Very Heavy Wall X-70 DSAW Pipe for Tension Leg Application

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ABSTRACT

Assembled to 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 being expected in waters of 7,000 feet and more. Pipes in the 40 mm (1.575") wall range are requested for these water depths. These pipes have to fulfill extreme tight tolerance and toughness requirements. Europipe made trials to manufacture those pipes. Experience and production data for these pipes and former productions of similar orders is the content of this publication.

KEY WORDS: Tendon Pipes, collapse, CTOD, ovality, straightness, heavy wall

INTRODUCTION

Assembled to strings Tendon Pipes connect the Tension Leg Platform (TLP) and it's topsides with the sea floor. 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 wave and current activities. So called dry well heads are possible. The maximum water depth for a TLP project has been so far 4,700 feet in the Gulf of Mexico and for a long time was considered the limit for TLPs. 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, specially in the GoM are in the 6,000 to 7,000 feet range. Reaching these water depths the Tendon Pipes have to carry not only the loads from the platform but in addition the collapse pressure of such water depths.

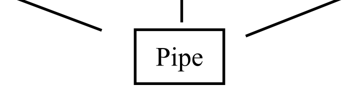
The design requests pipes with a wall thickness of about 40 mm (1.57"). In a first trial Europipe proved that X-70 pipes with 40 mm wall thickness are feasible. The outside diameter (OD) of these pipes is 32" (813 mm). Tendon Pipes are normally used in the OD range of 26" to 40", in lengths of 58-59 feet in order to reduce the number of girth welds, and in the wall thickness range of 25 to 35 mm, mostly X-70 material. Fatigue in the girth weld is an important design criteria. Due to this the dimensional tolerances are very tight. Table 01 shows the main criteria for these pipes. Additionally the weight is tolerated very tight in order to achieve neutral bouyoncy of the legs.

Table: 01: 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%

The most economic production method for these pipes is the DSAW process with plates being thermomecanically rolled.

Fig.: 01: Steps during DSAW manufacturing most important for tendon pipe manufacturing



The three aspects of this manufacturing method which are challenged most to provide pipes with the required properties for this application are listed in figure 01.
For fatigue performance additionally to the geometrical aspect toughness of the HAZs of the welds is the most important criteria. Due to the main load directions being perpenticulary to the girth weld the girth weld is considered to be more critical compared to the long seam which is only very little exposed to some percentages of the bending loads. The toughness of the HAZ is much influenced by the base material. Measures impacting HAZ toughness of the long seam are described in (1,2) and listed in table 02. These facts are also valid for the girth weld HAZs.

Table 02: Measures to optimize CG HAZ toughness behavior , (2)

Measure	**Result**	**Remarks**
Decrease of C-content	Upper shelf toughness FATT	Important in connection with TM/TM+C
Limitation of CE	FATT	TM/TM+C
Limitation of V-,Nb -, and Ti-content	FATT	Standard Limited YS
High steel cleanness (S,P,O)	Upper shelf toughness	Standard

Due to the different design criteria and environment for tendon pipes the fracture arrest transition temperature (FATT) is requested not as low as for other applications. However, measures to shift the FATT to lower temperatures help also to reduce the number of isolated, localized upper bainite grains with MA constitute, so called local brittle zones (LBZ) significantly . Additionally the heat input during welding including the cooling time from 800 to 500 °C, $t_{8/5}$, does have an influence on the formation of these very randomly distributed grains. They are very little, localized and isolated but can not completely be avoided and impact the practical testing of the pipes. A validation of these LBZ in an otherwise high toughness matrix has been done in (2, 3, 4). For the application of the pipes in service the commonly specified toughness values, specially CTOD, are very conservative, specially under consideration of the today applied very much advanced NDT technologies providing an excellent investigation of the weld area. Additionally these low values are found only in areas with a very little probability of DSAW process defects. Still some codes important for the approval process request these values (5). It costs efforts and might not be possible to receive a concession for an even well proven deviation.

PLATE PRODUCTION

The base material of the pipes is the plate, slab casted and rolled in the steel plans of Europipe's mother companies. Used for the 40 mm wall thickness trials were the "Dillinger Route" with slabs and plates produced in Dillinger and the "Mannesmann Route" with Huette Krupp Mannesmann (HKM) for the slabs and Mannesmannroehren Muelheim (MRM) for the plate rolling.

To fulfill the high toughness requirements for the HAZs of girth welds and the long seams a very high toughness of the base material is essential. The analysis and rolling practice have to be adjusted to provide this toughness level. The common requirements for the mechanical properties of an API 5 L, X-70 tendon pipe are listed in table 03.

Table 03: Common mechanical Requirements for Tendon Pipes (provided by *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

Specially the high level of toughness for the weld metal and the HAZ are remarkable. The measures listed in table 02 are applied in Europipe's production in order to create the best steel for these high toughness HAZ requirements:

Chemistry

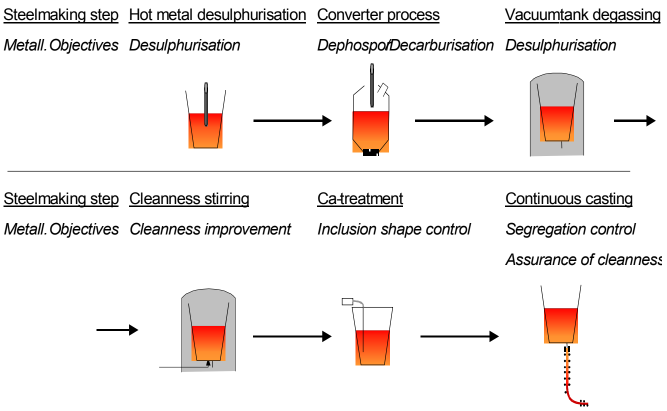
Low carbon content and limited microalloying elements were chosen in order to improve weldability and to reduce the number of LBZs in the later HAZ as much has possible.

Table 04: 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 the 30 mm orders and the 40 mm trial are listed in table 04.

Figure 02: Steel making process, toughness optimized



According to table 02 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

Another essential requirement is a clean steel, i.e. inclusion content and shape, reduced center line segregations plus internal homogeneity Figure 02 describes the different steps applied in order to create such a clean steel. The carbon and phosphorus contents are reduced in the BOF converter with bottom stirring. Degassing in a vacuum tank enables a strong de-sulphurisation, expulsion of nitrogen and hydrogen. The result of this treatment is a sulfur content of 0.001% in the finished cast. Additionally the molten steel is stirred with an ration 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 metal 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 the TMCP process different metallurgical mechanisms can be utilized to achieve the required mechanical properties. The most important strengthening mechanisms and micro-structural features involved are:

- grain refinement (e.g. through rolling in the non recrystallisation regime of micro-alloyed austenite, accelerated cooling (ACC), etc).
- type and distribution of microstructural constituents (e.g. bainite fractions, pearlite islands and suppressed banding).
- precipitation hardening (e.g. by NbCN)
- dislocation hardening (e.g. due to finishing of rolling in two-phase $\alpha + \gamma$- region)

The following parameters have to be designed and controlled during the production process

- slab reheating (temperature and gradient)
- number of rolling stages
- starting and finishing temperatures in each rolling stage
- reduction per pass in each rolling stage
- cooling conditions between the rolling stages
- Parameters of air cooling, accelerated cooling in a water cooling system or slow down cooling in a pile, adopted to cool the finish-rolled plate leaving the run out table.

PIPE PRODUCTION

FORMING

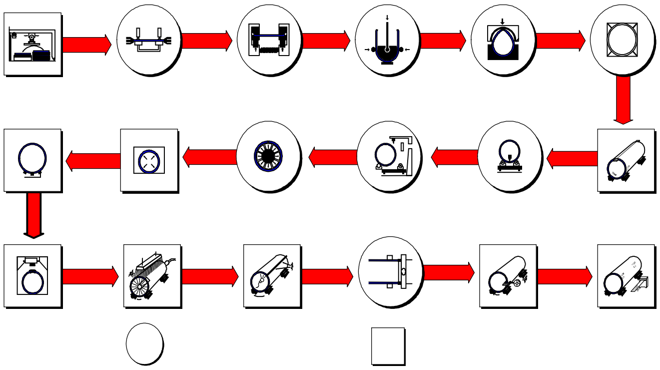
The manufacturing flow of the Europipe UOE DSAW pipe mill producing tendon pipes is outlined in figure 03:

After the welding preparation, applying taps and trimming, the plate enters the forming part which consists out of the three steps to form the plate into the pipe shape. Crimping , U-ing and O-ing. These three steps are very important for the fulfillment of the tight dimensional tolerances described above.

For the Oman India Project, a pipe line designed to resist collapse pressure down to a water depth of 3,000 m (ca 10,000 ft), Europipe investigated many aspects impacting the resistant of pipes against external hydrostatic pressure. During the trial production of ca 100 joints 28” x 44 mm, (1.732”), in X-70 Europipe collected many experiences.

This knowledge is important not only to achieve the tight tolerances for the pipe ends of Tendon Pipes as listed before but also for the collapse behavior for deep water TLP projects. Out of roundness (OOR) over the entire pipe length as one of the major factors for collapse resistant was investigated very closely. Figure 04 shows an FEA analysis of the behavior of an already U-shaped plate in the O-ing process. Goal is to achieve very constant residual stresses over the circumference which helps to receive a homogeneous circular shape over the entire body which supports also the final cold expansion process after welding.

Figure 03: Manufacturing scheme for DSAW Pipes

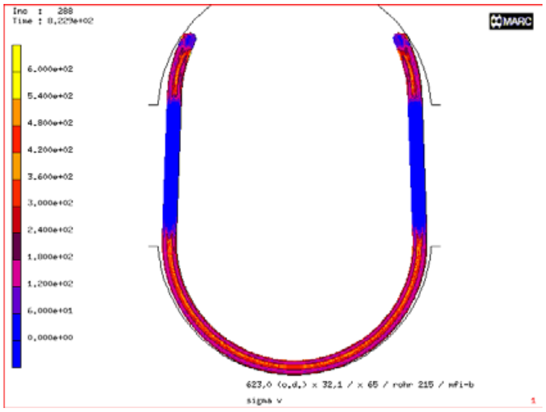


The cold expansion after the welding process is a very important production step.

WELDING

As described in figure 01 beside the plate production and the forming operation welding is the third main aspects to produce pipes being fit for the special requirements of a Tendon Pipe. The main aspect is the toughness of the weld metal (WM). As described

Figure 04: FEA Simulation of the O-ing Process



before welding is the second parameter to impact the toughness of the HAZ also. The welding process starts with a GMAW tack welding. The tack weld is applied continuously over the entire pipe lengths including the taps. This provides later an extreme stable final welding process. The tack welding wire is from the same chemistry as the wires used for the later welding operation and will be completely re-molten during this later welding. The main welding process applied in this case is a two-pass welding operation beginning with a three or four wires inside welding succeeded by a four wires outside welding submerged under flux. For a high toughness level of the WM a slightly basic flux will result in a balanced oxygen content of the WM so that a fine grained acicular ferritic microstructure is developed and the amount of oxide inclusions is minimized which would impact the WM toughness significantly. The chemical composition should not support the formation of the lower toughness eutectoid ferrite. The WM composition should be as lean as possible. For this application a MoTiB and/or a TiB based chemistry was selected for the wire providing the required strength for an X-70 and the toughness required. The use of Mo or not depends on the wall thickness of the pipes. 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 9 kJ/mm and a cooling time $t_{8/5}$ which results in the formation of localized upper bainitic coarse grains.. The lower toughness values not only in the WM but also in the BM structure, specially in the HAZ and fusion line, FL, was discussed already before. Fracture mechanically wise the required values to provide excellent performance are much lower as requested in all Tendon Pipe Specification known to the authors.

After welding cold expansion is performed as described before. This production step finalizes all efforts regarding geometry control and provides a stress relieving function due to plastic deformations implied during this process.

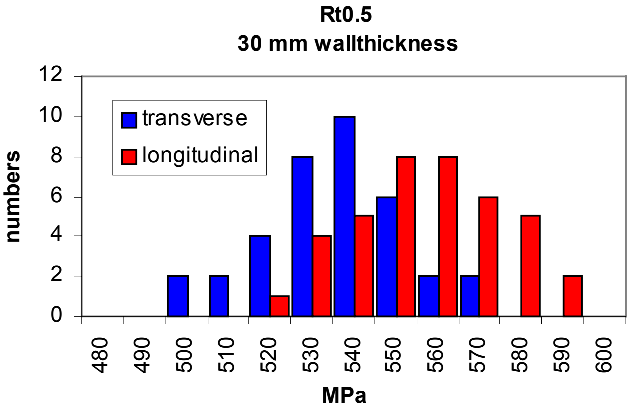
RESULTS, 30 mm WALL THICKNESS ORDERS

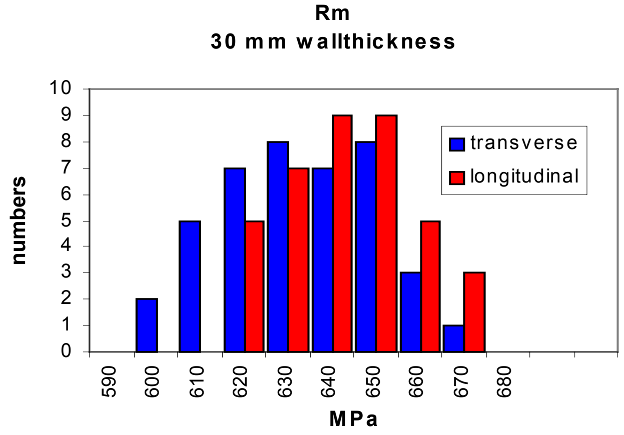
Mechanical Properties

Figure 04 shows the strength distribution for several Tendon Pipe orders with a wall thickness of 30 mm. Please notice the narrow window of 80/100 MPa achieved even over several orders and the requirement for longitudinal and transverse tensile tests which are requested due to the load situation of Tendon Pipes.

Figure 04: Strength distribution from several orders with 30 mm wall thickness in X-70, a: YS, b: TS

Figure 05: Charpy Impact values (single values) in the BM and HAZ





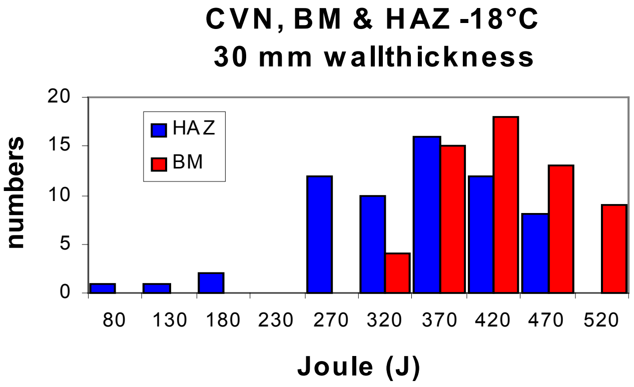
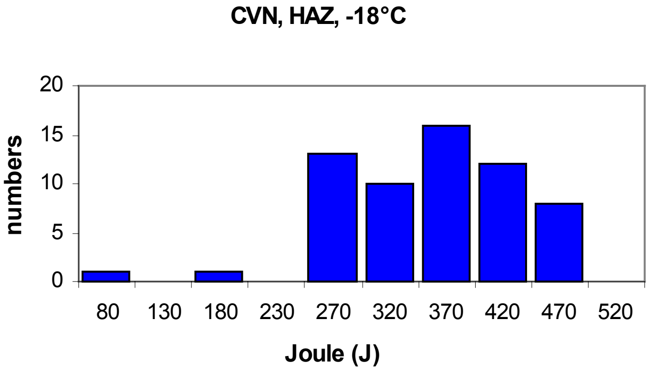


Figure 05 shows the Charpy impact values from several orders in X-70 with 30 mm wall thickness determined for the BM and HAZ. The former discussed phenomena of the localized areas of lower toughness can be seen in this figure.
The HAZ is clearly governed by the BM toughness. Some areas with lower toughness where found. Due to the measures described before they are very seldom and randomly and the listed specified requirements are met in all cases.

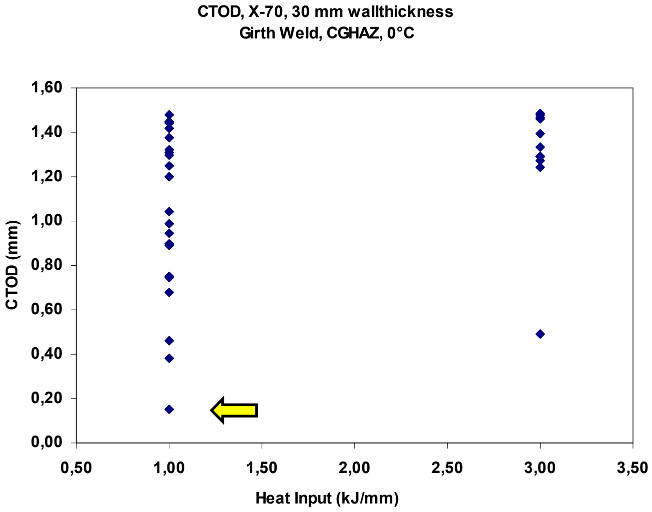
The toughness requirements for the weld material as listed in table 03 are also fulfilled, figure 06.

Figure 06: Charpy Impact values (single values) of the weld material



The girth weld is one design element of the Tendon String which is very much exposed to the main stresses. According to all TLP providers and operators the safety of this girth weld is essential for the safety concept of Tendoners and are very much investigated including fracture mechanical assessments. The common fracture mechanical assessment of the girth weld is based on CTOD values. The required values are very much driven by API RP 2Z. With today's knowledge these values are very conservative, specially with the NDT methods being available today. Nevertheless, good past experience with this code, criticality of the weld and the regulatory status is so that they are still required today. Figure 07 shows CTOD values achieved again over several orders. 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. Fabrication yards are using today mostly automated girth welding methods 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 provide an already conservative value. The higher heat input is mostly used to cover repair welding procedures. As already discussed in some cases during CTOD testing, and also during CVN testing, isolated grains of upper bainite carrying a martensite structure are being discovered providing lower toughness readings. These grains do not impact the performance of the pipes. Due to the selected parameters they are extremely small, very seldom and randomly distributed over the wall thickness. In this particular case due to fracture mechanical review the one lower value shown in figure 07 at 1.0 kJ/mm heat input was released.

Figure 07: CTOD values (single values) of the girth weld

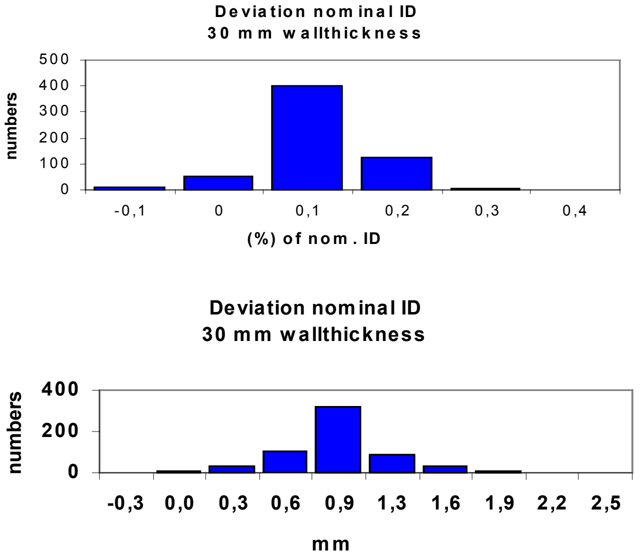


A set of three more CTOD sample from the same area provided values in the normally expected range.

Geometrical Properties

The geometry of the pipes is the second main aspect of a Tendon Pipe. The tolerances are listed in table 01.

Figure 08: Deviation of the inside diameter in mm and in % of nominal ID measured over several orders



The diameter should be very constant and as close as possible to the ideal shape of a circle. Figure 08 represents the deviation from the nominal outside Diameter, OD, for the production of several orders. The narrow scatter band assures a matching 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. 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 09: Out of roundness (OOR) values measured over several orders

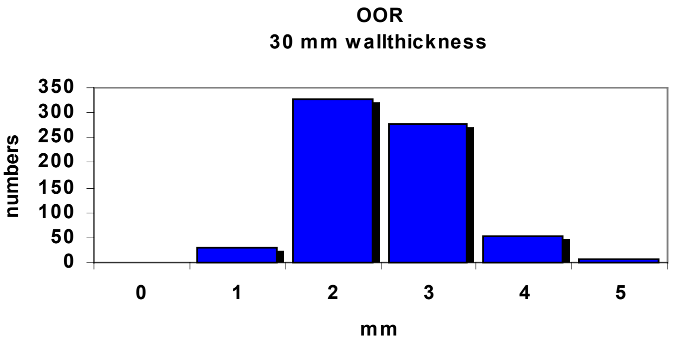
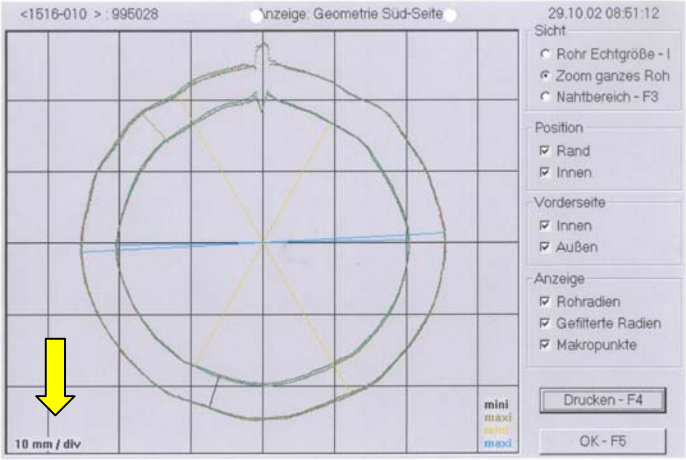


Figure 09 exhibits OOR values again measured over several production campaigns. It can be seen that the criteria of a very small OOR is well met and only a very small amount of pipes showing OOR values above 3 mm. Additionally to the low absolute value also the shape of the OOR is very consistent, Figure 10. Please consider the very high magnification of this picture. This assures not only the desired little high-low's after alignment before welding of the girth weld but also reduces the costly selection and positioning of the pipes during the welding preparation in the fabrication yard.

Figure 10: Characteristic shape of a pipe end



Sicht
○ Rohr Echtgröße - I
● Zoom ganzes Roh
○ Nahtbereich - F3

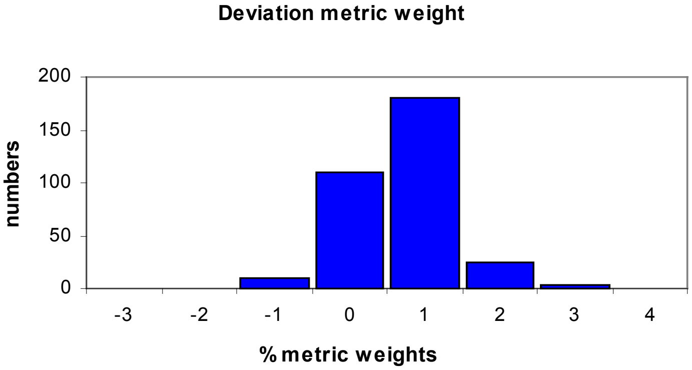
Position
☑ Rand
☑ Innen

Vorderseite
☑ Innen
☑ Außen

Anzeige
☑ Rohradien
☑ Gefilterte Radien
☑ Makropunkte

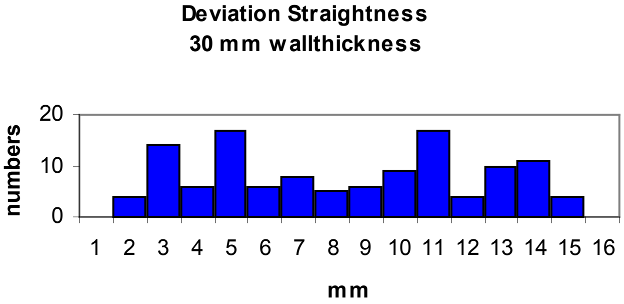
In order to avoid an impact on the payload of TLPs due to the weight of the steel tendoners the principle of neutral buoyancy is one goal in the design and manufacturing of the tendoners. A very small wall thickness tolerance and with this a small variation of the specific weight of the pipes is very important. The distribution of the deviation from the nominal specific weight in [%] is shown in figure 11. Please consider also in this case that these values represent the production of several orders. For one order the scatter band would be even smaller.

Figure 11: Distribution of the deviation from the nominal metric weight over several orders.



The straightness of the pipes is an additional important parameter. The deviation of the straightness can results in a deflection of the axial stresses out in the girth weld with an significant impact on the life time of the girth welds.

Figure 12: Distribution of the deflection from the straightness at over several orders



The listed figures show the distribution of the deviation of the straightness over several orders. It can be seen that in some cases a rework was necessary to achieve the requirement of 15 mm for a 60 feet long pipe. This rework level is very small but gives a not normal distributed curve.

RESULTS, 40 mm WALL THICKNESS TRIAL

Mechanical Properties

A test research for TLPs with advanced designs, like ETLP or TLPs of the 4th generation, provide solutions to use TLP concepts reaching water depths of 7,500 feet or even passing this limitation. Additionally to the normal concepts these water depths request to incorporate collapse pressures in the tendon design. These large water depths require Tendon Pipes with much heavier walls as mostly been used until today.

In order to proof the feasibility of pipes in X-70 with such heavy wall thickness Europipe produced in a trial pipes with an OD of 36" and a wall thickness of 40 mm (1.57"). This trial included a comprehensive testing program to provide data to potential users and to the authorities for an approval requested if such pipes shall be used in TLP projects including the GoM. During this trial several production parameters were varied and investigated in order to find the best set up for the production.

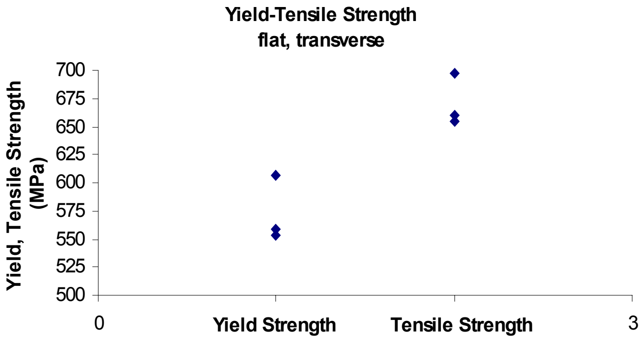
Fourteen pipes were produced. Three pipes were finally selected for testing in order to represent the different production routes being utilize for the slap and plate supply. The supply chain represents Europipe's two mother companies and was described already in the plate section. In order to provide the highest flexibility in the delivery all three options were investigated and part of the approval program.

The following routes are listed

- slab Dillinger, plate Dillinger, DH-DH
- slab Dillinger, plate Mannesmannroehren Muelheim, DH-MRM
- slab Huette Krupp Mannesmann, plate MRM, HKM-MRM

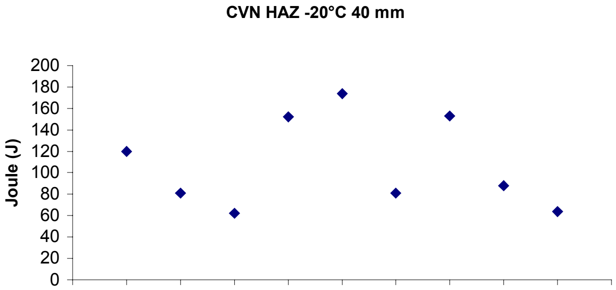
The determination of the mechanical properties showed, figure 13, that the strength level achieved for the pipes was very high and already in the range of an X-80 material.

Figure 13: Strength properties of three selected 40 mm trial pipes



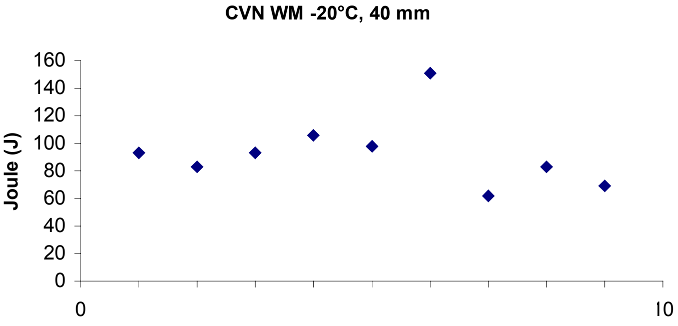
The high strength impacts the Charpy-V-notch test results specially in the CGHAZ of the long seam. Figure 14 shows the Charpy-V-notch values for the three production routes. In some cases they are just border lined. They will improve in a production where the chemistry and rolling practice for the base material, the plates, is re-adjusted to fulfill the level of an X-70 grade. Also for the weld material the achieved Charpy-V-notch values, figure 15, are still above the limits known to be required for most of the TLP projects in the past. Compared to the production values of the 30 mm orders they are somewhat lower.

Figure 14: Charpy-V-notch values (single values) of the HAZ at 40 mm trial pipes



Also the strength level of the weld material was higher and will be re-adjusted for a further production with the same positive impact on toughness as described already for toughness values for the HAZ..

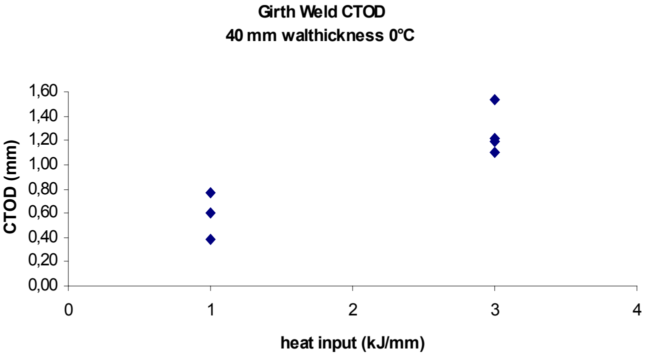
Figure 15: Charpy-V-notch values of the weld material at 40 mm trial pipes



It was already discussed that the girth weld is more critical for the fatigue behavior of the tendon string than the long seam. High CTOD values in the HAZ of this part of the tendoners provide a high safety for the entire string

The toughness of the girth weld HAZ is very much depending on the base material where all measures were taken to provide a good base for high CTOD values. The girth weld is made by an multi layer welding method with low heat input which is very much independent from the wall thickness of the pipe. The heat input is low in comparison to the double seam method for the longitudinal weld which is much influenced by the wall thickness and the cooling time $t_{8/5}$. Due to this the CTOD values of the girth weld are very well above the limits and similar to the 30 mm wall thickness, results figure 16.

Figure 16: CTOD values from girth weld 40 mm trial pipes

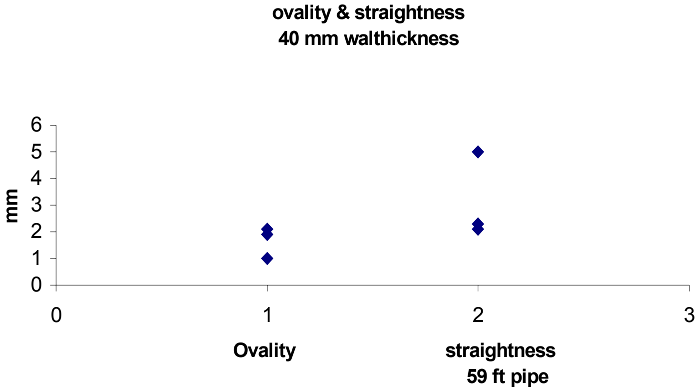


The chemistry concept of the 40 mm wall thickness trial pipes is basically very similar to that for the 30 mm wall thickness production, see table 04.. The excellent CTOD values did proof this being the right selection..

Geometrical Properties

Additionally to the mechanical properties all measures were taken to reproduce or even to improve the already very good geometrical tolerances achieved at the 30 mm orders. The finally produced pipes provided excellent results for the critical geometrical parameters as of straightness and ovality. Figure 17 shows these values.

Figure 17: Geometrical values of critical parameters at 40 mm trial Pipes



It has to be stated that these three trial pipes do not have a good statistical relevance. For a normal production also higher values have to be considered. It can be stated that with the straightness requirements of 14 to 15 mm and ovality requirements of 4 to 5 mm the listed values proof that these limitations will be reachable.

CONCLUSIONS

Europipe did collect experience out of several Tendon Pipe orders in the 30 mm wall thickness range how to meet the high pipe requirements for this application. With this experience and additionally with the knowledge about manufacturing pipes to resist buckling under high external hydrostatic pressure Europipe produced in a trial Tendon Pipes with 40 mm wall thickness which will fulfill the requirements of the future generation of deep water TLPs. After finalizing of this work not only the pipes for these new projects will be available but also the approval process will be well under way.

REFERENCES

3 Bai, Y., G. Knauf, G. Hillenbrand
Materials and Design of High Strength Pipelines
ISOPE-2000-YB-001

1 Graef, Michael, Niederhoff, Kurt
Properties of HAZ in two-pass submerged-arc welded large-diameter pipe
Europipe publication, 2001

2 Graef, M. and K. Niederhoff
Toughness behavior of the heat affected zone (HAZ) in double submerged-arc welded large-diameter pipe;
Pipeline Technology Conference, 15-18 October 1990,
Oostende,
Belgium

4 Fu, B., Guttormsen, S., Vu, D. Q., Chauhan,V., Nokleebye, A.
Significance of Low Toughness in the Seam Weld HAZ of a 42-inch Diameter Grade X-70 DSAW Line Pipe – Experimental Studues.
Paper, 13th Biennial, 2002, Berlin

5 API RP 2Z, 1987, Recommended Practice for Production for Steel Plates for Offshore Structures, API, Washington, DC

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