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VERY HEAVY WALL X-70 DSAW PIPE FOR TENSION LEG APPLICATIONS

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Abstract

Assembled in strings, Tendon Pipes connect the Tension Leg Platform (TLPs) and it's topsides with the sea floor. So far, a water depth of 5,000 feet has been considered the limit for TLPs. New TLP concepts are passing this limit approaching 10,000 feet. The new larger oil and gas fields, specially in the Gulf of Mexico (GoM), are expected in water depths of 7,000 feet and more. Pipes in the 40 mm plus (1.6") wall thickness range are requested for these water depths. These pipes have to fulfill extremely tight tolerances and toughness requirements. This article discusses the manufacturing of these pipes with the Submerged Arc Welded (SAW) UOE process. Experience and data out of order executions and trials are presented.

Introduction

Assembled in strings, Tendon Pipes connect the Tension Leg Platform (TLP) and it's topsides with the sea floor (Figure 1). The platform is slightly submerged so that the natural buoyancy of the structure applies a tension on the vertical pipe strings. This principle provides the most stable system beside gravity based platforms with only little movements as reaction to the waves and current. So called "dry" well heads are possible. The maximum realized water depth for a TLP project has been so far 4,700 feet in the Gulf of Mexico. New TLP concepts are under investigation to pass 5,000 feet and going even beyond 7,500 feet. The new larger oil and gas fields in the GoM are in the 6,000 to 7,000 feet range. Reaching these water depths, the Tendon Pipes carry not only the loads from the platform but in addition the collapse pressure of such water depths.

These new designs require pipes with a wall thickness of about 40 mm (1.57"). EUROPIPE proved, with already delivered pipes (with a wall of 38 mm in the X-70 grade) and with a trial production of 40 mm wall thickness X-70 pipes that these pipes can be supplied. So far Tendon Pipes have been used in the OD range of 26" to 40", in lengths of 56-59 feet in order to reduce the number of girth welds, and in the wall thickness range of 25 to 38 mm, mostly X-70 material.

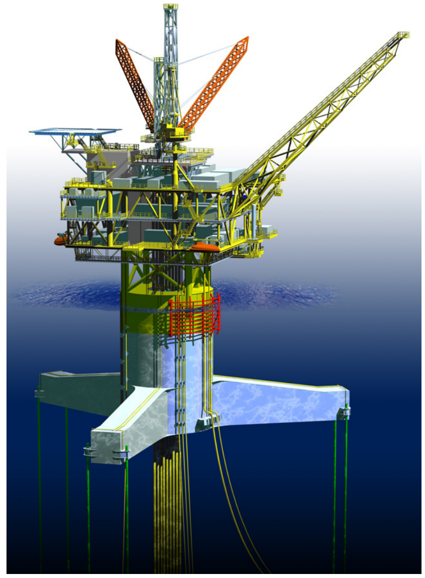

Figure 1. Principle of a TLP (the Atlantia Offshore Sea Star Design)

Fatigue is one of the main concerns for the tendon leg design. Due to the main load directions being perpendicular to the girth weld, the girth welds in the leg are considered to be more critical compared to the long seam which is only exposed to little bending loads. Beside a high toughness of the material, the fatigue resistance requires excellent geometry, specially at the pipe ends. Due to this, the dimensional tolerances are very tight. Table I shows the common main dimensional requirements for these pipes. Additionally, the weight tolerance is very tight in order to achieve neutral buoyancy of the legs.

Table I. Main Dimensional Requirements for Tendon Pipes.

	Tolerances
OD pipe ends	+/- 1.5 mm
Max. ovality pipe ends	5 mm (30% max)
Peaking	1.5 mm
Wall thickness	-1%/+3%
Straightness	14 mm for 18 m
Pipe weight	- 1%/+3%

Good toughness is requested for the base material (BM), weld material (WM) and the heat affected zone (HAZ) in order to provide a high defect tolerance level. The most economic production method for these pipes is the submerged arc welding process in two passes with the plates being thermomecanically rolled. The manufacturing of DSAW pipes generally consist of four principle production steps.

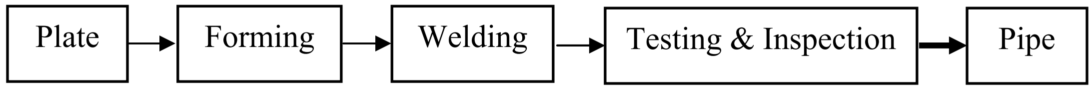

Figure 2. Steps during DSAW manufacturing most important for tendon pipe manufacturing

Steps 1 to 3 of this manufacturing method are the most challenging to provide pipes with the required properties for this application (Figure 2). High performance welding processes, DSAW for the not so critical long seam and multi layer SAW for the girth welds are characterized by a higher heat input with cooling conditions which impact on the toughness properties in the zone adjacent to the weld. The microstructure and herewith the toughness of this heat affected zone (HAZ) is mainly influenced by the cooling time $t_{8/5}$ from 800°C to 500°C, the maximum reheating temperature and the chemical composition of the base material. The HAZ is characterised by a wide range of different microstructures, depending on the distance from the fusion line and the cooling conditions. Generally the lowest toughness values are expected in the grain-coarsened heat affected zone (CGHAZ), as the toughness decreases with increased heat input and an increase in grain size. With increasing cooling time the microstructure in the HAZ is transformed from martensite to upper bainite as shown in Figure 3. This transformation to upper bainite is shifted to longer cooling times by significant additions of nickel which leads to lower Fracture Appearance Transition Temperature (FATT) even at a higher carbon equivalent.

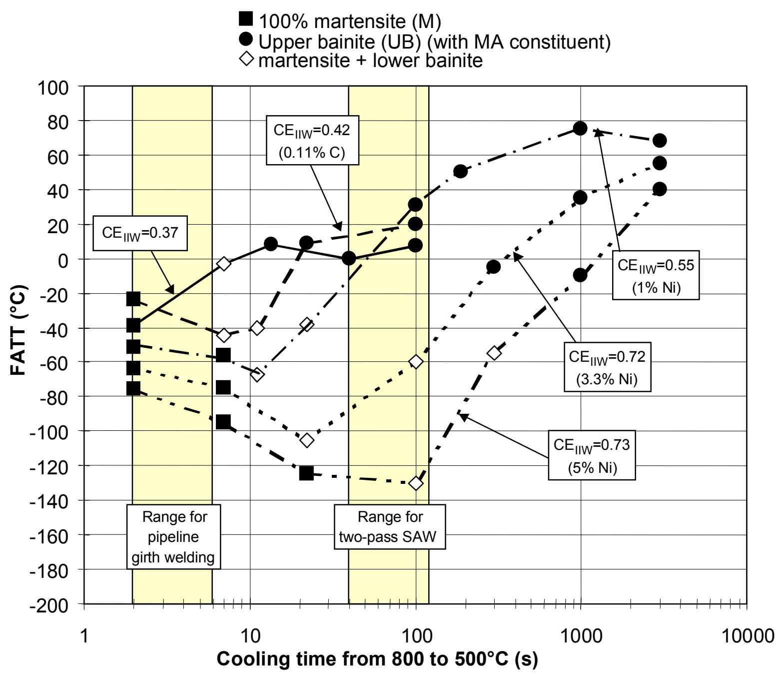

Figure 3. Correlation between FATT and the cooling time t8/5 for different steel compositions and microstructures occurring in the CGHAZ (acc. [2,3])

The upper bainite is coarse grained and exhibits fractions of M-A constituents. Both microstructure features typically reveal low toughness properties. As the cooling conditions in two pass SAW welding remain virtually constant irrespective of wall thickness the grain growth and the formation of M-A constituents has to be limited by appropriate plate chemical composition. The main measures currently known to improve HAZ toughness by optimised chemical composition are summarised in Table II. Reduction of carbon plays the predominant role in avoiding the formation of M-A constituents. Furthermore the controlled use of limited additions of microalloying elements, e.g. Nb, is reported to inhibit the grain coarsening by formation of finely dispersed nitrides and/or oxides. These favourable effects have been confirmed by weld cycle simulation tests for a variety of steel compositions.

Table II. Improvement of HAZ toughness by adapted steel composition

Measure	with positive influence on		Remarks
	FATT	upper shelf energy	
Reduction of C	●	●	Decreases hardenability & limits formation of M-A constituents
Limitation of Nb, V	●		Decreases hardenability & limits formation of M-A constituents
Controlled use of Ti	●	●	Restricts austenite grain coarsening
Addition of Ni	●		Retards the formation of upper bainite to longer cooling times
Low S, P, O		●	Reduces precipitations and segregations

The review of the published results shows that there is a fair level of understanding and that this knowledge is continually exploited in the steel chemistry and processing routes for line pipes, by which the overall HAZ toughness has been considerably improved and the statistical probability of having low toughness values in the HAZ has been reduced. Nevertheless values below the minimum requirement are still found due to the presence of LBZ's when the notch is favourably positioned in the CGHAZ. LBZ's are discrete microstructural regions of low toughness within the CGHAZ, but surrounded by microstructures with higher toughness. As the toughness of the CGHAZ depends mainly on the chemical conditions and the welding procedure (heat input, cooling time), which are technically constant due to strict control within narrow ranges for a specific line pipe production, it becomes obvious that LBZ are existing statistically distributed in each pipe of production. The number and size of LBZ's can be influenced and with this the probability of being discovered. The impact on the pipe integrity has been assessed (5,6). The result is that in a high quality steel with a low number of small sized LBZ's the integrity of the pipes is not jeopardized.

Plate Production

The plates for EUROPIPE's pipe production are slab cast and rolled in the steel plants of EUROPIPE's mother companies. Used for the tendon pipe production and the 40 mm wall thickness trials were the "Dillinger Route" with slabs and plates produced in Dillinger and the "Mannesmann Route" with slabs from Huette Krupp Mannesmann (HKM) and the plate rolling performed at Mannesmannroehren Muelheim (MRM).

In consideration of the previously discussed topics the analysis and rolling practice in the plate mill were adjusted accordingly. The common requirements for the mechanical properties of an API 5 L, X-70 tendon pipe are listed in Table III. Specifically the high level of toughness for the weld metal and the HAZ are remarkable.

Table III. Common mechanical Requirements for Tendon Pipes (EWI*Microalloying, Houston*)

Property	**Requirements**
YS, long. & transv.	70 – 85 ksi
TS, long. & transv.	82 – 97 ksi
CVN BM, -10°C	60/75 ft-lb
CVN WM, HAZ,-10°C	40/60 ft-lb
Shear area BM	85%
CTOD girth weld, 0°C	0,25/0.35 mm

Chemistry: Low carbon content and limited microalloying elements were chosen in order to improve weldability and to reduce the number of LBZs in the later HAZ as much as possible.

Table IV. Chemistry (average in %)

C	Mn	P	S	Ni	Nb+V+Ti	CE	PCM
0.05	1.6	0.010	0.001	0.4	<= 0.5	0.35	0.02

The average values of the elements used for wall thickness of 30 mm and heavier are listed in Table IV. The somewhat negative impact of the microalloying elements on the HAZ toughness is very much overcompensated by the advantage of a low carbon content. According to Table 2 the content of V and Nb should be limited. This has to be compensated by adding Ni in order to achieve X-70 properties.

Cleanness: The cleanliness of the steel, i.e. inclusion content and shape, reduced center line segregations and an excellent internal homogeneity is mandatory for the pipe ends. There negative impact on the fatigue exposed girth welds shall be minimized. Figure 5 describes the different steps applied. Reduction of carbon and phosphorus contents in the BOF converter with bottom stirring, de-sulphurization by degassing in a vacuum tank, expulsion of nitrogen and hydrogen.

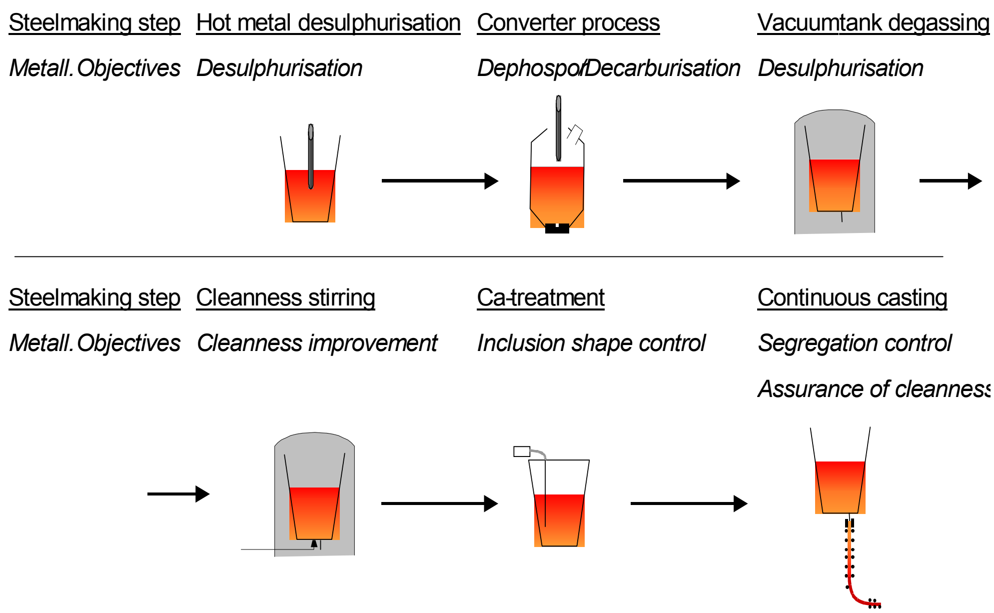

Figure 5. Steel making process, toughness optimized

The result of this treatment is a maximum sulfur content of. 0.001% in the finished cast. Additionally the molten steel is stirred with a ratio optimized inert gas. This reduces the oxygen content to 0.002% max. A CaSi cored wire is used to shape control the melt.

Casting: The molten steel is continuously strand cast into slabs in a sealed off system including shrouding of the pouring stream. Soft reduction is applied to minimize centerline segregation. Bulging of the slabs between the rolls is prevented by an intensive cooling that results in low slab surface temperatures. This practice stiffens the shell of the strand.

Rolling: The Thermo-Mechanical-Control Process (TMCP) is employed to produce the plates. In this TMCP process the most important strengthening mechanisms and micro-structural features are employed as grain refinement by rolling in the non recrystallisation regime austenite, accelerated cooling (ACC), precipitation hardening (e.g. by NbCN) and dislocation hardening (e.g. due to finishing of rolling in two-phase $\alpha + \gamma$- region).

Pipe Production

The pipes are manufactured in EUROPIPE's 18m line in Muelheim with the UOE process. To achieve the tight geometrical tolerances the forming process was optimized by FEA analysis. The simulation of the different forming steps, as shown in Figure 6 for the O-ing, results in a well adjusted forming chain and optimized tooling. Very important is the latest forming step, the cold expansion which is performed after the welding. This production step finalizes the geometry control and provides a stress homogenation function due to the plastic deformations implied.

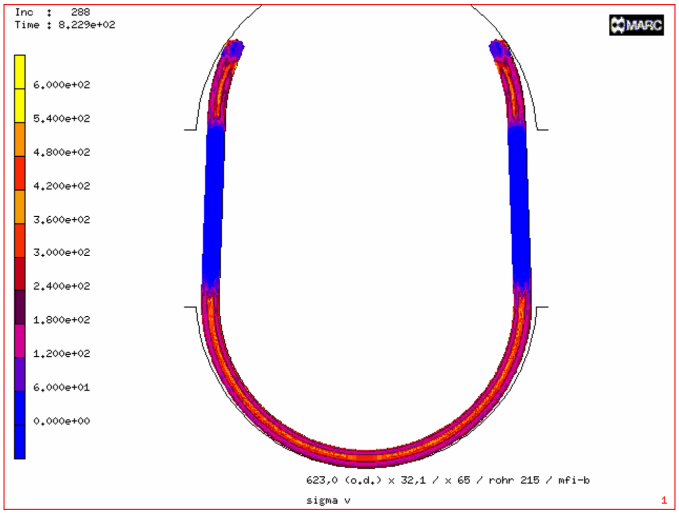

Figure 6. FEA Simulation of the O-ing Process

The welding process consists of continuous GMAW tack welding followed by the main welding process. This is a two-pass welding operation beginning with a four wire inside welding and succeeded by a five wire outside welding. Inside and outside welding are submerged under flux. For a high toughness level of the weld metal (WM) a slightly basic flux is used. A balanced oxygen content in the WM is the result so that a fine grained acicular ferritic microstructure develop and the amount of oxide inclusions is minimized which supports high WM toughness levels. The chemical composition should avoid the formation of the lower toughness eutectoid ferrite. The WM composition should be as lean as possible. For this application a MoTiB based chemistry was selected for the wire providing the X-70 strength and the toughness required. The overmatching criteria for the long seam is fulfilled. The double seam arc welding process is based on a relative high heat input of about 20 kJ/mm and a cooling time $t_{8/5}$ which results in the formation of a some LBZ's as discussed previously.

Production Results

Mechanical Properties

Figure 7 shows the strength distributions for executed orders with a wall thickness of 38 mm. Please notice the narrow window of 80/100 MPa achieved for both the longitudinal and transverse tensile tests. Longitudinal properties are requested due to the load situation of Tendon Pipes.

The trial of X-70 pipes with 40mm wall thickness produced a yield strength $Rt_{0.5}$ of 524 to 609 MPa and a tensile strength Rm between 655 and 689 MPa. This strength level was too high and can easily be adjusted in a later production. A leaner chemistry with a lower stress level will improve the toughness and the economics of the production.

In Figure 8 it can be seen that the charpy toughness values for the base material, the weld material and the fusion line are on a level with sufficient margin to the specified limits. The analysis concept discussed before leads to an excellent toughness. During 2004 new power sources were installed in our welding lines. Due to this a higher welding speed is possible resulting in a lower heat input which is favorable for the HAZ toughness. For the 40 mm wall thickness trial production the same analysis design provided also toughness values much better than the specified minimum as can be seen in Figure 09. Due to these excellent results the qualification for walls heavier than the 38 mm was achieved.

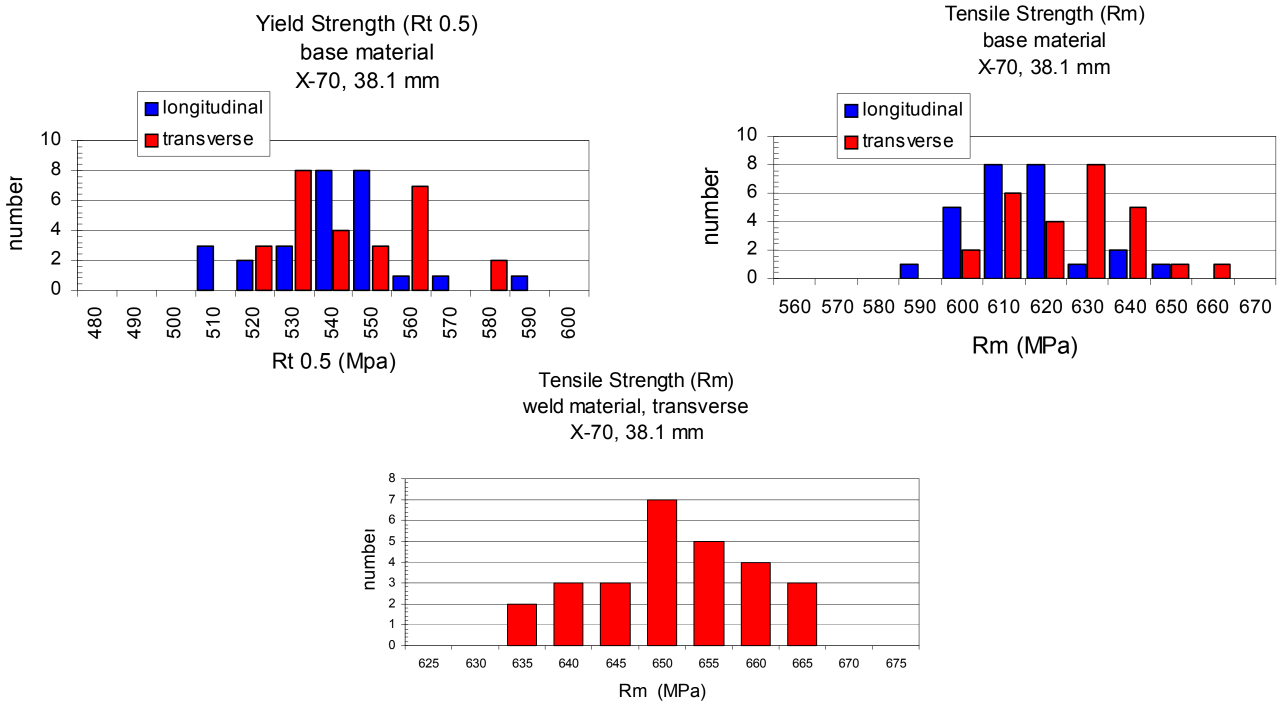

Figure 7. Strength distributions from orders with 38 mm wall thickness in X-70

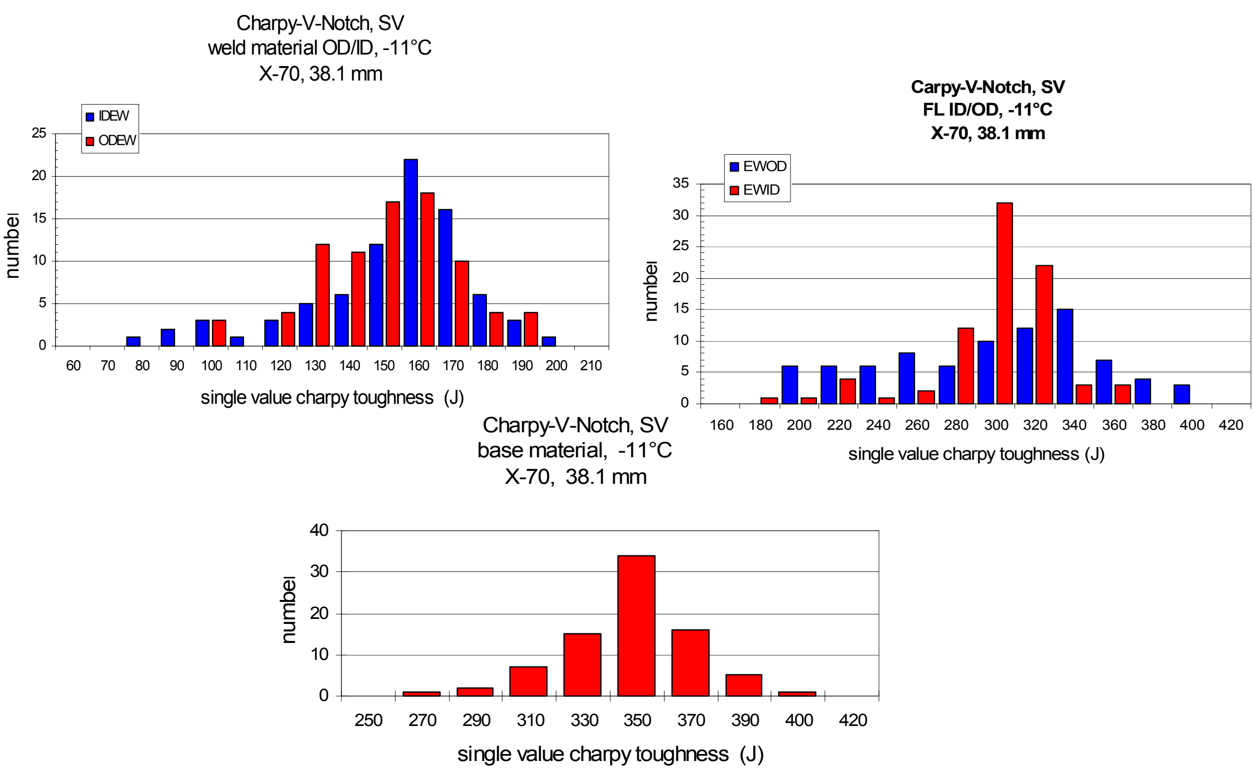

Figure 8. Charpy toughness Values (single values) for WM, HAZ (FL) and BM

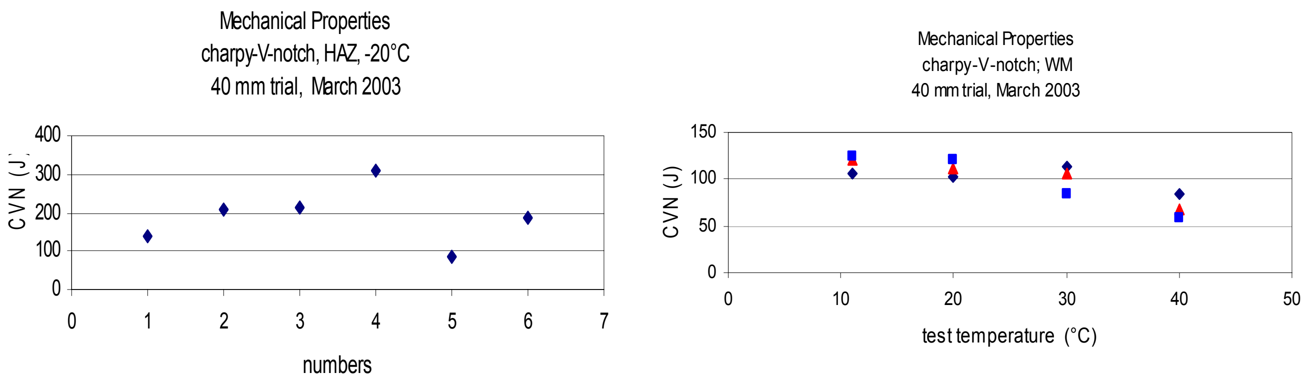

Figure 9. Charpy toughness Values (single values) for WM, HAZ (FL) for 40 mm wall

As mentioned already the girth weld is very much exposed to the main stresses in the tendon sections. The common fracture mechanics assessment of the girth weld is based on CTOD values.

The required values are very much driven by the principals described in API RP 2Z. With today's knowledge these values are very conservative, specially with the NDT methods being applied today. Nevertheless, good past experience with this code, criticality of the weld and the regulatory status manifests this requirement.

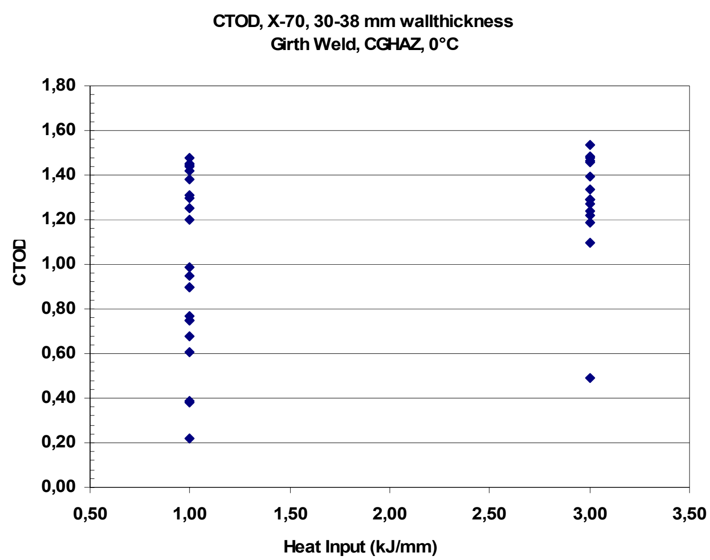

Figure 10. CTOD values (single values) of the girth weld

Figure 10 shows CTOD values achieved again over several orders with wall thickness between 30 and 38 mm. The girth welds were produced as requested with low heat input (1.0 kJ/mm) and high heat input (3 kJ/mm). It can clearly be seen that the low heat input produces trend wise lower CTOD values in the coarse grain heat affected zones (CGHAZ) of the welds. Today fabrication yards are using mostly automated girth welding equipments with a heat input of 1.5 to 2.0 kJ/mm. The CTOD testing of welds produced with 0.8 -1.0 kJ/mm provides an already conservative value. The higher heat input is mostly used to cover repair welding procedures. For the 40 mm trials we received CTOD values of 0.26, 0.61 and 0.77 mm for the heat input of 1.0 kJ/mm and 1.10, 1.21 and 1.54 mm for 3.0 kJ/mm heat input. These results are again in compliance with the before mentioned values from executed orders for wall thicknesses up to 38 mm.

Geometrical Properties

Also the geometry achieved for the 38 mm production and the 40 mm trial exceeded the limits specified by the TLP designers. To receive an outside diameter as close to nominal as possible is important because of the neutral buoyancy being desired for the tendon section in order to compensate the deviation with costly measures as buoyancy elements, etc. Figure 11 represents produced outside diameter and it's deviation from nominal. The narrow scatter band assures this neutral buoyancy as much as possible and additionally leads to the good match of the pipe ends during girth welding with a very small high-low from pipe face to pipe face. These high-low steps are desired to be as small as possible to minimize the impact on the life time of the girth weld.

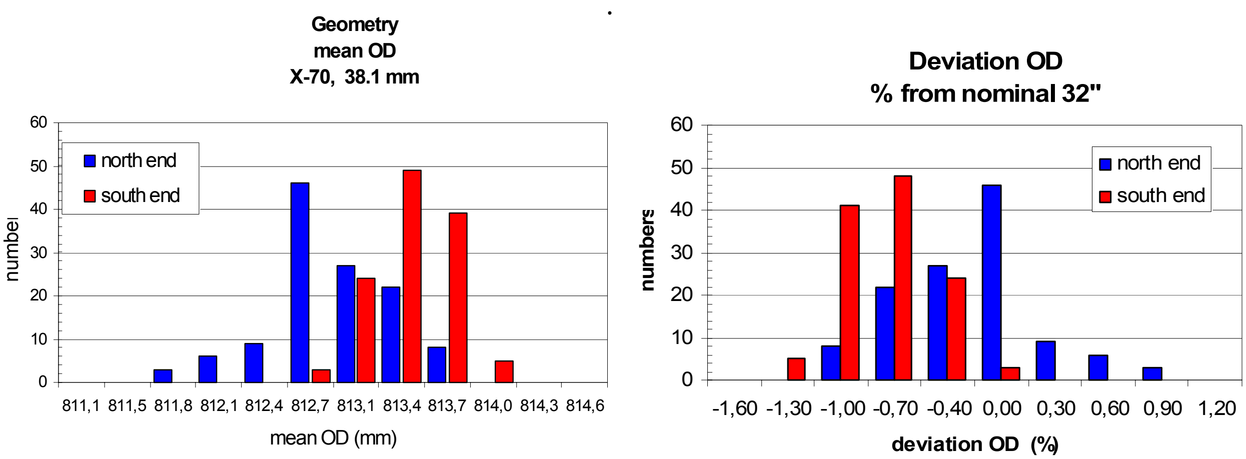

Figure 11. Deviation of the inside diameter in mm and in % of nominal ID for 38.1 mm wall

Beside the constant OD, the second factor for this criteria is a very small out of roundness (OOR) of the pipe ends combined with a consistent appearance of the location of the long and short axis of the OOR from pipe to pipe in order to adjust the pipe ends accordingly before welding. Figure 12 exhibits OOR values. An excellent roundness is being provided and only a very small amount of pipes show OOR values larger than 3 mm. Additionally to the low absolute value also the shape of the pipe ends is very consistent. Figure 13 is characteristic for the appearance of the pipe ends. The figure shows the shape of the pipe end of a pipe 28" x 1.60" wall thickness.

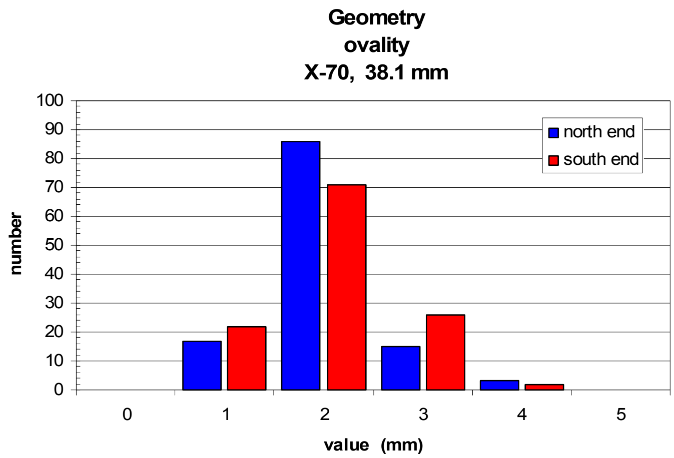

Figure 12. Out of roundness (OOR) values measured at orders with 38 mm wall

Reading the picture the resolution of 10 mm/square side of the measurement unit should be considered. The somewhat polygon appearance is in the range of 0.2 mm. This shape assures not only the desired little high-low's after alignment and before welding but also reduces the costly selection and positioning of the pipes during the welding preparation in the fabrication yard.

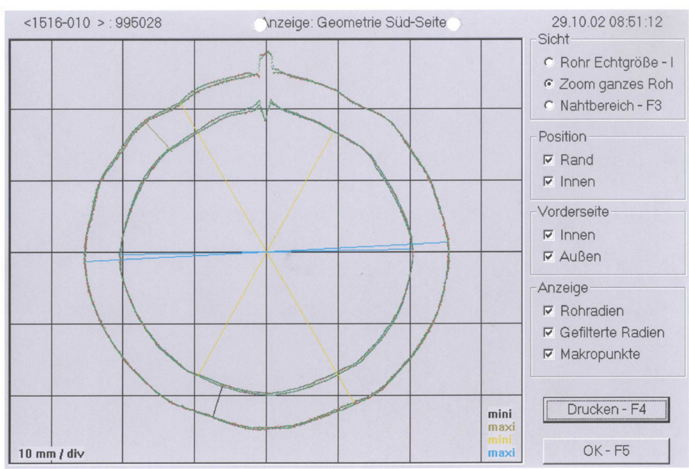

Figure 13. Characteristic shape of a pipe end

Buoyancy is not only based on the outside diameter but also the wall thickness and with this the kg/m weight of the pipes. The distribution of the deviation from the nominal specific weight in [%] is shown in figure 14. It can be seen that the nominal metric weight combining all dimensional parameters is very close to the specified metric weight which should be somewhat in the plus tolerance and not in the minus tolerance. As discussed before this prevents costly measures to compensate weight differences for neutral buoyancy.

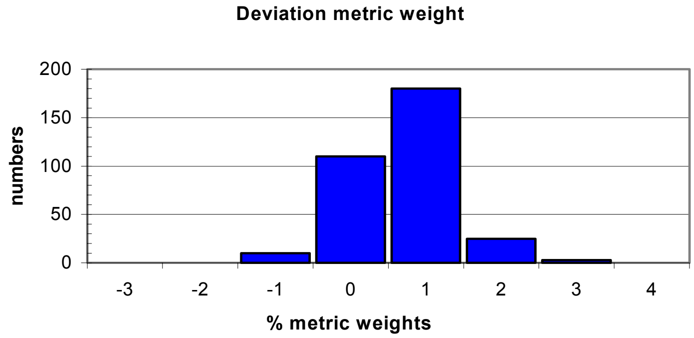

Figure 14**.** Distribution of the deviation from the nominal metric weight

The straightness of the pipes is the latest important parameter. The deviation of the straightness can result in a deflection of the axial stresses in the girth weld with a significant impact on life

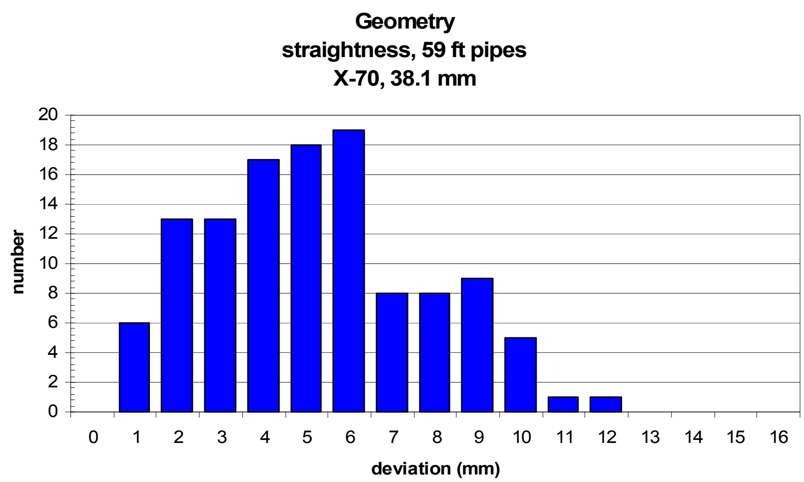

Figure 15. Distribution of the deflection from the straightness at over several orders

Figure 15 shows the distribution of the deviation from straightness for the 38.1 mm wall thickness orders. The very tight limits resulted in some cases into a rework in order to deliver the 15 mm maximum deviation for a 60 feet long pipe.

Conclusions

The extreme load scenario for tendon sections requires a pipe as close as possible to the ideal circle and straightness. A weight per meter as close as possible to the nominal weight results in cost savings for a neutral buoyancy situation. High toughness levels provide an excellent defect tolerance of the system under fatigue loading. The combination of the DSAW and UOE manufacturing process is the most cost efficient method to produce these pipes with a length up to 60 feet and a wall thickness up to 1.6 inches. A fine tuned chemistry with a micro alloying concept including Nb is the basis for the high toughness levels for these heavy wall plates and pipes. The supply of pipes with a wall thickness up to 1.60” in the grade X 70 in 60 ft length coming from the cost effective UOE DSAW manufacturing process is possible.

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