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MANUFACTURING OF X100 PIPES FOR THE TAP PROJECT

Dr. Hans-Georg Hillenbrand
EUROPIPE GmbH
Wiesenstraße 36
45473 Mülheim, Germany

Dr. Andreas Liessem
EUROPIPE GmbH
Pilgerstraße 2
45473 Mülheim, Germany

Dr. Fabian Grimpe
Mannesmannröhren Mülheim
Wiesenstraße 36
45473 Mülheim, Germany

Volker Schwinn
AG der Dillinger Hüttenwerke
Hüttenstraße
66763 Dillingen, Germany

ABSTRACT

The application of high strength steels like X100 are considered as an economical necessity in order to supply large volumes of gas over long distances in a competitive manner. The development of the grade X100 started more than 10 years ago and has progressed significantly. Therefore the focus of actual development and research work is focused on questions regarding the installation and the service behaviour of such high strength steels. In this context the TAP project has been launched by the ENI group in order to provide answers regarding the economic viability, the technological reliability and the real possibility of constructing high pressure pipelines with this newly developed steel grade.

In this paper the manufacturing of line pipe in grade X100 for the TAP project including the two fibre reinforced crack arrestors will be summarized and the production results regarding strength and toughness are presented. Furthermore the analysis of tensile test results regarding the influence of specimen type, anisotropy and the effect of thermal treatment (low temperature ageing) on the stress-strain curve will be discussed.

Keywords: X100, strength, toughness, anisotropy, ageing effect, crack arrestor

INTRODUCTION

ENI initiated in the mid 90's a huge research effort on the subject of looking for a competitive option of gas-to-market via High Pressure (greater than traditional 8 to 10 MPa) and High Grade (X80 and X100) line pipes for long distance gas transmission lines (4 to 6000 km) crossing harsh environments.

In this R&D framework, ENI is currently performing a 3 years project, called TAP (Trasporto gas Alta Pressione), with the aim of studying constructability and field performance of modern high grade line pipe in operation, as well as to define and specify new technologies for soon-to-come long distance natural gas pipeline projects [1].

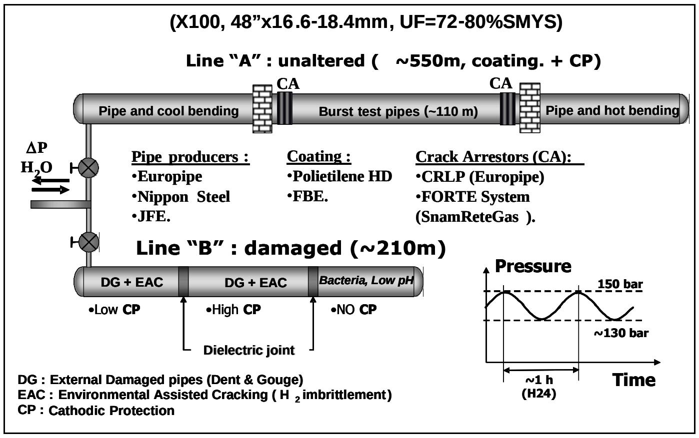


Figure 1 - X100 Pilot Section formed by two lines , "A" and "B"

Despite the significant effort spent in recent years on the X100 issue, a series of open questions, mainly regarding integrity of high grade line pipe in operation over the envisaged life span in real environment, is still under discussion. The TAP project, led by Snamprogetti and carried out in cooperation with competent divisions of ENI, is aiming to fill this gap, by integrating laboratory and full scale experimental programs, including the realization and simulated operation of a X100 pilot section (formed by two separate lines "A" and "B", see Figure 1) in the CSM full scale test station, Perdasdefogu, in Sardinia island, Italy.

Operation includes typical fluctuation in pressure over a period of time, 18 months, sufficient to detect line pipe susceptibility to Environmental Assisted Cracking (EAC), accounting for different wall thicknesses/usage factors (72% and 80% of SMYS) as well as the presence of typical defects from third party interference.

In 2004 EUROPIPE produced about 500m of L690MC equivalent to X100 with 48” outside diameter with 16.6mm and 18.4mm wall thickness for the TAP project. The plates used for this pipe production have been manufactured by the plate mill of Mannesmannröhren Mülheim and Dillinger Hütte respectively. After production the pipes have been coated with Fusion Bonded Epoxy (FBE). As the recent full scale burst tests demonstrate that intrinsic crack arrest can not be guaranteed even at very high CVN toughness as high as 270J, the use of crack arrestors are regarded as inevitable. Therefore two fibre reinforced crack arrestors were designed and delivered for the TAP project.

PLATE PRODUCTION

For the X100 pipes plates in thickness of 16.6mm and 18.4mm were produced in the plate mills of Dillinger Huette and Mannesmannröhren Mülheim. On the basis of the existing experience in developing and producing X100 plates and pipes [2, 3, 4] suitable steel and plate making route, including chemical composition (Table 1), were chosen.

Element	***content, wt%***
C	0.06
Mn	1.90
Nb	0.04
Ti	0.02
N	0.004
Others	V, Cu, Ni, Mo, Si
CEV (IIW)	0.48
Pcm	0.20

Table 1: Chemical analysis

The target values for the mechanical properties on plate were carefully defined considering the cold deformation during pipe forming and expanding.

Clean steel treatment provides the basis to achieve high toughness properties. Appropriate casting technique results in reduced segregation and keeps the low inclusion content achieved after secondary metallurgy process. To produce the target ultra high strength and toughness, a very fine grain bainitic microstructure is indispensable. Consequently special attention was focused to achieve low austenite pancake thickness during TMCP processing before final cooling. In combination with the chemical composition fully bainitic microstructure was achieved by adequate cooling (rate and cooling stop temperature) after finishing rolling (Fig. 2).

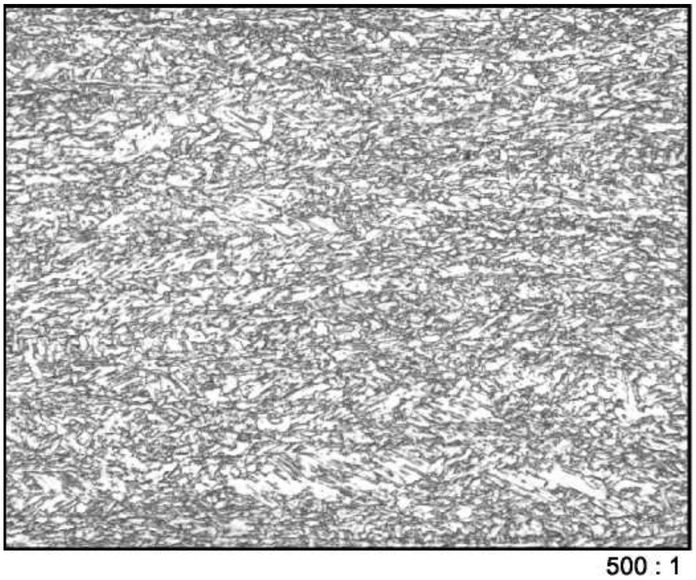


Figure 2: Typical microstructure

PIPE PRODUCTION

The pipes were manufactured in the UOE pipe mill of EUROPIPE in Mülheim. After forming the plates with the 60,000t O-ing press of the 18m-line the pipes were submerged arc welded using 4-wire technology for the inside weld seam and 5-wire technology for the outside weld seam. After welding and in-house non-destructive testing the pipes were expanded to their final pipe shape. A second non-destructive inspection is performed according to customer specification before the final inspection of pipe surface and geometry completes the pipe production.

The requirements regarding the mechanical properties are given in table 2.

Properties	***Unit***	***Specified Values***
Rt0.5	MPa	690 – 825
Rm	MPa	760 – 970
Y/T	-	max. 0.95
El (A5)	%	min. 11
CVN BM @-10°C	J	min. 180 / av. 240
CVN Weld @-10°C	J	min. 50 / av. 75
DWTT @-10°C	% SA	min. 75 / av. 85

Table 2: Mechanical property requirements of L690MC in transverse direction for TAP project

In order to gain higher statistical relevance each individual pipe was tested instead of the usual heat-wise testing. The above mentioned requirements on tensile tests had to be fulfilled in transverse direction using un-flattened round bar specimen (8mm dia, mid-wall position) in order to exclude the Bauschinger effect. The mean values (appr. 40 values) for the 16.6mm and 18.4mm thick pipes are summarized in table 3.

Properties	***Unit***	***Mean Values***	
		16,6mm	***18,4mm***
Rt0.5	MPa	741	764
Rm	MPa	786	815
Y/T	-	0.95	0.94
A5	%	16.9	17.5
CVN BM @-10°C	J	274	248
CVN Weld @-10°C	J	180	185
DWTT @-10°C	% SA	98	93

Note: Tensile tests performed using round bar specimen

Table 3: Mechanical Properties of L690MC for TAP Project

It can be stated that the requirements given in table 2 have been fulfilled reliably apart from the Y/T ratio where values above the upper limit of 0.95 up to a maximum of 0.98 occurred. The results for the two different wall thickness representing two different plate manufacturers are very comparable revealing no significant variations. Therefore the following results are discussed only for the 16.6mm wall thickness for simplicity reasons.

The transition behaviour of the L690MC was characterised by Charpy-V notch testing and full wall pressed notch Drop Weight Tear Test (DWTT). As shown in figure 3 the Charpy-V notch energy amounts to 270J in the upper shelf, and the transition area starts at temperatures below -30°C. Down to this temperature 100% shear fracture was observed on all specimens. The transition temperature for 50% of upper shelf energy is below -70°C, maybe estimated at -80°C.

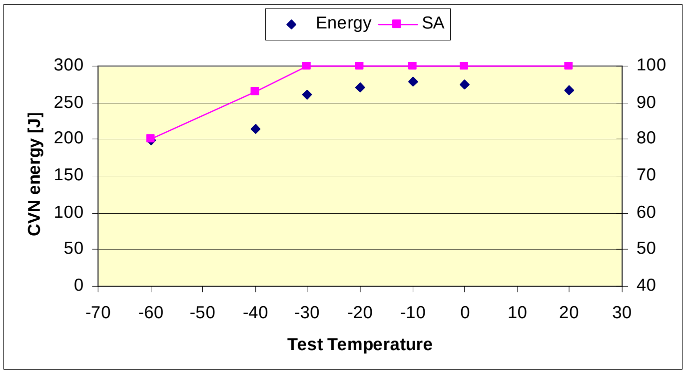


Figure 3: CVN transition temperature L690MC with 16.6mm wall thickness

The DWTT transition curves are given in figure 4. Beside the shear area fraction (SA), the total energy and propagation energy have been determined. The tests were performed using a drop weight test equipment with 110kJ maximum impact energy. The shear area in the upper shelf region reaches up to 100%, whereas the transition area onsets below 0°C. The transition temperature for 85% shear (average of two specimens) was found to be at -15°C. The total energy was measured to be higher than 8kJ in the upper shelf. Two third of this total energy could be contributed to the propagation energy.

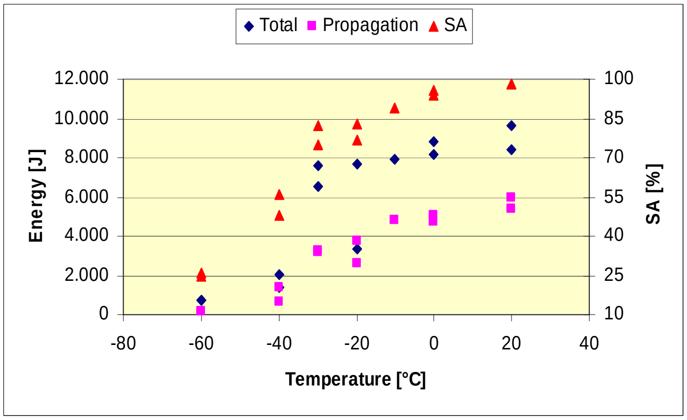


Figure 4: DWTT transition curve L690MC with 16.6mm wall thickness

High strength steels like X100/L690MC are currently investigated and developed with regard to their applicability in strain-based design. Whereas the conventional tensile properties as yield strength, ultimate tensile strength and fracture elongation are sufficient to define the material's behaviour for stress-based design, line pipe material applied in strain-based design needs further investigation. In particular, the strain hardening and the shape of the stress strain curve are of great significance when the amount of plastic deformation and consequently the maximum acceptable defect sizes are determined [5, 6]. It is furthermore important to determine these properties in their final condition after coating as the tensile properties and the stress-strain curve are influenced by ageing.

Within this context a detailed tensile test program has been performed in order to investigate not only the influence of the specimen type and specimen orientation, but also the influence of a thermal heat treatment similar to the one applied during coating. The program comprises the following tests:

- Influence of specimens type: Round bar (8mm dia.) vs. full wall rectangular specimen (flattened in case of transverse orientation)
- Influence of specimen orientation (Anisotropy): Transverse vs. longitudinal
- Influence of simulated coating heat treatment: as-welded, 200°C for 2/5/15minutes holding time

The parameters of the simulated heat treatment were chosen considering the actual coating conditions for FBE coating applied at the coating plant of EUPEC GmbH, a subsidiary of EUROPIPE. Typically the pipes are heated by induction up to a temperature around 200°C and the pipe material is exposed for 4-5 minutes to this temperature level during coating application. Hereafter the pipes are rapidly cooled down with water. The chosen holding times for the heat treatment simulation of 2min, 5 min. and 15 min. cover a wide range, variations of the process or even the situation that a pipe has to pass the induction heating device twice prior to coating application.

Figure 5 reveals the mean tensile properties yield strength, ultimate tensile strength and Y/T ratio in the as-welded condition both in transverse and in longitudinal direction.

Furthermore the influence of the specimen type (Round bar vs. full rectangular) can be analysed. As at least each individual pipe joint was tested, i.e. more than 20 values are incorporated in each reported mean value which a certain statistical confidence is secured.

By comparing the transverse properties of round bar specimen with those from flattened rectangular specimen, the strong Bauschinger effect typically observed in transverse direction for steels of such high strength is confirmed. The difference in yield strength amounts to 65 MPa between these two specimen types. It again shows that the round bar specimen proves to be the most suitable specimen for determination of tensile properties in transverse direction for high strength steels. The ultimate tensile strength is not significantly influenced by the type of specimen; the difference is less than 10MPa. As a consequence the Y/T ratio is higher in the case of the round bar type.

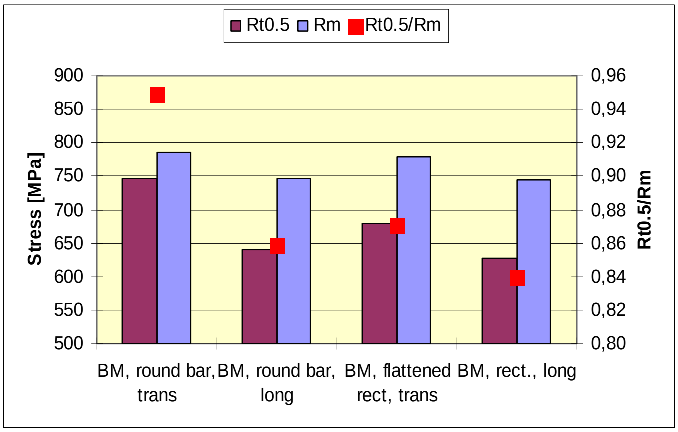


Figure 5: Mean tensile properties for 16.6mm wall thickness in the as-welded condition

A comparison of the properties in transverse and longitudinal direction indicates a significant anisotropy in case of the yield strength. A difference of 100 MPa is determined which is caused by the initial anisotropy as a consequence of the rolling process and the strain hardening in transverse direction due to cold expansion. In longitudinal direction no significant differences is found between round bar and full wall rectangular specimen. However as the full wall specimen is more representative for the pipe cross section and in addition less costly in machining, this specimen is recommended in longitudinal direction instead of the round bar specimen.

The results for fracture elongation and uniform elongation are summarised in figure 6. The pronounced anisotropy observed on the tensile properties in transverse and longitudinal direction almost disappears when comparing the fracture and uniform elongation. In case of the round bar specimen, the values for the proportional fracture elongation A_5 averages 16.9% in transverse direction, respectively 17.1% in longitudinal direction.. Accordingly the uniform elongation U_{el} is likewise nearly independent of the rolling direction at a level of about 4%.

However an influence of the specimen type is determined. The full wall specimens reveal again no significant influence of the specimen orientation, but the values for fracture and uniform elongation are found to be at a lower level. The fracture elongation reaches for 14% on average and the uniform elongation is measured to be 3.2% on average. The fact that the transverse specimens are flattened seems not to have any influence on the elongation results.

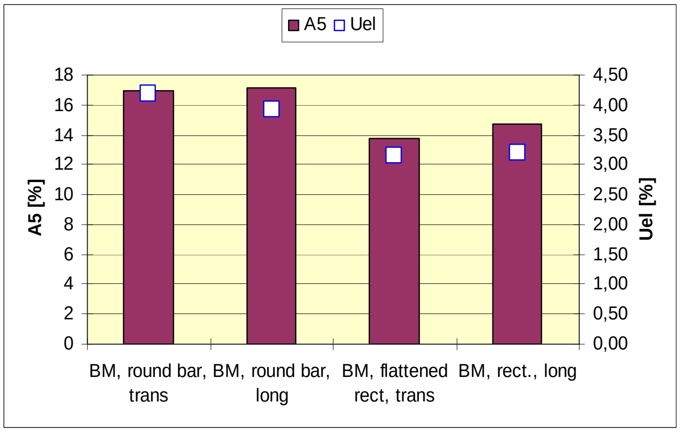


Figure 6: Mean fracture and uniform elongation for 16.6mm wall thickness in the as-welded condition

The following figures 7 and 8 explain the influence of a simulated coating heat treatment on the tensile test results in the transverse direction for round bar specimen. In this investigation two specimen from one pipe were tested. The comparison with a non-treated round bar tensile test shows that both the yield strength and the ultimate tensile strength are raised by the heating. As the increase of yield strength is more pronounced the Y/T ratio reaches values close to 1. The heat treatment is effective already at a holding time as short as 2 minutes. Longer times up to 15 minutes do not change the results any further.

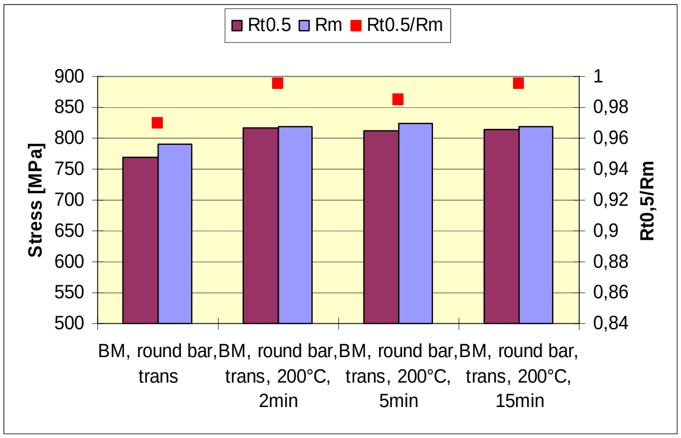


Figure 7: Influence of coating heat treatment on tensile properties for 16.6mm wall thickness in transverse direction

Despite the evident influence on the tensile strength properties, the fracture elongation and the uniform elongation are only little affected as shown in figure 8. The coating heat treatment appears to have a slight beneficial effect on the uniform elongation, which could be attributed to the increase in ultimate tensile strength. As expected from the results of figure 7, the holding time has no relevant influence within the investigated time range.

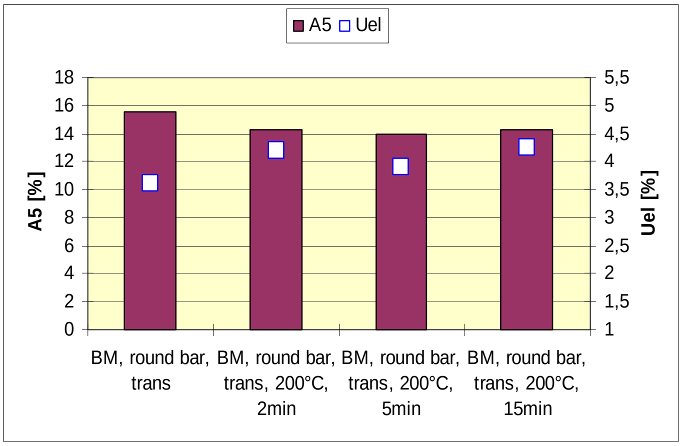


Figure 8: Influence of coating heat treatment on fracture and uniform elongation for 16.6mm wall thickness in transverse direction

The influence of the coating heat treatment on longitudinally orientated specimens is summarized in figure 9 and 10. In addition to the round bar tensile tests the results for a full wall rectangular specimen after heat treatments are included in the diagram. As for the transverse direction the strongest effect is determined on the yielding behaviour leading to an increase of the yield strength by 40 MPa. The ultimate tensile strength is only slightly affected and raises by 10 MPa. As a result the Y/T ratio increases accordingly.

The tested full wall rectangular specimens surprisingly reveal an even stronger effect on the yield strength whereas the ultimate tensile strength was found to be at the same level as the round bars. Whether this difference is really significant requires further investigation.

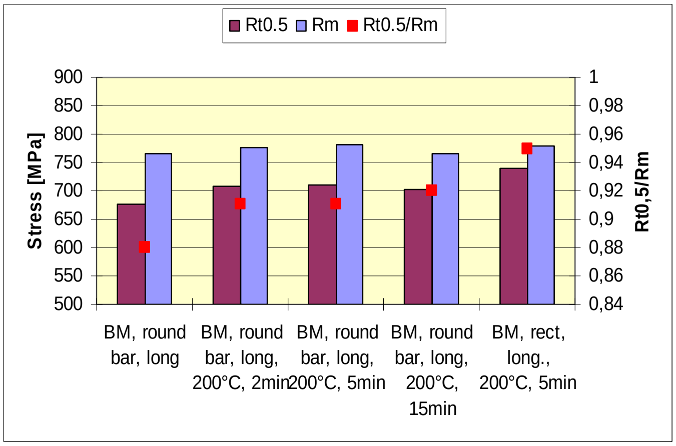


Figure 9: Influence of coating heat treatment on tensile properties for 16.6mm wall thickness in longitudinal direction

The fracture elongation and uniform elongation in the longitudinal direction after simulated coating heat treatment are shown in figure 10. As found already in case of the transverse specimen the uniform elongation has improved after being exposed to the heat treatment. However this increase seems to be more evident in the longitudinal direction. The values raise from 3.5% up to 4.5% for the heat treated material. Compared with this, the fracture elongation is only slightly improved and reaches values around 17%. As already seen in figure 6 the full wall specimen delivers lower values compared with the round bar specimen.

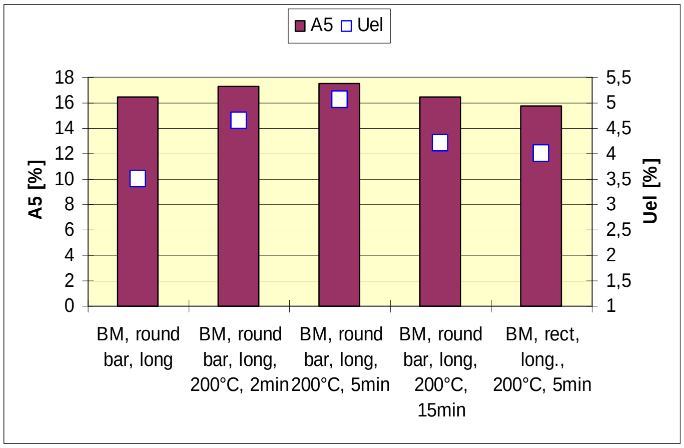


Figure 10: Influence of coating heat treatment on fracture and uniform elongation for 16.6mm wall thickness in longitudinal direction

As expected from the presented results the shape of the stress-strain curve is affected by the heat treatment. In figure 11 three different conditions are compared for round bar specimen in the longitudinal direction. The shape of the stress-strain curve of line pipe material in longitudinal direction is of particular significance for strain-based design.

The heat treatment modifies in particular the yielding behaviour and the ultimate tensile strength. As a consequence the uniform elongation is improved. Even after the longest holding time of 15 minutes the stress-strain curves do not show any pronounced Lüders elongation and the curve keeps its round-house shape. A difference between the two different holding times is not evident.

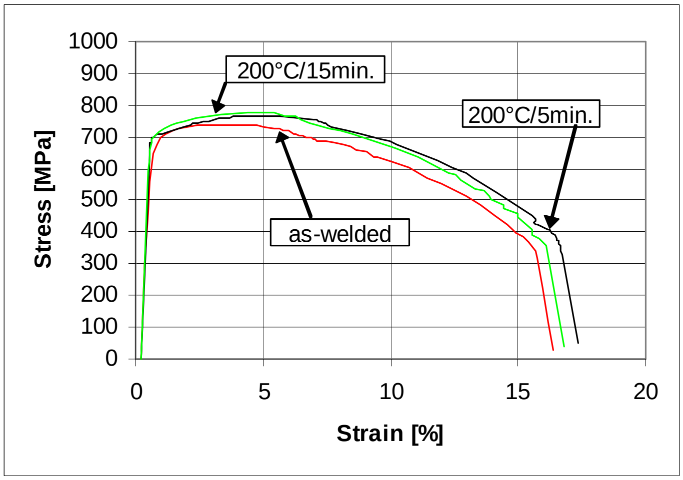


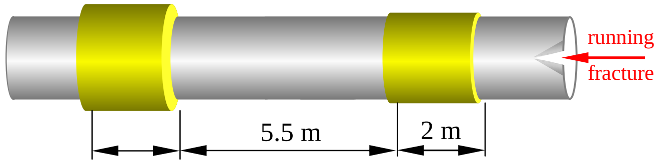
Figure 11: Influence of simulated coating heat treatment on the stress-strain curve in longitudinal direction (round bar specimen)

MANUFACTURING OF CRACK ARRESTOR

In case of transportation of gaseous media through pipelines, the toughness level of the pipeline steel is crucial for prevention of long-running cracks. For ultra-high grade steel gas pipelines the required toughness is on the borderline of or even beyond technical feasibility. Additional crack arrestors can be installed at predetermined intervals along the pipeline, in order to limit the crack propagation to the axial spacing between two successive arrestors. Full-scale tests have shown the usability of fibre reinforcements as crack arrestors [7]. Today no calculation method is available in literature for an accurate design of crack arrestors, but first attempts have been carried out for simulation of the behaviour of crack arrestors [8].

In the present investigation it was chosen to use a glass fibre reinforcement with epoxy resin, and a simple design criterion was proposed for the strength distribution between the pipe and the fibre reinforcement, as has been used previously e.g. in [7]. It was such that the hoop stress generated by the test pressure is shared in equal measure by the composite wrap and the pipe [9].

The wall thickness of the crack arrestor was designed for an internal test pressure of 16.0 MPa. Using the specified minimum strength properties for grade X100, an outer diameter of 48 inches (1219.2 mm), a wall thickness of 18.4 mm and an ultimate strength of the reinforcement of 1050 MPa, the wall thickness of the crack arrestor (fibre wrapping) has been calculated to 11.7 mm, and to 20.0 mm adding a security factor of 1.0 against a full fracture in circumferential direction. In order to gain information about calculation methods it has been chosen to use a double-level crack arrestor, as shown in Figure 12.



Crack Arrestor

- Material: Glass Fibre with Epoxy Resin
- Dimensions:
  Wall Thickness = 10 mm / 20 mm
  Length = 2000 mm
- Mechanical Properties:
  R_m = 1050 MPa

Figure 12: Schematic drawing of the crack arrestor and the double-level design of the present test.

The wall thickness of the crack arrestor the fracture will encounter was chosen to be 10 mm and 20 mm for the second fibre wrapping. Both crack arrestors have a width of 2000 mm. They have been installed on a 12 m pipe with an axial spacing of about 5.5 m (Figure 13).

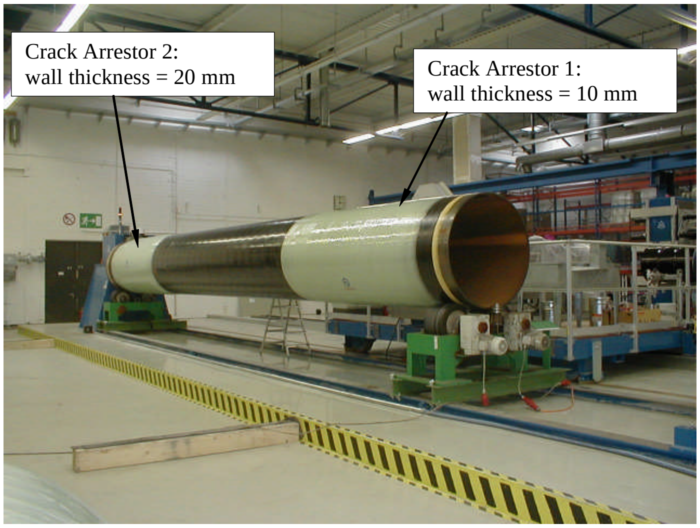


Figure 13: Crack arrestors being installed on a test pipe.

CONCLUSIONS

The TAP project has been launched by the ENI group in order to investigate the technological reliability, the constructability and the field performance of modern high grade line pipe in operation. EUROPIPE supplied 500m of grade L690MC equivalent to X100 with an outside diameter of 48” and wall thicknesses of 16.6mm and 18.4mm. The plates were rolled at the plate mills of Dillinger Hütte and Mannesmannröhren Mülheim on the basis of existing experience in developing and producing X100. The pipe requirements were reliably fulfilled apart from the Y/T ratio in transverse direction where some values above the maximum allowable of 0.95 were determined. The toughness properties investigated using Charpy-V notch and DWTT tests were found to be satisfactory.

As high strength grades like X100 are currently under evaluation regarding their applicability for strain-based design, the question of how the tensile properties and the strain hardening behaviour of the material can properly be determined is under discussion. Especially the evaluation at onset of yielding and the uniform elongation is of particular significance. Therefore a comprehensive tensile program was performed in order to investigate the influence of the specimen type and the specimen orientation. For transverse orientated tensile tests the round bar specimen is confirmed to be the best solution as the Bauschinger effect can be excluded. However this specimen type does not reflect the full wall and has therefore greater scatter. In longitudinal direction the full wall rectangular specimen is recommended as less expensive in machining and revealing lower scatter as the full wall thickness is tested.

Referring to the anisotropy it can be stated that the tensile properties and the stress-strain curves significantly differ in transverse and longitudinal direction. The fracture elongation and the uniform elongation are however at a similar level independent of the orientation.

In order to evaluate the influence of a coating application on the stress-strain curve additional tensile tests were performed after simulated heat treatment of 200°C with three different holding times (2min., 5min., 15min.). Such a heat treatment leads to a significant increase of the tensile properties both in transverse and longitudinal direction even at the shortest investigated holding time of 2 minutes. The elongation values are less affected in the transverse direction, whereas in longitudinal direction a slight beneficial effect could be observed. A prolongation of the holding time does not have any further influence. As the actual holding time during coating application is around 4 minutes, it should be sufficient to have a holding time of 5 minutes for the simulation tests.

As intrinsic crack arrest for high pressure pipelines built with high grade steels can not reliably be achieved by high toughness values, the use of crack arrestors are regarded as inevitable for X100. For the TAP project EUROPIPE supplied two crack arrestors manufactured using glass fibre reinforcement with epoxy resin. A simple design criterion was proposed for the strength distribution between the pipe and the fibre reinforcement. It was such that the hoop stress generated by the test pressure is shared in equal measure by the composite wrap and the pipe.

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