DEVELOPMENT AND PRODUCTION OF LARGE-DIAMETER LINE PIPE FOR OFFSHORE APPLICATIONS

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Abstract

The continuous analysis of market requirements for large diameter line pipes used in offshore application reveal that overall the requirements are becoming more and more stringent. This development is triggered by the fact that offshore pipelines are installed in deeper water and operated under higher pressures. Therefore the line pipe material has to show higher strength properties with simultaneously increased toughness. In case that the gas to be transported contains certain amount of H_2S additional requirements regarding HIC (Hydrogen Induced Cracking) resistance have to be taken into consideration. As installation of offshore line pipes play a significant role within the whole project costs also the pipe geometry has to be improved steadily with tighter tolerances especially for out of roundness and wall thickness in order to facilitate and speed up pipe laying.

Consequently the applied technologies from steel making to pipe production are continuously improved in order to increase the quality level and the productivity by reducing non-quality costs. In this paper, the crucial manufacturing steps necessary to fulfil these stringent requirements for offshore line pipes are described. Special attention is paid to the pipe forming, the welding process and its control as they are of essential importance for the intrinsic pipeline safety. This will be supplemented by review of current project examples for different offshore applications with specific requirements such as thick wall pipe for North Sea offshore application and production of sour service line pipes.

1. Manufacturing

The steady increase in the operating pressures of oil and gas pipelines, pipe laying and service under extreme conditions in the offshore regions have led to increasingly severe property requirements for pipeline steels. Today, not only greater wall thicknesses but also higher strengths are needed. Further requirements are related to excellent toughness, good weldability and pipe geometry within narrow tolerances. In case of sour service application the line pipe steel has in addition to withstand the aggression of corrosive media.

The most economic production method for line pipes fulfilling such high quality requirements is the UOE manufacturing route with submerged arc welding process in two passes. However, the quality control for DSAW (Double Submerged Arc Welded) line pipes of EUROPIPE already starts in the steel plant of the plate manufacturer. Table 1 gives an overview of the different manufacturing steps and quality aspects, which are of primary importance during the production flow of large diameter line pipes.

Table 1: Main manufacturing steps and quality aspects for SAW large diameter line pipes

Product Stage	Manufacturing Step	Primary Quality Aspect
Steel	Ladle Treatment BOF Secondary Metallurgy Continuous Casting	Chemical Composition Cleanness/Inclusion Control Segregation Control Surface Quality
Plate	Slab Reheating Rolling Parameter Cooling Parameter	Microstructure Mechanical Properties Corrosion Resistance Plate Geometry
Pipe	Forming Welding Expanding NDT	Pipe and Weld Geometry Mechanical Properties Reduction of Residual Stresses Weld Quality Corrosion Resistance

The production of steel with high cleanness begins with the hot metal desulphurization. The carbon and phosphorus contents are reduced in a BOF converter with bottom stirring to achieve values required within the metallurgical design selected for the particular application.

The application of a vacuum tank degassing enables a strong desulphurization and degassing, i.e. the expulsion of nitrogen and hydrogen to be achieved simultaneously. Following the vacuum degassing the molten steel is stirred with an optimized inert gas ratio to improve the cleanness further. As a result, the total contents of residual elements like Phosphorus, Sulphur, Nitrogen, Hydrogen and Oxygen are reduced to very low values providing an excellent cleanness of the steel [1].

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.

Starting from defined steel composition, the target-microstructure and corresponding properties are achieved by the application of TMCP (Thermo-Mechanical Control Process) incorporating a special time and temperature sequence. This incorporates the reheating of the slab to specific temperatures, the rolling to successive thicknesses with specific reductions at prescribed temperatures interrupted by cooling periods accelerated. The cooling after final rolling can be performed with water down to specific final cooling temperature (followed by cooling on ambient air) with specific cooling rate [2].

In the large-diameter pipe mill the plates are formed into pipes using the UOE process. Line pipes manufactured for offshore applications require well equipped and maintained forming presses with high forces due to the challenging combinations of wall thickness, outside diameter and steel grade. The crimping press represents the first important forming step where the basis for the final pipe geometry in terms of out of roundness is laid. The subsequent U-ing press transforms the crimped plate to an open slit pipe with vertical plate edges guaranteeing a trouble-free entry into the O-ing press. At the UOE mill of EUROPIPE in Mülheim the formed plate obtains its round shape with applied forces up to 60.000t. Each different nominal diameter necessitates specific forming dies. High precision and permanent control of all forming parameters is necessary in order to fulfil most stringent requirements regarding ovality and straightness after welding and expansion.

The next challenging step in the production of line pipe is the welding of the longitudinal seam. A wide range of different quality requirements have to be achieved reliably and under economic conditions. The production of a weld seam suitable for the purpose of high pressure line pipe is more than just joining two plate edges. The following Table 2 summarises the most important quality aspect of a submerged arc welded longitudinal seam:

Table 2: Quality aspects for SAW (Submerged Arc Welded) seams

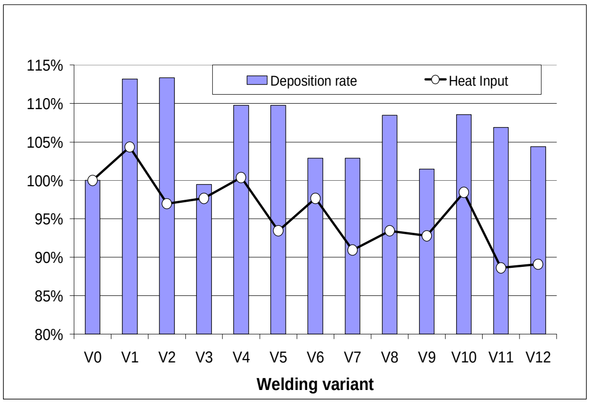
SAW quality aspects		
Mechanical Properties **Corrosion Resistance**	**Weld shape**	**Imperfections/Defects**
Strength Matching ratio Toughness Hardness HIC/SSCC resistance	Misalignment Radial offset Weld bead height Weld contact angle Weld bead width Interpenetration Weld linearity	Undercuts Slag inclusions Porosities Lack of fusion/interpenetration Cracks
Key factors: (Welding parameters) Consumables, Base metal	**Key factors:** Welding parameters (Consumables)	**Key factors:** Welding parameters (Consumables)

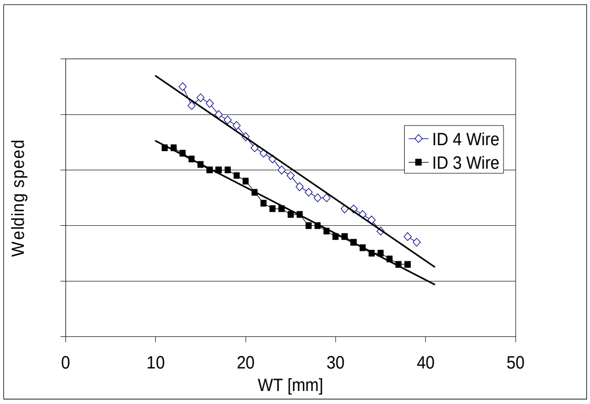
Whereas the mechanical properties/corrosion resistance is predominantly defined by the selection of appropriate welding consumables the weld shape and the occurrence of imperfections or defects is strongly influenced by the welding parameters.

In the EUROPIPE mill in Mülheim up to 15km of weld seam can be manufactured per day. Stable welding processes are mandatory to guarantee lowest repair and rejection rates. To further improve the process we invested in the latest technology of digital power sources.

This new welding equipment enables to improve the welding speed in order to reach high productivity and low heat input without the risk of increasing defect rates which is essential for thick wall line pipes. Figure 1 (left) shows the optimisation of heat input while increasing the deposition rates at a given wall thickness. A reduction of 11% heat input with a parallel increase of deposition rate of 4% was achieved by using the power waves options.

Figure 1: Optimisation of deposition rate, heat input and welding speed

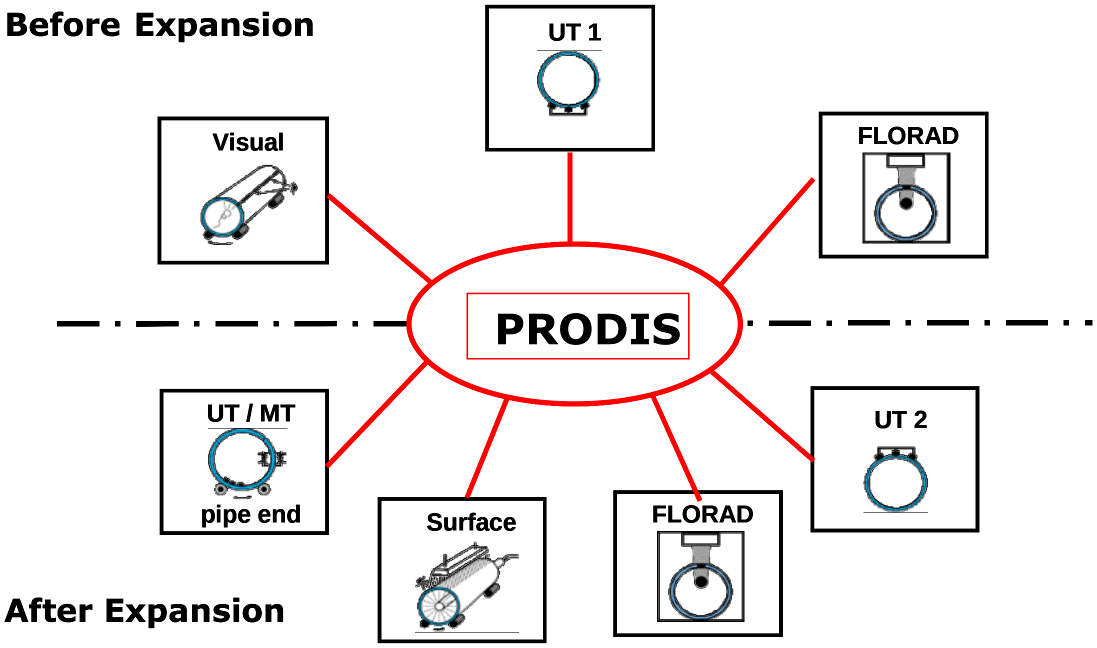




The installation of the new power sources went hand in hand with the introduction of 4-wire welding inside and 5-wire welding outside. The resulting increase of welding speed (Figure 1, right) of 25- 30% allowed a reduction from eight to seven welding lines. Nevertheless the welding capacity could be improved by 15%.

The next step is the fast feed back between non-destructive testing and welding to avoid systematic deviations. EUROPIPE relies on a combination of visual inspection, automated UT and X-ray. As shown in Figure 2 the visual testing immediately follows outside welding. Both internal and external pipe surfaces including weld seam are controlled. All kind of surface defects are detected and entered in PRODIS, the integral production data information system. Beside real defects such as undercuts the testing registers process deviations i.e. irregular weld shape or width and height of the weld seam. An automated 100% ultrasonic testing (UT) of the weld seam reports all internal imperfections. UT indications are confirmed by filmless radiography called FLORAD and/or verified by manual UT [3].

Figure 2: Non-destructive quality control linked to PRODIS



All test results are available in PRODIS. A list with all defect codes is on hand at any time to the welding operators. The consequent process control in combination with fast access to the essential information at any time and any place in the mill lead to a permanent reduction of rework and losses due to weld defects. The final forming step is expanding the pipe to its final outside diameter with carefully selected expansion ratios between 0.8 and 1.5%. Due to the plastic deformation the cold expansion reduces residual stresses within the pipe induced by forming and welding.

After expansion the remaining quality control steps according to the customer specification are performed as automatic ultrasonic testing and X-ray inspection of weld seam, hydrotesting and NDT (Non-Destructive Testing) inspection of pipe ends by UT and MPI (Magnetic Particle Inspection). Optional a full body MPI can be carried out on customer's request.

2.1 Thick wall X65 Pipe for Sour Service

First deliveries of sour service line pipe grade by EUROPIPE (former Mannesmann) were executed now more than 25 years ago. The development of line pipe steels for sour service over these years has been greatly governed by market trends. In total more than 3 million tons of line pipes for sour service in material grades up to X70 and wall thicknesses up to 41mm have been supplied documenting greatest experience in sour service production. One challenging order with regard to the sour service acceptance criteria in combination with stringent requirements on mechanical properties was the production for the RAS GAS project in Oman, where a grade X65 with a maximum wall thickness of 33.1mm was specified. In total 135,000t of line pipe were manufactured and delivered. The agreed HIC (Hydrogen Induced Cracking) test acceptance criteria are far beyond the usual requirements as defined by EFC 16 [4] or ISO 3183-3 [5]. Table 3 summarizes the most important production results. In Table 3a the mechanical properties are described by means of average values for specimens orientated transverse to the rolling direction. The requirements for grade X65 pipe were comfortably met.

Table 3a: Mechanical Properties

Mechanical Properties	**Mean Value**
Yield strength $R_{t0.5}$ [MPa]	480
Tensile strength R_m [MPa]	564
Y/T [%]	86
Elongation A2" [%]	50.0
DWTT @ 0°C [% SA]	89
CVN Toughness @-10°C Weld metal [J] FL [J] FL + 2mm [J] Base metal [J]	 175 422 410 433

The essential requirements for the chemical composition of HIC resistant steel are low concentrations of carbon, manganese and sulphur. As Table 3b reveals these requirements have been strictly observed in the chemical composition of the pipe used for this X65 offshore project. Besides the low carbon and manganese contents, the steel features micro-alloying additions in the way of vanadium and niobium, which were made to meet the requirements for the mechanical properties.

The HIC test results on this order are given in Table 3c. It has to be pointed out, that the severe sour service requirements for this order could only met by using extraordinary precautions during steel making, casting and plate rolling, respectively. Under the standard test conditions according to NACE TM02-84 [6] solution A (pH 3, 1 bar H_2S) the specified acceptance criteria are reliably fulfilled.

Table 3b: Mean Chemical Composition (weight %)

C	**Si**	**P max.**	**S max.**	**Mn**	**Others**	**CE(IIW)**	**Pcm**
0.037	0.28	0.015	0.0015	1.38	Nb, V	0.33	0.13

Table 3c: HIC Test Results

Specification Requirements		**Results on Pipe**
Test Condition	Acceptance Criteria	Base + Weld Metal
pH 3	CTR: ≤ 1.5 %	CTR ≤ 1.2 %
1 bar H_2S	CLR: ≤ 10 %	CLR <= 5 % for 90 %
	CSR: ≤ 1 %	CSR ≤ 0.5 %

Table 3a-c: Results on production pipes of 135,000t with 36" ID x 27.2 - 33.1mm WT Grade X65 intended for sour service pH 3

2.2 Offshore SAWL 485 IFD Pipe

The Langeled pipeline transports natural gas from Nyhamna on the Mid West coast of Norway via the offshore platform Sleipner to Easington in England. Unprocessed gas is transported by two 30"OD pipelines from the Ormen Lange field at about 1000m water depth outside mid-Norway to the gas terminal at Nyhamna, where the gas is treated before it is sent through Langeled as the first pipeline bringing gas from Norway directly to the U.K (see Figure 3).

The Langeled North is a 630km long 42"OD pipeline. The design pressure out from Nyhamna is 250bar, requiring up to 34mm wall thickness. In order to optimise the steel quantity and the welding time, the Langeled North has been designed with two different design pressures, 250bar for the northern half and 215bar for the southern half. The Langeled South is a 550km long 44"OD pipeline. The design pressure in this case is 156bar, requiring a wall thickness of 23 to 24mm. The design of the pipeline is according DNV-OS-F 101 in grade SAWL 485 IFD [7].

Figure 3: Major pipeline projects in the North Sea

Langeled Project

EUROPIPE had to supply 835km or 630,000t. About 800km were produced in Mülheim and the remaining part of 35km in Dunkerque pipe mill. Pipe production started in April 2004 and was finished in December 2005. A lot of 30,000t per month had to be shipped to Norway to receive corrosion and heavy coating. The following will summarize the pipe production and the logistical challenge.

For this project logistics in terms of plate delivery, handling of samples and specimens and pipe dispatch was quite a challenge.

In total about 630kt of steel, of plate and of pipes had to be produced for 25 delivery lots and to be transferred from one production step to the next and all quality assuring topics had to be taken into account. About 3,700 heats were cast to produce pipes with about 835km total length. To get the required quantity in time all plate production routes available were used.

The fundamental requirement for steels intended for offshore line pipe for the North Sea can be defined in terms of internal homogeneity and high toughness of the material at low temperatures, i.e. microstructural design.

All steps in the production of such steels have to be optimized in order to meet the requirements. The first step in the design has been the choice of the chemical analysis. After several rolling trials at the research lab with very promising results a few heats were cast and used in the steel works in order to roll heavy plates in the entire wall thickness range from 23 to 34mm. The assessment of the plate properties revealed that all required mechanical properties on plate was reached safely with one chemical composition, but optimized Thermo-Mechanical-Control Process (TMCP) rolling concepts adapted to individual wall thickness. The thicker wall required a more stringent accelerated cooling after rolling of the plates. The chosen composition is given in Table 4. With this concept the properties of strength, toughness, weldability and fabricability were comfortable met.

Table 4: Mean Chemical Composition (weight %)

C	**Si**	**P max.**	**S max.**	**Mn**	**others**	**CE(IIW)**	**Pcm**
0.08	0.3	0.015	0.003	1.6	Nb, Ti	0.38	0.19

Compared to routine approaches the present steel had no Vanadium additions and is very lean in composition. The steel was desulphurized and dephosphorized to low sulphur and phosphor levels, respectively. The carbon and manganese contents and the microalloying elements Titanium and Niobium served to ensure that the steel attained the required mechanical properties.

As can be seen from the data given in the table 5, the pipe could be produced with a high statistical confidence level, despite its heavy wall. Both the transverse and longitudinal tensile properties of the pipe are comfortably above those required for grade SAWL 485 IFD. The comparison of mechanical properties in transverse and longitudinal direction showed that the yield strength is on the same level but the tensile strength in transverse direction is about 20MPa higher.

Table 5: Results on 44"OD x 23.3 - 24.0mm (left) and 42"O.D. x 29.1 - 34.1mm WT (right) SAWL 485 IFD line pipe production for the Langeled project

Mechanical Properties	**Mean Value**
YS $R_{t0.5}$ (MPa) Transverse Longitudinal	 522 515
UTS R_m (MPa) Transverse Longitudinal	 628 603
Y/T (%) Transverse Longitudinal	 83 85
Elongation A5 (%) Transverse Longitudinal	 20.8 22.5
CVN energy @ -30 °C Weld metal (J) HAZ (J) Base metal (J)	 151 225 209

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The Charpy V-notch impact energy values measured on the base material at -30°C are all in excess of 200J. Even at test temperatures as low as -70°C the Charpy energy (CVN) is safely above 150J. The high toughness of the base material is shown in the temperature transition curve for the CVN (Figure 4) and the Battelle Drop Weight Tear Test (BDWT test) (Figure 5) for the heavy wall material.

Figure 4: CVN temperature transition curve for 42"OD x 33.3mm WT, SAWL 485 IFD

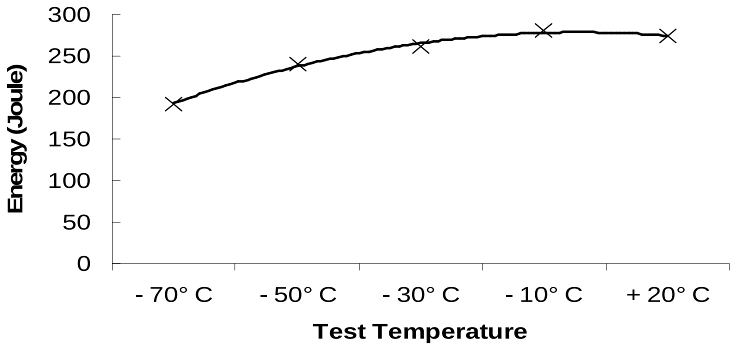
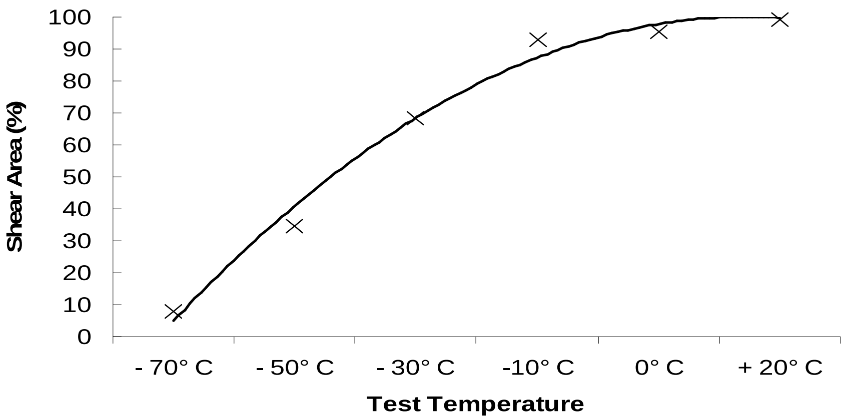


Figure 5: BDWT temperature transition curve for 42"OD x 33.3mm WT, SAWL 485 IFD



In the course of the production the base metal chemistry has been further optimised, e.g. reduction of Carbon and Titanium content in order to promote the properties in the base metal and HAZ.

Thus, the steel chemistry selected and the steel making practice adopted as well as the rolling and welding parameters have proven the right approach to execute this big order successfully.

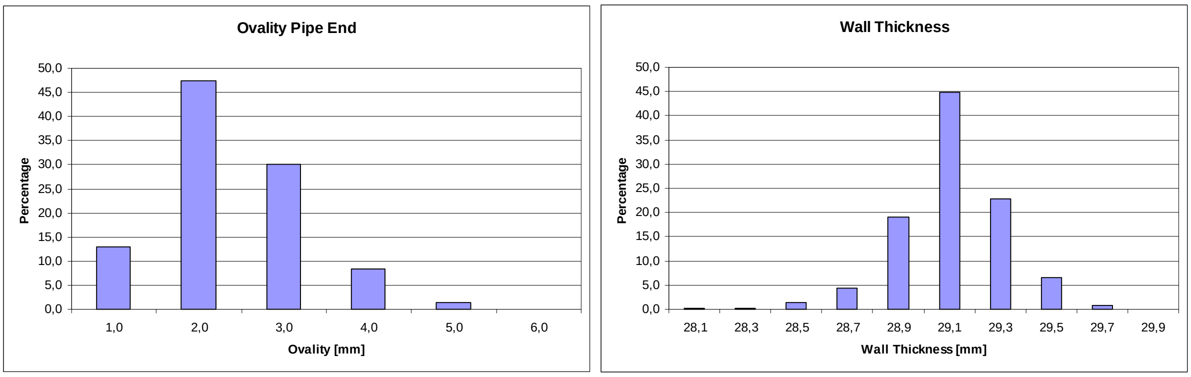
In order to allow efficient handling during offshore welding the following severe dimensional requirements were set (Table 6):

Table 6: Main Dimensional Requirements of Line pipes for Langeled Projects

Dimension	Tolerances
OD pipe ends	-0.6/+1.6mm
Ovality pipe ends	Max. 5mm
Peaking	1.5mm
Wall thickness	±1mm
Straightness	0.15% Length

In Figure 6 the statistical distributions for the ovality and the wall thickness measurements are shown as example for the production with 29.1mm wall thickness. The specified tolerances are met with high statistical reliability. For more than 80% the measured ovalities are below 4mm and the actual delivered wall thickness range amounts to 1.2mm for more than 95% of the pipes.

Figure 6: Statistical distribution of ovality and wall thickness for 29.1mm nominal WT



3. Conclusions

This paper describes the main manufacturing steps for longitudinal submerged arc welded large diameter line pipe essential to serve the increasing requirements of offshore applications. Consistent quality control starting in the steel plant and continuously going through all subsequent production steps is the basis for high quality. Special attention is paid to the pipe forming, the welding process and its control as they are of essential importance for the intrinsic pipeline safety.

Production results of recent orders for offshore projects with challenging requirements such as thick wall pipe for North Sea and production of sour service line pipes are presented to give an impression about actual market developments and to describe the corresponding EUROPIPE solution. The two examples show how specific demands like severe sour service acceptance criteria, narrow ranges for mechanical properties and dimensional tolerances are reliably fulfilled in time even for very large order quantities.

4. References

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