).

Pipe	C %	Si %	Mn %	P %	S %	Cr %	Ni %	Cu %
9,5mm	0,05	0,20	1,51	0,014	0,001	0,01	0,02	0,01
19,1mm	0,05	0,21	1,56	0,015	0,002	0,02	0,35	0,27
Spec max	0,16	0,45	1,60	0,025	0,005	0,30	0,30	0,25

Pipe	Nb %	V %	Al %	N %	Ti %	Pcm %	IIW %
9,5mm	0,045	0,001	0,028	0,002	0,017	0,14	0,31
19,1mm	0,042	0,001	0,027	0,003	0,013	0,15	0,36
Spec max	0,05	0,10	0,015-0,06	0,012	0,06	-	0,40

Table 1: Pipe chemical composition

Production test results are presented in Figures 3 to 13. Pipe body tensile test results are show in Figures 3 & 4.

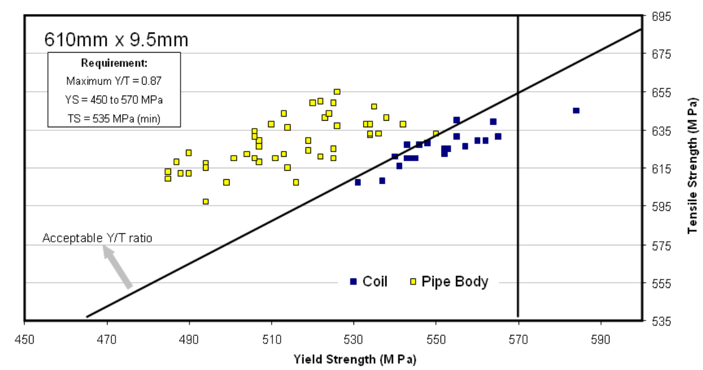


Figure 3: Tensile results (9.5 mm pipe)

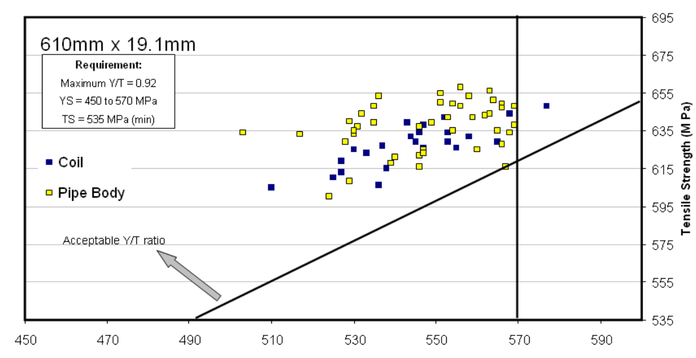


Figure 4: Tensile results (19.1 mm pipe)

Transverse tensile properties for the 9.5 mm pipe ranged from 460 to 550 MPa (Re) and 591 to 655 MPa (Rm) with a maximum Y/T ratio of 0.87. Transverse tensile properties for the 19.1 mm pipe ranged from 503 to 569 MPa (Re) and 600 to 670 MPa (Rm) with a maximum Y/T ratio of 0.92. Longitudinal tensile testing was carried out for information purposes only, as part of the manufacturing procedure qualification tests. For the 9.5 mm pipe results measured were 551, 556 MPa (Re) and 607, 610 MPa (Rm) with a maximum Y/T ratio of 0.92. For the 19.1 mm pipe results measured were 569, 593, 622 MPa (Re) and 610, 648, 685 MPa (Rm) with a maximum Y/T ratio of 0.93.

Transverse weld tensile test results are shown in Figure 5. Results comfortably exceed the minimum requirement with values for the 19.1 mm pipe generally achieving 600MPa and above.

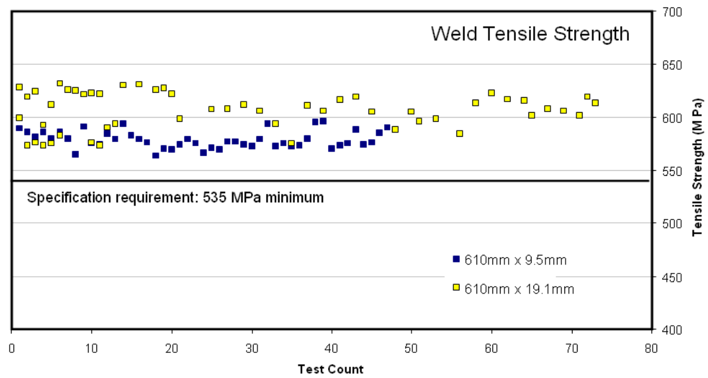


Figure 5: Weld tensile test results (9.5 mm & 19.1 mm pipe)

From the results of tensile testing it is evident that the strength levels being achieved were substantially higher than the minimum specified levels. This was particularly notable for the 19.1 mm pipe for which yield strength exceeded SMYS by a minimum of approximately 50 MPa (tranverse test) and approximately 100MPa (longitudinal test), i.e. in the latter case achieving an X80 grade strength level. Yield to tensile ratio for the 19.1 mm pipe was as high as had been anticipated (i.e. up to 0.92 for transverse test) and for longitudinal test was high for both the 9.5 mm & 19.1 mm wall thickness pipe (i.e. 0.92 & 0.93 respectively).

Pipe body and weld seam Charpy results are shown in Figures 6 & 7. Pipe body toughness is very good with minimum values of around 170 J at -10°C and mean values well in excess of 200J for both 9.5 mm & 19.1 mm pipe. Weld seam Charpy toughness, whilst lower than pipe body values, is also generally good with relatively low occurrence of values below 80 J and in all cases the minimum requirement of the specification (i.e. 40 J average /30 J individual) was achieved.

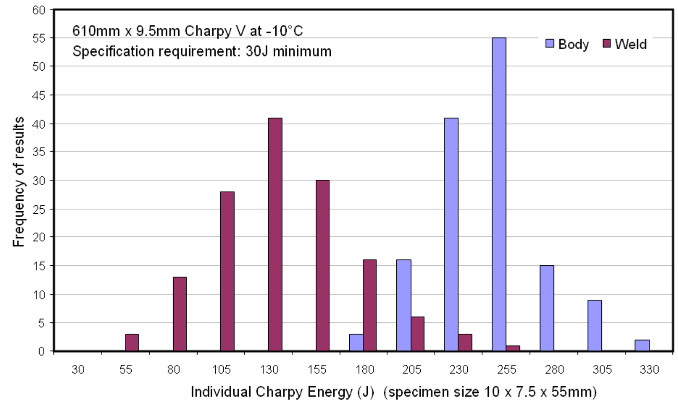


Figure 6: Charpy test results (9.5 mm pipe)

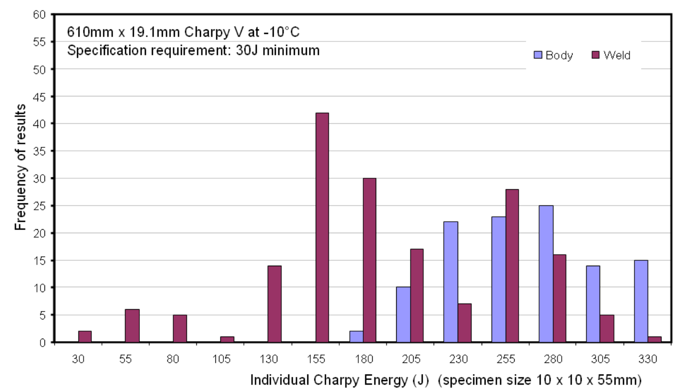


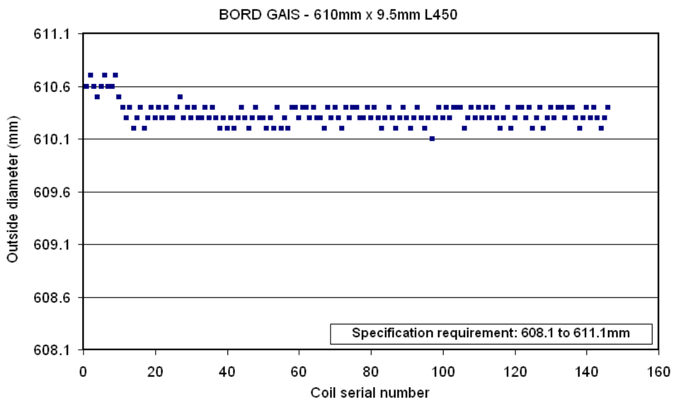
Figure 7: Charpy test results (19.1 mm pipe)

Drop weight tear test results (see Figure 8 below) again met the specification requirement, with the 9.5 mm pipe achieving ≥ 95% shear area in all tests.

Shear area	No. of DWTT specimen pairs achieving indicated % Shear area (average)	
	610 mm x 9.5 mm	610 mm x 19.1 mm
≥ 95%	47	19
≥ 90 - 95%	0	9
≥ 85 - 90%	0	13
< 85%	0	0
Total no. of specimen pairs	47	41
Minimum Shear area requirement at 0°C = 85% (average)		

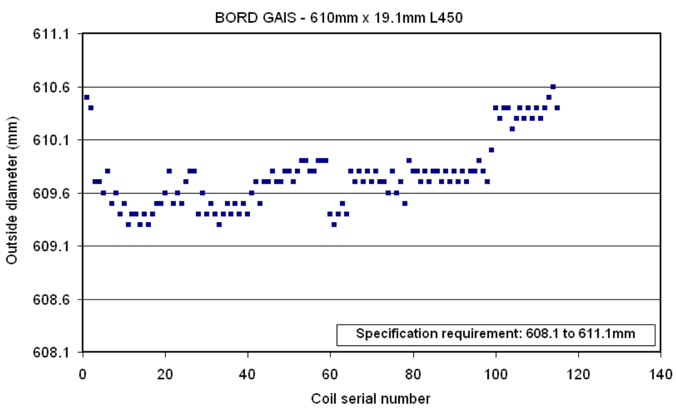
Figure 8: DWTT results (9.5 mm & 19.1 mm pipe)

Dimensional tolerances are presented in Figures 9 to 12. The range in outside diameter was 0.7 mm for the 9.5 mm wall thickness pipe and 1.5 mm for the 19.1 mm wall thickness pipe. This compares with the specification requirement of 3 mm maximum. Out of roundness was in all cases less than 1 mm compared with a specification requirement of 6 mm maximum for the pipe body and 3 mm maximum for the pipe ends. Both outside diameter and out of roundness results can therefore be seen to be well within the specification tolerance limits.



Note: y-axis boundary correspond to acceptance criteria

Figure 9: Pipe body Diameter tolerance (9.5 mm pipe)



Note: y-axis boundary correspond to acceptance criteria

Figure 10: Pipe body Diameter tolerance (19.1 mm pipe)

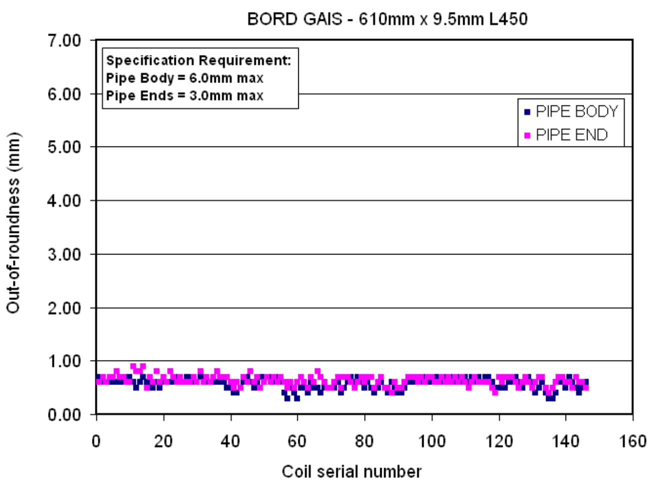


Figure 11: Out of Roundness (9.5 mm pipe)

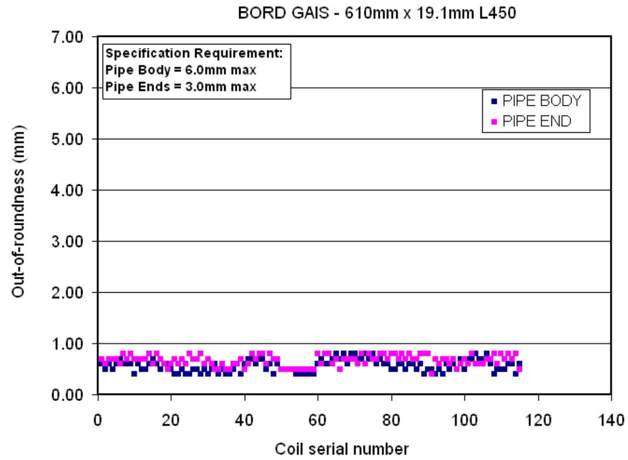


Figure 12: Out of Roundness (19.1 mm pipe)

Finally, examples of weld seam microsections taken during production of the 19.1 mm pipe are included in Figure 13 and Figure 14. Through wall penetration of the on line heat treatment was confirmed on all production test specimens.

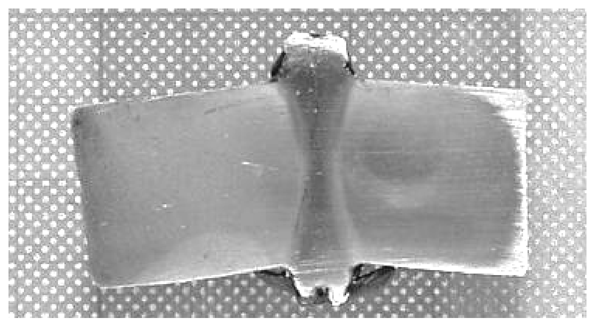


Figure 13: Pipe in as welded condition

Figure 14: Pipe after double normalizing with intermediate cooling

DUPLICATE TESTING

Duplicate testing was undertaken at the Exova (formerly Bodycote) Teesside (UK) and Emmen (Holland) test laboratories on both the 9.5 mm and 19.1 mm wall thickness L450MB (X65) pipe produced for the project. The purpose of the testing was to confirm the accuracy of Corinth Pipeworks internal test house procedures. The tests were performed on the same pipe as that selected for manufacturing procedure qualification testing in the pipe mill. Duplicate testing included, tensile, Charpy and DWTT tests on parent material, ring flattening tests, transweld tensile, weld seam Charpy, macro / hardness surveys and microstructural examination.

When comparing the results of the duplicate tests with the pipe mill qualification tests conducted on the same pipe a degree of scatter was evident as may be expected. The results were nevertheless generally similar. There was some tendency for slightly lower yield strength and slightly higher tensile strength in the duplicate tests. There was also limited occurrence of higher parent hardness and lower weld seam Charpy toughness for some of the duplicate tests. It was however concluded that duplicate testing produced results that were generally comparable with results recorded by the pipe mill at the time of pipe production and that although some differences were observed, the accuracy of the Corinth Pipeworks internal test house procedures at the Thisvi pipe mill was broadly confirmed.

WELD MICROSTRUCTURE INVESTIGATION

Micro-alloyed low carbon hot-strip steels gain a fine ferritic microstructure after controlled rolling due to a twofold action of the micro-alloying addition. These are grain refinement (Nb, Ti) and precipitation hardening (V, Nb, Ti). In this case, Nb initially refines austenite within the austenite recrystallization region (1050 - 900^{o}C) and later, strengthens ferrite by precipitation hardening performed by fine Nb (C, N) precipitates at temperatures below 800^{o}C. A thorough investigation has been performed on the influence of welding and post-weld heat treatment (PWHT) cycles on the weld zone and HAZ microstructures for the chosen welded hot-strip microalloyed HSLA steel.

Figure 15 shows the microstructure of the weld zone and HAZ in two positions of the welded pipe, top and middle respectively. Acicular ferrite morphology is found in the weld zone in contrast to the polygonal and / or globular ferrite type present in the HAZ. The forge welding procedure introduces a large amount of dislocations in the weld zone. This explains why ferrite grain boundaries in the weld zone are difficult to distinguish by comparison with the HAZ where they are clearly visible. The ferrite in the “as-welded” condition in the weld zone has a grain size between 2.7 μm in the central part of the specimen thickness and 4.2 μm near the outer surface. In the HAZ the grain sizes are very close to those in the weld zone, being 2.4 μm and 4 μm in the centre and outer surface regions respectively.

“Double normalising with intermediate cooling” with heating applied from top of the pipe alters the microstructure, both in the weld zone and HAZ. Traces of a harder second phase, pearlite, are now found in the PWHT microstructure due to the final air cooling step. The volume fraction of pearlite is however small. The weld zone is affected most by PWHT. In the outer surface region of the weld zone, the ferrite grain size is doubled in size (i.e. 8.6 μm) and in the central portion of the pipe thickness the ferrite grain size is tripled (i.e. 9 μm). Ferrite growth in the HAZ is less extensive; the average ferrite grain size is 5 μm in the central portion of the pipe thickness and 4.7 μm in the outer surface region. The fine ferritic PWHT microstructure with pearlite traces justifies the assumption of keeping adequate combinations of strength, toughness and yield / tensile ratio.

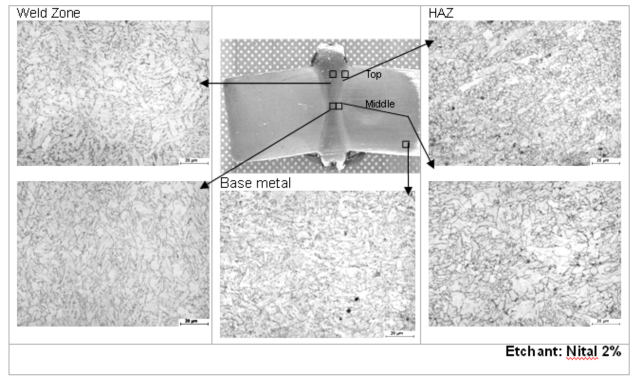


Figure 15: Weld, HAZ and base metal “as-welded” microstructures

Figure 16 shows the microstructure following PWHT. The HAZ is now more extended, with the ferrite growth and its morphology becoming more polygonal with entrapped smaller sized globular grains. For all pipes examined, full coverage and penetration of PWHT was found; this is an essential requirement, particularly for thick walled HFW pipe welding.

Due to the relatively fine, mainly ferritic, microstructure occurring all transweld tensile test results of the weld in the PWHT condition proved to be well in excess of 550 MPa.

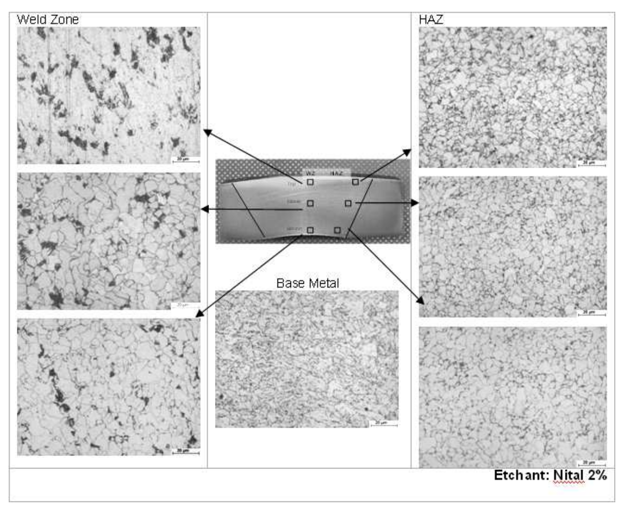


Figure 16: Weld, HAZ and base metal PWHT microstructures

WELDABILITY TESTING

The requirement for full scale weldability testing is considered an important element of the Bord Gáis Éireann pipe specification. In view of the high Cu & Ni contents of the 19.1 mm wall thickness HFW pipe, which as previously mentioned exceeded the maximum permitted values in the pipe standard EN 10208-2, weldability testing in this instance was considered to be of particular merit to provide an early opportunity to identify any potential issues that may arise during weld procedure qualification testing. Specifically, weldability testing would confirm or otherwise whether normal preheat levels would be adequate to ensure avoidance of cracking, and also whether or not maximum HAZ hardness and fusion line Charpy toughness requirements could be achieved. Pipe selection for the tests was made on the basis of casts / heats having highest carbon equivalent values and having Cu & Ni contents at the upper end of the range supplied.

The full scale weldability test closely simulates site welding, utilizing full pipe lengths, a cellulosic stove pipe SMAW weld procedure and incorporating a lift and lower operation following completion of the root pass. The test is usually performed without preheat to provide a safety margin when compared to pipeline construction welding. Weldability tests were carried out on both 9.5 mm & 19.1 mm pipe. In the latter case a second test was undertaken using a composite procedure involving a cellulosic stove pipe root and hot pass, followed by low hydrogen vertical down SMAW filling and capping passes. The purpose of this latter test was to evaluate a procedure designed to achieve weld metal strength overmatching compared to the actual parent pipe strength which in both transverse and longitudinal directions was significantly higher than the specified minimum requirement.

Each weld was subjected to NDT (i.e. root MPI & X radiography), transverse tensile testing, Charpy testing (i.e. weld metal and fusion line at -10 ºC), microsection examination (minimum of 16 specimens) and macro / hardness survey (6 specimens). A summary of the results of the weldability tests is given in Table 2.

For all three weldability tests no cracking was observed and the transweld tensile, Charpy and HAZ hardness results were all acceptable. The 9.5 mm and 19.1 mm pipe therefore passed the weldability tests. However, some interesting observations arose from the weldability tests. Firstly, several out-of-specification parent hardness values were recorded for both 9.5 mm and 19.1 mm pipe (i.e. up to 268 HV maximum in the parent material compared with 250 HV maximum specified) reflecting the high strength of the parent pipe. This was flagged up as a potential problem for weld procedure qualification testing but in the event this was found to be a relatively localized occurrence and no subsequent problems were encountered. It should be noted that out-of-specification parent hardness values did not arise during pipe production. For the composite procedure the weld metal hardness in the cap region (i.e. 290 HV maximum exceeded the 275 HV limit of the BGE construction welding specification. This is not unexpected due to the use of an X80 (L555MB) welding consumable (i.e. E10018-G) for this test. The results did meet the 300 HV maximum weld metal hardness limit for X80 (L555MB) in British standard BS 4515-1 which recognizes the higher weld metal hardness levels that can occur when attempting to overmatch this grade of material. A relaxation of the 275 HV limit would have been required had this welding procedure been adopted for pipeline construction.

Test Type	Weldability Test		
	9.5 mm Cellulosic	19.1 mm Cellulosic	19.1 mm Composite (Cellulosic / LHVD)
Transweld tensile			
UTS (MPa)	564, 613, 593, 594	586, 589, 592, 605	682*, 650, 675*, 661
Spec requirement	535 MPa min		
▪ Failure position	All in weld	All in weld	Weld and parent*
Charpy Energy J (at -10 ºC)			
▪ Weld Metal	57 – 72 J	62 – 86 J	62 – 86 J
▪ Fusion Line	94 – 257 J	145 – 299 J	145 – 299 J
Spec requirement	40 / 30 J min (average / individual.)		
Hardness (HV10)			
- Cap HAZ	227 max	274 max	294 max
Spec requirement	325 max (cellulosic) 350 max (low hydrogen)		
- Cap weld metal	210 max	240 max	290 max
Spec requirement	275 max		
- Parent	200 - 262	200 – 268	200 - 258
Spec requirement	250 max		
Microsections	No cracks	No cracks	No cracks

Note: Charpy specimen size: 10 x 10mm for 19.1mm pipe and 10 x 7.5mm for 9.5mm pipe

Table 2: Weldability test results

The high strength of the L450MB (X65) 19.1 mm pipe, particularly in the axial direction was confirmed by the results of the transweld tensile tests on the composite weldability test, where two out of four specimens broke in weld despite the use of an L555MB (X80) LHVD welding consumable (i.e. E10018 G). For the two cellulosic procedure weldability tests, all the trans-weld tensile specimens broke in the weld.

Although details are not included in this paper it should be noted that weldability tests were also successfully carried out on representative light and heavy wall induction bends supplied to the project.

POTENTIAL CONSTRUCTION ISSUES

Potential construction welding issues were identified, arising from the pipe production data for the 610 mm x 19.1 mm L450MB (X65) HFW pipe. Two features highlighted are discussed below:

Pipe tensile properties

The 9.5 mm pipe has typical transverse yield strength for L450 MB grade pipe. It was therefore considered that a conventional SMAW cellulosic welding procedure using E8010 strength electrodes would be suitable although during weld procedure qualification, transverse weld tensile test specimen fracture may occur in the weld due to the high longitudinal tensile strength of the pipe.

The 19.1 mm pipe has high transverse yield strength for L450 MB grade pipe i.e. 503 to 569 MPa, compared with a specified minimum of 450 MPa. Although the results are within the permitted maximum value, when combined with the high longitudinal yield strength of 593 MPa min there was considered a greater possibility that weld metal overmatching of actual strength rather than of specified minimum strength may not be achieved using conventional SMAW cellulosic procedures using E8010 strength electrodes.

The use of mechanised GMAW welding for mainline welding with appropriate filler wire selection would leave only the special fabrication and tie-in welds in the 19.1 mm thickness pipe where a weld metal overmatching issue may arise.

If actual pipe strength overmatching was to be required, a composite (i.e. cellulosic / low hydrogen vertical down) SMAW procedure was considered preferable to the use of higher strength E9010 cellulosic electrodes due to the increased risk of weld metal hydrogen cracking when welding heavier wall thickness pipe with the latter consumable.

Overmatching of actual pipe properties is not mandatory however and in view of the relatively low operating stress combined with the inherently higher tolerance to external loading of the 19.1 mm pipe, it was felt that the recommendation could be relaxed particularly because a separate assessment had confirmed that there was no particular ground movement issues for the pipeline. It was nevertheless considered beneficial to undertake a second weldability test on the 19.1 mm pipe using a composite SMAW procedure as described in the previous section of the paper in order to provide additional data.

Pipe chemical composition

A need to review welding procedure specifications and associated welding procedure qualification records of the project sub contractors welding free issue pipe pups to fittings was identified in relation to both tensile properties and pipe chemical composition considerations for the 19.1 mm pipe.

PIPELINE CONSTRUCTION PHASE

Pipeline construction occurred during the Spring and Summer of 2009. The construction contractor was SICIM Roadbridge. Mainline welding was undertaken using the mechanized GMAW process. Construction progressed well with no major issues arising, the project benefitting from the excellent pipe dimensional tolerances referred to earlier in the paper. The average construction rate achieved was approximately 50 welds per day, equivalent to just under one kilometer per day. The overall weld repair rate was around 3%. A selection of photographs taken during pipeline construction is given in Figures 17 to 20. The photographs include views of the following: a section of the pipeline prior to lower & lay, the mainline welding spread, mechanized GMAW girth welding, and cold field bending in operation. The pipeline was commissioned in Autumn 2009.

Figure 17: Curraleigh West to Midleton Pipeline – General view

Figure 18: Mainline welding spread

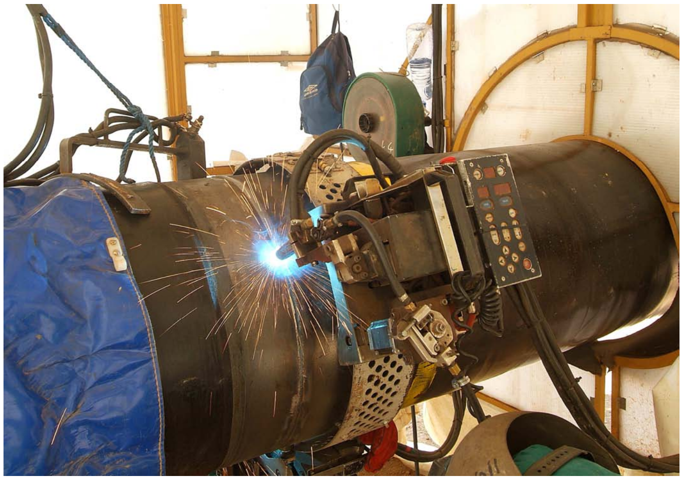


Figure 19: Mechanised pipeline girth welding

Figure 20: Cold bending

CONCLUDING REMARKS

The Bord Gáis Éireann Curraleigh West to Midleton pipeline in Southern Ireland, requiring 17km of 19.1 mm wall thickness L450MB (X65) HFW, pipe presented several technical challenges which have been described in the paper.

The combination of wall thickness and strength level was toward the upper end of that commercially available for HFW pipe, particularly as the actual strength of the starting coil was well above the minimum specified level for L450MB (X65). In addition, the chemical composition of the coil strip was above the permitted limits of the parent pipe standard EN 10208-2 for the elements Cu & Ni, and the pipe yield to tensile ratio of up to 0.92 was above the 0.87 maximum level requirement for L450MB (X65) grade pipe in the EN 10208-2 standard.

As a consequence Bord Gáis Éireann implemented various measures in order to mitigate risk to the project, including:

- Manufacturing procedure qualification (MPQ) undertaken at the start of production
- Additional production testing to verify weld line Charpy toughness properties
- Close monitoring during pipe production
- Duplicate testing using an independent test laboratory to confirm production test results
- Assessment of potential impact of high Y/T ratio for the project
- Identification of potential construction issues
- Weldability testing

The results of the above assessments and testing have been described in the paper. Corinth Pipeworks with its state of the art HFW pipe mill in Thisvi, Greece faced and successfully overcame the production challenges which included reduced production speed and an increased initial reject rate. Dimensional & mechanical property statistics from the production have been presented and were generally well in excess of the specification minimum requirements. Duplicate testing broadly confirmed the results generated by the pipe mill. Full scale weldability testing confirmed that both 9.5 mm & 19.1 mm pipe could be welded in the field using normal cellulosic welding procedures & preheat levels. The Y/T assessment confirmed that 19.1 mm wall thickness pipe with a maximum Y/T ratio of 0.92 would have no impact on the pipeline design process or fitness for purpose of the pipeline. Subsequent pipeline construction was completed in 2009 with no major issues arising. A key element to the overall success of the project was the close professional working relationship established between Bord Gáis Éireann and CPW which was underpinned by good communications and a strong commitment to succeed from both parties.

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