Proceedings of the 8th International Pipeline Conference
IPC2010
September 27-October 1, 2010, Calgary, Alberta, Canada

IPC2010-31252

MANUFACTURING OF 25MM HEAVY-WALL LINEPIPE USING THE HIGH FREQUENCY INDUCTION (HFI) WELDING TECHNIQUE, A CHALLENGE FOR A PIPE MANUFACTURER

Athanasios S. Tazedakis, Ph.D.
Corinth Pipeworks HFI Mill Director
Thisvi Plant
Vi.Pe Thisvis, Viotia, Greece

Nikolaos G. Voudouris, Ph.D.
Corinth Pipeworks Quality Control Director
Thisvi Plant
Vi.Pe Thisvis, Viotia, Greece

Mike Musslewhite
CPW America
Vice President Pipeline Projects
Houston TX 14800,United States

1. ABSTRACT

The current thickness limit of the HFI technique is about 20,6mm for grades up to X80. It is mainly governed by the necessary forming load, the coil edge formability and above all the optimisation of the power/heat input requirements on the weld seam area. The availability of hot rolled coils in thicknesses up to 25mm has made possible the exploitation of the HFI limits to such thicknesses. Following the successful industrial HFI welding production of 609,6mm (24”) x 25mm thick wall pipes at the CPW-Thisvi mill, the current paper deals with the development of the process regarding forming, welding, process automation and NDE inspection techniques for thicknesses up to 25mm. The latter made possible the broadening of the HFI process limits, currently for grades up to X60. Details of the technology used are described along with the investigation of the influence of welding and post-weld heat treatment (PWHT) cycles on the microstructure of the welding zone (WZ) and heat affected zone (HAZ) of the hot-strip micro-alloyed high strength low alloyed (HSLA) steel chosen. Mechanical testing of the pipe body and weld seam was used to characterise their performance. The dimensional tolerances of the pipe products are also described.

Results of the study showed properties which were uniform and satisfied API 5L requirements. The above research demonstrates that the HFI technique has a clear potential to provide the energy market with lower cost-options for the construction of heavy wall pipes.

Keywords: HFI pipe production, micro-alloyed steel, thick gauge pipes, high grade pipes.

2. INTRODUCTION

High Frequency Inductive (HFI) welding, a highly productive and consistent industrial welding process, is a commonly used technique in the production of longitudinally welded pipes from hot-rolled strip. The offshore sector has special requirements that are fulfilled via the use of high quality grades of steel with large pipe wall thicknesses. In this sector, HFI pipes are increasingly coming into use as an alternative to SAW and seamless pipes. Induction welding of pipes with increased wall thickness presents manufacturers with new challenges regarding production rates and quality in order to guarantee suitable performance during construction and service.

This paper reports the studies undertaken to expand HFI process limits from 20,6mm to 25mm for high grade applications (up to X60).

3. INDUSTRIAL HFI WELDING APPLICATION FOR MICROALLOYED 25MM STEEL PIPES

3.1 Raw material selection

Challenging operating conditions have resulted in increased dimensional and material requirements for linepipe [1-4]. Weld zone (WZ) and heat affected zone (HAZ) properties are significantly important. Micro-alloyed steels enable the achievement of satisfactory mechanical properties both in the WZ and HAZ due to ferrite grain refinement during welding and annealing and by their inherent weldability as a result of their low carbon content [1,5]. The physical metallurgical mechanisms behind this can be found in the role of the micro-alloying elements, such as Niobium (Nb), Vanadium (V) and Titanium (Ti) in refining austenite during solidification after welding (Nb, Ti) and strengthening ferrite with precipitation hardening (Nb, V, Ti).

Table 1 shows the chemical composition and the mechanical properties of the hot rolled steel selected for this study.

3.2 Pipe Forming and Welding

The CPW 26” HFI mill (outer diameter up to 660,4mm) is currently the largest-diameter HFI Pipe plant in the world using the cage roll forming method. It is considered to be the most effective forming technique for higher strength and larger diameters line pipe products (the general layout of the forming section is shown in Figure 1).

The theoretical analysis of the continuous roll forming mill is extremely complex due to the three dimensional deformation which every part of the steel is subjected [6]. A finite element model was developed in co-operation with SMS MEER in order to set the optimal parameters prior to production, thus setting-up optimized product forming based both on experience and actual stress measurements/calculations (see Figure 2). Modelling results were taken into consideration for the weld conditions and properties and also the pipe body properties. It was also used to prevent excessive forming loads at the various forming stages.

Considering that at elevated temperatures, steel is paramagnetic and its electric conductivity drops significantly, welding of thicker walled pipes is much more difficult to perform, as problems related to uniformly distributing the needed heat for the welding thermal pattern arise. As a result of the non uniform heat distribution in the through thickness direction mainly identified in medium and thick-wall tubes, the HAZ has an hourglass shape , i.e. the corners are heated more than the centre of the pipe walls (see Figure 3) [7, 8]. The less heated centre limits the maximum weld speed, even if the forming components of the mill have additional capacity and the welding power supplies have additional power. Choosing proper welding parameters for thick walled pipes becomes both a crucial and challenging job.

The main welding parameters utilized for the welding of the 25mm material are described in Table 2. Vee length, vee angle and induction coil positioning also have a very significant role in avoiding deterioration of the weld quality and particularly edge overheating. Although someone can explain in depth each of the above parameters by discussing their influence on the product quality and integrity, it is reasonable to point out that in most cases the combination of these parameters is more important than their individual values.

The length of the heated area both at the outer and inner surface as well as the critical mid-wall thickness is presented in Table 3 for a number of wall thicknesses (24” pipe OD, API Grade X60). It can be observed that the parameter combination utilized for the 25mm results in a sufficiently wide centre width without a significant increase of the centre/outer width ratio as can also be observed in Figure 3.

Taking into account the higher power level that has to be employed to compensate for the colder center and therefore avoid problems related to cold weld conditions, the weld profile obtained can mainly be attributed to:

- the appropriate forming parameters which minimize strip corners overheating and
- the lower frequency operation enabled by the development of transistor technology which ensures a more uniform heat profile at the edge of the strip material due to the more favorable temperature differential [7,9].

3.3 Heat Treatment

During welding, the microstructure of the steel on the bond line transforms to austenite. The rapid heat removal which occurs after welding due to the cold metal surrounding the weld results in the local formation of acicular plate-like ferritic phases of reduced toughness (Figure 4). The recovery of the weld properties was obtained by a post welding normalizing heat treatment of the weld and HAZ. In the production of heavy-wall HFW line pipe, normalizing was performed by a series of twenty-one externally positioned induction heating units. The soaking time above A_{c3} is limited by the welding speed, being approximately 80secs. In order to obtain through thickness austenitizing of the 25mm weld cross-section it was necessary to target a higher than usual normalising temperature of 1180^{o}C, as measured by optical pyrometer on the weld outside surface. The metallographic examination of 25mm weld cross sections (Figure 4) showed that the selected heat treatment procedure resulted in a fully refined ferrite -pearlite microstructure. The average grain size in the normalized weld zone, as measured with image analysis technique, was approximately 9μm for both the outside and inner positions. The grain size uniformity obtained is satisfactory considering that the weld seam area is induction heated from the outside surface. Due to the nature of induction heating the eddy currents producing the heat are more intense on the outer surface, while heat flows to the interior of the weld cross section by conduction [8]. The above mechanism may result in the OD surface being more susceptible to grain coarsening. The microstructural uniformity obtained after post weld normalizing may be also depicted by the HV10 hardness mapping of the weld seam cross section (see Figure 5). Weld hardness levels ranged between 170-185 HV10 over the entire thickness, slightly softer than the base material (200-215 HV10) due to the normalizing process. The impedance of grain coarsening can be explained by taking into account the solubility of the NbN and TIN precipitates, which are two of the main microalloying precipitates for this steel and remain undissolved even at equilibrium conditions for this temperature [10]. These precipitates help to inhibit austenite grain coarsening by pinning austenite grain boundaries [11]. Moreover, given the short soaking time, it may be assumed that a fraction of NbC remains also undissolved assisting the above mechanism. To additionally validate the absence of ferrite grain coarsening as a result of the heat treatment, several specimens of Nb-Ti and Nb-V-Ti alloyed steels in grades between X42 and X70 were reheated in a laboratory furnace at 1180°C for 2 minutes and subsequently cooled in air (table 4). Small specimens (5cmx5cmx2cm) were employed in order to simulate as close as possible thermal equilibrium. The specimens were subsequently polished, etched with nital and examined under the metallographic microscope. All samples showed equiaxed ferrite grains with no significant coarsening, indicating the suitability of the examined steel qualities for the specific heat treatment cycle.

4. PIPE INSPECTION AND TESTING

4.1 Design of heavy wall weld seam ultrasonic inspection for HFI pipes

Heavy wall ultrasonic pipe line inspection constitutes a technical quality assurance challenge, especially in respect to the reliable detection and evaluation of mid-wall positioned discontinuities. The inspection of mid-wall defects in CPW mill is performed by four dedicated transmitter-receiver probes operating in indirect pitch-catch (tandem) configuration. Combined with two dedicated pulse-echo probe pairs for the OD and ID weld seam areas respectively, CPW's ultrasonic equipment is well equipped for continuous inspection of heavy wall HFW pipe up to 25mm. In the current production of 25mm line pipe, through-thickness coverage was demonstrated by the detection (under dynamic conditions) of longitudinal notch and hole artificial reflectors positioned at various depths along the weld seam cross-section as presented in Figure 6. More specifically, an ultrasonic calibration block with artificial defects as presented in Figure 6 was EDM machined on a 25mm heavy wall pipe. Dedicated pulse-echo and transmitter-receiver probes in tandem configuration were used to scan the entire thickness at *uniform* sensitivity levels. The results confirmed the efficiency of the automated ultrasonic inspection to reliably inspect the entire weld seam at API 5L or higher sensitivity levels.

4.2 Heavy Wall Pipe Compliance to API5L requirements

All produced 609,6mm (24'') x 25mm X60 pipes were successfully subjected to the following quality control inspections as per API 5L:

- Hydrostatic testing at 90% of SMYS
- Ultrasonic inspection of weld seam for longitudinal defects at N5 sensitivity level
- Ultrasonic inspection of parent material (full body testing) for laminar defects
- Visual and dimensional inspection
- Flattening test at coil start-end locations

Dimensional data for the produced pipes are depicted in Table 5. The mechanical properties of the produced pipes also fulfilled the requirements of API 5L specification, as presented in Table 6, in regard to tensile, toughness (Charpy-V) and hardness.

5. CONCLUSIONS

The following conclusions can be drawn from the industrial research described above:

- The limits of the industrial HFI welding for high pressure pipelines have been expanded to 25mm following the successful production of 609,6mm (24") X 25mm X60 micro-alloyed HSLA steels.
- The advantages of micro-alloyed steels for highly controlled PWHT cycles were evaluated.
- New forming and welding parameters were set for welding micro-alloyed thick gauge steel pipes using FEM analysis for process optimisation before actual pipe production.
- Specifically designed heavy wall NDT ultrasonic inspection proved welding quality meeting or exceeding API 5L requirements.
- Consistent, mechanical properties meeting specification requirements were achieved in the PWHT conditions.
- Even after "extensive normalising", ferrite average grain sizes remain small (9 μm maximum) for the selected steel chemistry.
- Micro-alloyed steels offer a significant benefit toward other steel grades: their homogeneous microstructure leads to consistent and similar mechanical properties for base metal, weld and heat affected zone.
- Micro-alloying (here: mainly Nb-micro-alloying) positively influences the steel's microstructure, especially during post-weld heat treatment cycles, as it restricts ferrite grain growth and also strengthens ferrite by precipitation hardening.

6. ACKNOWLEDGMENTS

The authors would like to thank Dr. Spyros Papaefthymiou (Hellenic Research Centre for Metals (ELKEME S.A.)), for his valuable support on the metallographic analysis of the produced samples.

7. REFERENCES

[1] B. Ouaissa; J. Brózda; M. Pérez-Bahillo; S. Bremer; W. de Waele: **Investigations on microstructure, mechanical properties and weldability of a low-carbon steel for high strength helical linepipe**, in proceedings of the 17th JTM, 11/15 May 2009, Milan, Italy

[2] H.-G. Hillenbrand; C. Kalwa; A. Liessem; J. Schroeder: **Nord stream project - a challenge for a pipe manufacturer**, in proceedings of the 17th JTM, 11/15 May 2009, Milan, Italy

[3] R. T. Hill: **Offshore oil and gas development activities and challenges**, in proceedings of the Int. Symposium on Microalloyed Steels for the Oil and Gas Industry, TMS, Araxas Brazil, 23.-26.01.2006.

[4] J. Hammond: **Development of Standards & Specifications for High Strength Line Pipe**, in proceedings of the Int. Symposium on Microalloyed Steels for the Oil and Gas Industry, TMS, Araxas Brazil, 23.-26.01.2006

[5] D. Stalheim; K.R. Barnes; D.B. McCutcheon: **Alloy Designs for High Strength Linepipe Steels**, in proceedings of the Int. Symposium on Microalloyed Steels

for the Oil and Gas Industry, TMS, Araxas Brazil, 23.-26.01.2006
[6] E. Yokoyama, T. Toyooka et al.: **Steel Sheet Deformation Behavior and Forming Load in the 26-inch Cage Forming ERW Pipe Milll**, Kawasaki Steel Technical Report No. 4 December 1981.
[7] B. Grande, J.I. Asperheim: **Factors Influencing Heavy Wall Tube Welding, Tube and Pipe Technology**, March-April 2003.
[8] R.E Haimbaugh: **Practical Induction Heat Treating 2001**, ASM International, pp. 5-17
[9] O. Hablowetz: **Induction heating for the tube manufacturing industry**, Heat Processing, Issue 1, 2005
[10] R. Honeycombe, H. Badeshia: **Steels, Microstructure and properties**, 2nd Ed., Butterwort-Heinemann, 1995
[11] B.K.Panigrahi, **Processing of low carbon steel plate and hot stirp – an overview**, Bull. Mater. Sci. Vol. 24, No. 4, August 2001, pp. 361-371

Table 1: Chemical composition and mechanical properties of the 25mm HSLA steel.

Grade	OD	WT	Chemical Composition (wt%)									Mechanical Properties (MPa)	
			C	Mn	P	S	Si	Al	Nb	Ti	V	Y.S	TS
API 5L X60	24”	25mm	0,05	1,30	0,0095	0,0022	0,23	0,032	0,03	0,016	0,002	457	545

Table 2: Main welding parameters.

Welding Power (kW)	Welding Speed (m/min)	Welding Frequency (kHz)	Squeeze out (%)
1750	9	110	0,52 (*)

(*) expressed as outside diameter reduction before and after the squeezing stand welding station.

Table 3: Width of the heated area at the outer, inner and mid-wall thickness surface.

Wall thickness (mm)	Outer length (mm)	Inner length (mm)	Centre (mm)
15,9	6,2	6,1	2,3
19,1	7,0	6,9	3,1
25	8,3	8,4	4

Table 4: Chemical composition (wt. %) of pipeline steel specimens tested for ferrite grain coarsening after laboratory furnace heating at 1180^{o}C for 2min.

Grade	C	Mn	P	S	Si	Ni	Ti	Nb	V	Al	P_{cm}	IIW
X56	0,07	1,06	0,015	0,002	0,20	0,11	0,007	0,026	0,001	0,034	0,12	0,24
X60	0,06	1,45	0,016	0,001	0,22	0,02	0,021	0,038	0,002	0,030	0,14	0,31
X65	0,05	1,45	0,017	0,001	0,23	0,25	0,016	0,052	0,005	0,036	0,13	0,31
X65	0,06	1,58	0,019	0,003	0,22	0,02	0,023	0,048	0,001	0,024	0,14	0,33
X42	0,07	1,13	0,015	0,002	0,19	0,02	0,015	0,009	0,001	0,029	0,13	0,26
X60	0,07	1,17	0,015	0,004	0,21	0,01	0,008	0,038	0,001	0,034	0,13	0,26
X52	0,07	1,11	0,014	0,004	0,20	0,32	0,001	0,011	0,032	0,021	0,14	0,27
X56	0,06	1,34	0,016	0,001	0,20	0,02	0,012	0,022	0,001	0,028	0,13	0,29
X52	0,06	1,26	0,015	0,005	0,05	0,02	0,014	0,033	0,004	0,035	0,13	0,27
X65	0,06	1,44	0,017	0,017	0,22	0,02	0,021	0,037	0,001	0,026	0,14	0,30
X70	0,06	1,62	0,016	0,001	0,22	0,02	0,018	0,018	0,001	0,032	0,15	0,33
X60	0,05	1,30	0,009	0,002	0,23	0,02	0,016	0,030	0,002	0,032	0,13	0,28

Table 5: Dimensional properties of 25mm produced pipes

	Outer diameter (body) mm	Outer diameter (pipe end) mm	Wall thickness mm	Straightness %	Out of roundness % (mm)		Height of internal flash mm	Depth of groove mm
					Body	End		
API 5L 44^{th} ed.	606,4 - 612,8	608,0 - 611,2	23,50-26,50	0,20% max	2,0% max (12,2mm)	1,5% max (9,1mm)	1,5 max	1,25 max
Indicative pipe results	611,4	610,0	Body: 25,35 Weld: 25,50	0,02%	0,03% (0,2mm)	0,03% (0,2mm)	-	0,7
	611,4	610,2	Body: 25,37 Weld: 25,47	0,02%	0,03% (0,2mm)	0,03% (0,2mm)	-	0,5

Table 6: Mechanical properties of pipe body and weld

	$YP_{0.5}$ [body, T180°] MPa	TS [body, T180°] MPa	TS [weld, T] MPa	Elongation %, 2''	YP/TS
API 5L 44th Ed.	415-565	520-760	520min	23min	0.93max
Results	501-503	551-554	531-545	46-47	0.90-0.91

Notch location	Charpy-V values at 0°C J	Specimen size (*) mm^3
Weld seam	338 - 355 (345 aver.)	10 X 10 X 55
Parent metal (T, 90°)	357 – 376 (364 aver.)	

(*) Specimens were extracted from the mid wall location for both weld seam and parent metal.

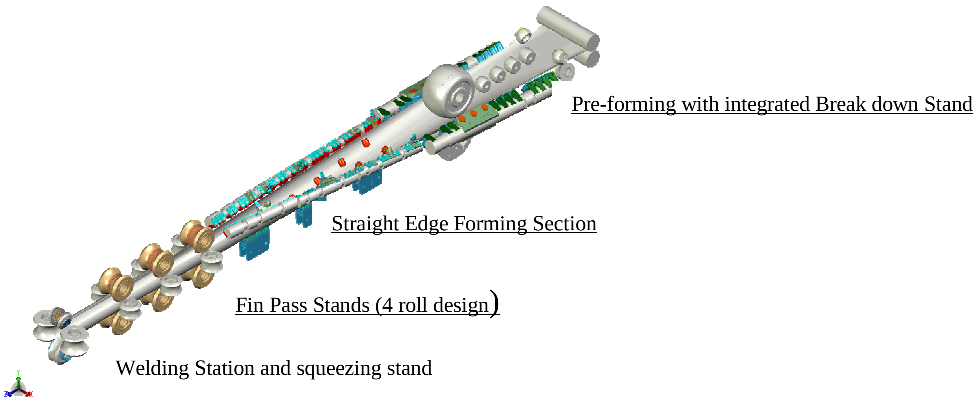


Figure 1: General Forming Layout – Main Components of the Forming Mill

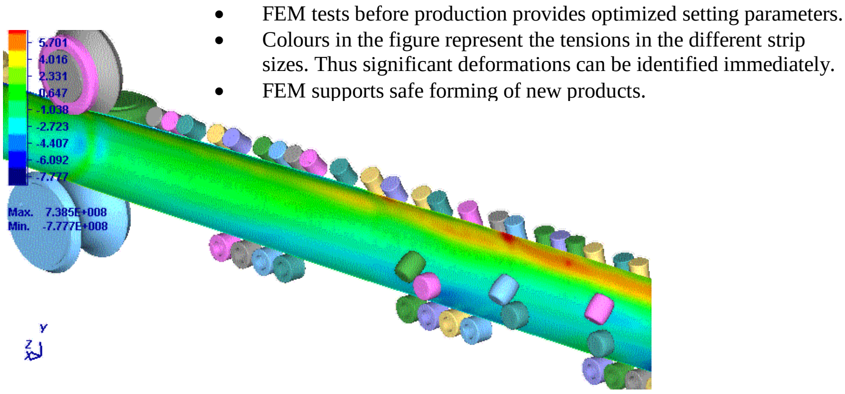


Figure 2: FEM Integrated Analysis for forming optimisation

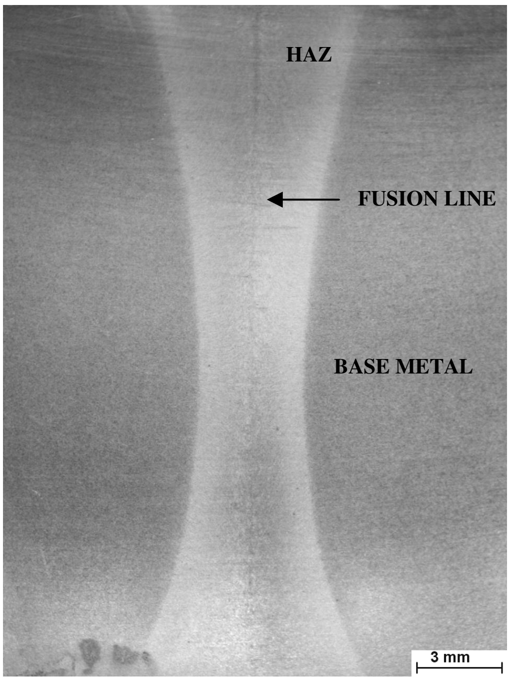


Figure 3: Cross section specimen of the weld (24” X 25mm X60, as weld condition)

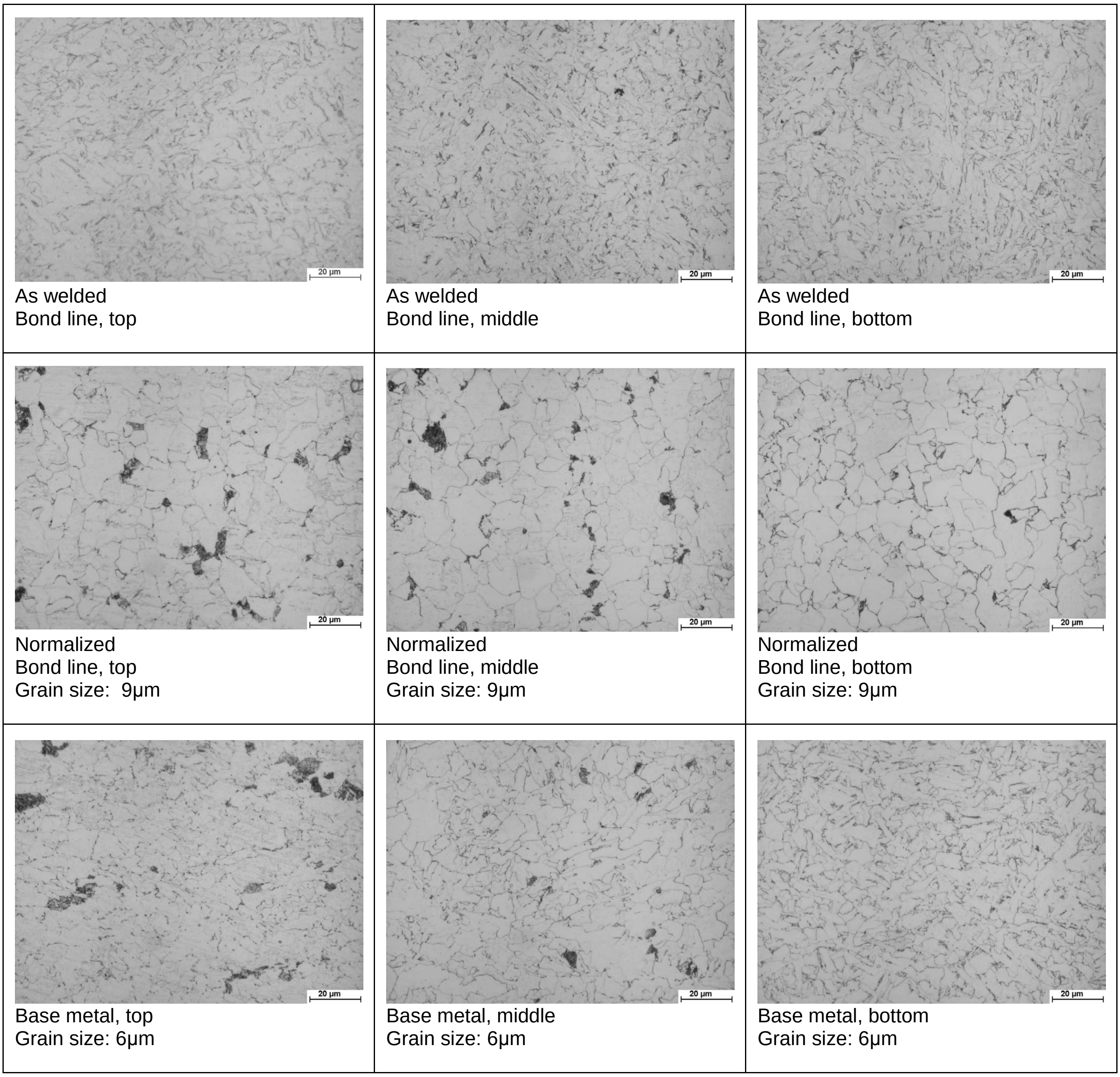


Figure 4: Microstructure of as welded, normalized and base metal 25mm samples. Average grain size measured with image analysis. Samples were polished and etched with 2% nital.

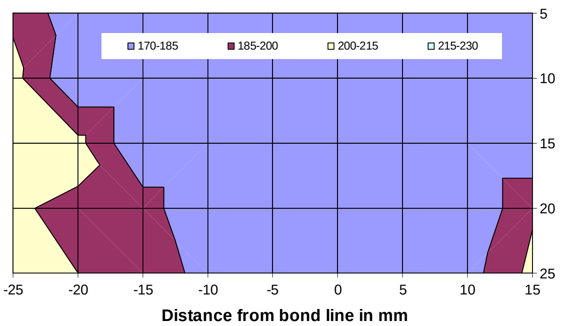


Figure 5: HV10 hardness mapping of the weld seam cross section

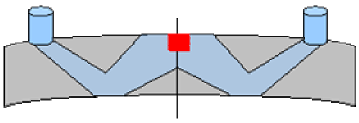
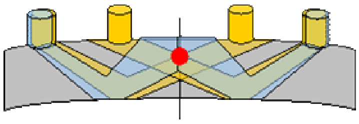
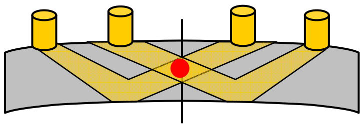
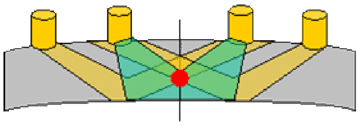
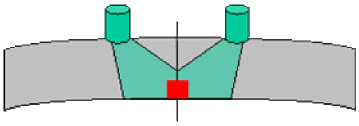
	Design step	Schematic outline of beam paths and artificial reflectors
1	Artificial defect: N5 notch (OD) Inspected by: OD pulse-echo probe pair (45^o or 60^o)	
2	Artificial defect: Ø 3.2mm longitudinal hole at t/3 Inspected by: OD pulse-echo probe pair (45^o or 60^o) and indirect pitch-catch (tandem) probes in transmitter-receiver mode.	
3	Artificial defect: Ø 3.2mm longitudinal hole at t/2 Inspected by: Indirect pitch-catch (tandem) probes in transmitter-receiver mode.	
4	Artificial defect: Ø 3.2mm longitudinal hole at 2t/3 Inspected by: OD pulse-echo probe pair (45^o or 60^o) and indirect pitch-catch (tandem) probes in transmitter-receiver mode.	
5	Artificial defect: N5 notch (ID) Inspected by: OD pulse-echo probe pair (45^o or 60^o)	

Figure 6: Design principle for automatic ultrasonic inspection of 25mm linepipe.