Technological solutions for ultra-high strength gas pipelines

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ABSTRACT

Long distance pipelines are a save and economic way to transport the gas from remote gas fields to the end users. To find technological solutions in view of increasing pipeline length and operating pressure the development of ultra-high-strength steels is a very fundamental necessity.

EUROPIPE has delivered more than 500km line pipe made of X80 and comparable grades. Therefore we consider X80 as a standard grade in the entire supply chain from steel making to plate making and to pipe manufacturing. The production results of one of the latest X80 projects are presented in this paper.

After having developed X100 several demonstration lines have been installed and have been put into operation. As the development to X100 gives an intention of future challenges and possibilities updated production results of X100 pipes are presented to describe the materials properties as well as the service behaviour.

The next step in the development work consequently led to grade X120. The latest results from the production of a number of prototype pipes in grade X120 demonstrate that this ultra high strength steel grade as well is feasible. Amongst various technical limitations the development of appropriate technologies for pipe forming and seam welding are the most challenging aspects of an industrial scale production.

KEYWORDS

HSLA-Steels • Alloying Concepts • Pipe Manufacturing • Pipe Properties • X80/X100/X120 • Project Cost

INTRODUCTION

The development of high-strength steels is intensified world-wide to use the economic advantages. As the development of grade X80 is finished this grade is state of the art nowadays for high pressure gas pipelines. Grade X100 was recently developed but up to now only used for small demonstration lines. EUROPIPE started its development of X100 already in 1995. Since that time different approaches with regard to chemical composition and rolling parameters have been investigated in order to find the best balance between strength, toughness and weldability.

In order to increase the knowledge necessary for the utilization of X100 steel pipes EUROPIPE participated in an ECSC-Demonstration project (Demopipe), partially sponsored by the EPRG. /1/.

Within the scope of this project the most important questions arising in the technical field of a high pressure, high strength onshore gas pipeline have been examined like pipe manufacture, field welding, bending and fracture propagation behaviour. In this paper the development of X100 is shortly summarized, some Demopipe results are shown and finally production results of a small X100 order (TAP project) are given.

The use of materials with even higher strength such as grade X120 is the challenging next step as further cost savings for the gas transport companies seem to be possible. This paper gives an overview of the development of grade X120 pipe. Special attention is focused on the development of pipe forming and modified welding technologies which had to be adapted from the existing and well established processes. The production of trial pipes in grade X120 has been finished, but a definite statement on the above mentioned possible cost savings are still difficult.

Project cost reduction

Project cost reduction may be a result of the sum of the different benefits that can be derived by using high-strength steels, even when the price per ton of the pipe increases as the material grade increases /2/. The benefits include:

- reduced quantity of steel required
- lower pipe transportation costs
- lower construction costs.

The use of grade X80 line pipe in the construction of the first Ruhrgas X80 pipeline led to a material saving of about 20 000 t, compared with grade X70 pipes (**Figure 1**), through a reduction of the wall thickness from 20.8 mm for X70 to 18.3 mm for X80. This resulted also in a reduction of the pipe laying costs because of reduced pipe transportation costs and greatly reduced welding costs through reduced welding times needed with thinner walls. The use of materials with still higher strength, such as grade X100 or grade X120 could lead to further material savings as it is further illustrated in Figure 1.

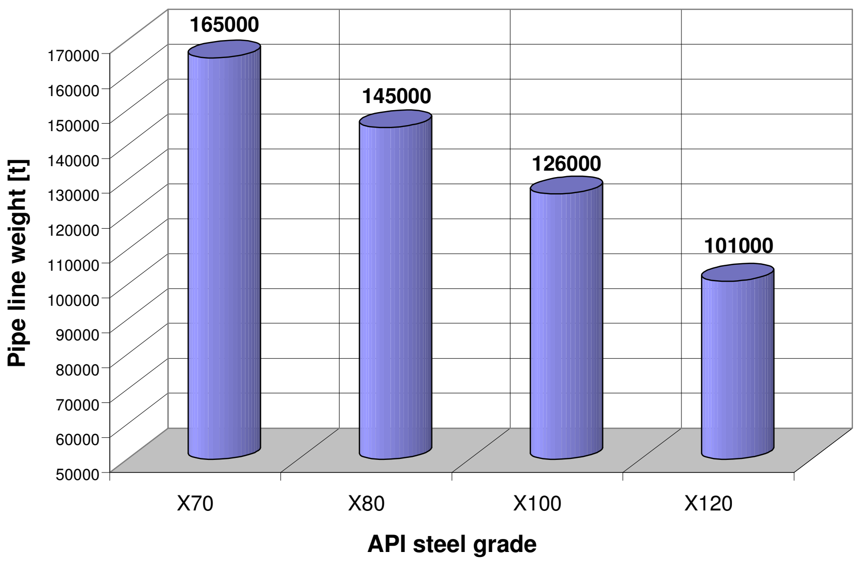

Figure 1: Possible material savings through the use of high strength material

A preliminary economic evaluation /3/ highlighted that high pressure X100 pipelines could give investment cost savings of about 7% compared with grade X80 pipeline. This study claims cost savings of up to 30 % when X70 and X100 are compared.

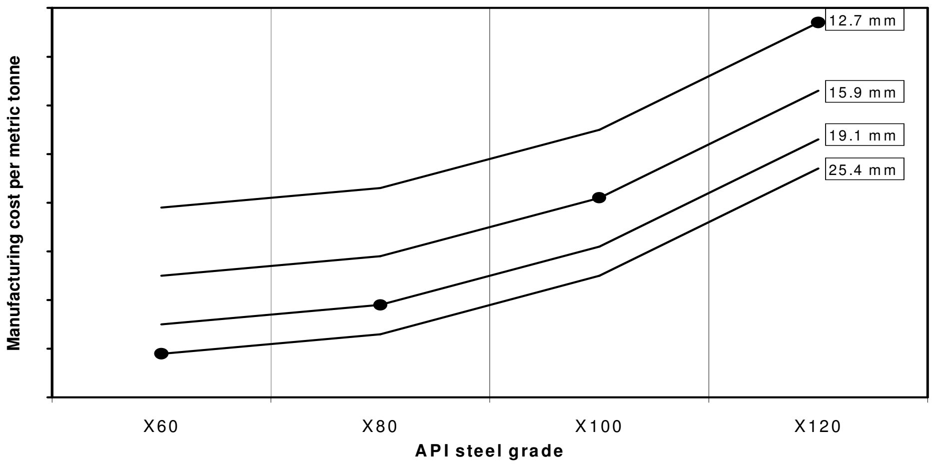

Figure 2: Manufacturing cost per ton of pipe for different steel grades and wall thicknesses to be used at a constant transport capacity

On the other hand, it becomes clear from **Figure 2** that the reduction in the manufacturing cost per ton of the pipe at a given transport capacity of a pipeline is enhanced not just by the increase in the material grade of the steel but also by the reduction in pipe wall thickness. From the point of view of pipe manufacturers, reduction of pipe wall thickness is not a preferred option. A reduction in pipe diameter at constant pipe thickness and a simultaneous increase in pipeline operating pressure would give a more favourable solution to the problem.

GRADE X80

X80 Projects

In the past two decades, EUROPIPE has carried out extensive work to develop high-strength steels in grades X80 to assist customers in their endeavour to reduce pipe weight and pipe laying costs. Since 1984 longitudinal seam submerged-arc welded grade X80 pipe has been used in the implementation of several pipeline projects in Europe and North America (**Table 1**). In the meantime more than 500 km of X80 were supplied by EUROPIPE.

Table 1: EUROPIPE Projects executed with line pipes made of grade X80 or equivalent.

Year	Project	Main Pipe Geometry	Pipeline Length
1984	Megal II	44“ x 13.6 mm	3.2 km
1985	CSSR	56“ x 15.4 mm	1.5 km
1991/92	Ruhrgas	48“ x 18.3 mm 48“ x 19.4 mm	250 km
2001 – 2004	National Grid (Transco)	48“ x 14.3 mm 48“ x 15.1 mm	210 km
2001/03	CNRL	24“ x 25.4 mm	12.7 km
2003	Murray	20“ x 20.6 mm	2.4 km
2004/05	Snam Retegas	48“ x 16.1 mm 48“ x 18.9 mm	10 km
2004	Stadtwerke Münster	56“ x 20.5 mm	1.6 km

The first pipeline using GRS 550 (X80) for its entire length of 250 km was the Ruhrgas Werne-to-Schlüchtern pipeline project implemented in Germany in 1992.

Production L555MB

Between 2001 and 2004, L555MB (X80) pipes were manufactured for National Grid (Transco) projects in the UK. Line pipe for several parts of gas pipeline networks of about 210 km length in total was produced. EUROPIPE supplied pipe of 48" diameter with the thicknesses of 14.3 mm and 15.1 mm and pipe length of up to 18 m. 350 further km are ordered for delivery in 2006.

In 2005 EUROPIPE supplied about 10 km of SAW pipes of material grade L555MB for a first pipeline section in Italy /4/. The quantities are given in **Table 2**. The production was performed on 18 m line by the UOE process. The TMCP rolled plates of both items were delivered by the plate mills of Mannesmann (MRM) and Dillinger Hütte (DH). The slabs for the MRM plates were cast by Hüttenwerke Krupp Mannesmann (HKM) in Duisburg and the slabs for DH plates by DH steel works, respectively. The pipes have been produced according to EN 10208-2 and Snam Retegas specification. They have been coated epoxy resin lining inside and 3-layer PE outside by Eupec Mülheim.

Table 2: Delivered quantities, chemical composition (wt.-%) and pipe properties

Item	WT	OD	Grade	No. of pipes	Average Length	Slab/Plate Supplier
001	16.1 mm	1216.5 mm	L555MB	504	14.4 m	DH / DH and HKM / MRM
002	18.9 mm	1222.1 mm	L555MB	201	14.3 m	

	C	Si	Mn	Al	Cu	Cr	Ni	Mo	Nb	Ti	CE_{IIW}
Max.	0.10	0.35	2.00	0.050	0.10	0.10	0.10	0.25	0.06	0.03	0.45

Properties		Specified Values	Production Results (average values)	
			Item 001	Item 002
YS ($R_{t0.5}$) Strip transv.		555-675 MPa	609 MPa	601 MPa
TS		625 MPa (min.)	709 MPa	700 MPa
Elongation		18 % (min)	20.3 %	19.3%
Y/T Ratio		0.90 (max.)	0.86	0.86
Impact Energy @-10 °C	BM	135/180 Joule	275 Joule	262 Joule
	Weld	30/40 Joule	190 Joule	208 Joule
	HAZ	30/40 Joule	102Joule	165 Joule

The chemical composition (max. values) and mean mechanical properties of the pipes are also summarised in Table 2. Tensile and toughness properties will be discussed below in detail on the basis of statistical data of item 001 (WT: 16.1 mm; OD 1216.5 mm) because this was the larger quantity.

Figure 3 shows the statistical distribution of tensile properties of the base material in transversal direction. The tests were performed on strip specimen at ambient temperature. The statistics are based on 56 individual test results. The histograms show usual distributions of all tensile properties in the specified limits for grade L555MB/X80. It can be concluded that the alloying concept and rolling technology of both plate suppliers are suitable for the production of L555MB (or similar steel grades) in big quantities for SAW pipes.

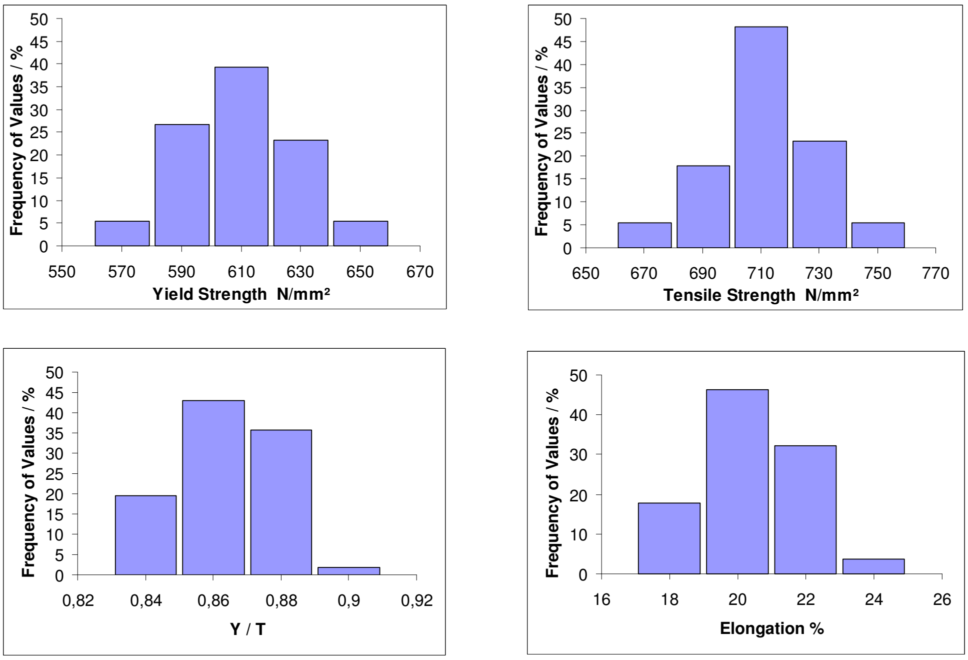

Figure 3: Statistical evaluation of tensile tests on strip specimen in transverse direction (WT: 16.1 mm; OD 1216.5 mm; L555MB, Snam Retegas)

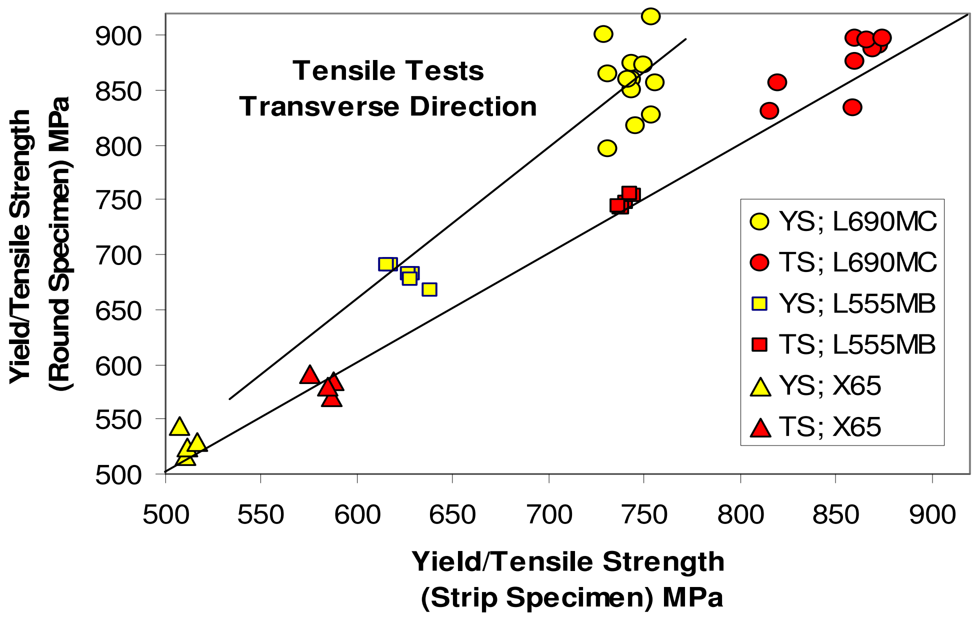

Figure 4: Correlation of yield strength (YS) and tensile strength (TS) between strip and round specimens in transverse directions

The release criteria for tensile properties are described in line pipe specifications as tensile test in transverse direction on flattened strip specimen. However, the flattening during specimen preparation results in a distinctive decrease of yield strength because of the well-known Bauschinger-effect in transverse direction. This phenomenon does not exist in longitudinal direction because there is no flattening for longitudinal samples.

The necessity to fulfil the tensile requirements on flattened transverse specimen lead to produce a base material that is actually stronger than required. This effect is more distinctive in case of high strength steel grades in comparison to lower grades. **Figure 4** shows the correlation between round and strip specimens of X65, L555MB and L690MC.

The level of carbon equivalent (CE) in TMCP rolled heavy plates usually does not cause any problems regarding the base metal toughness because of the extremely fine grain size of this material. Due to the special welding concepts of EUROPIPE the weld seam toughness is also on an adequate level and fulfils the toughness requirements. However, higher CE and the grain coarsening because of the twofold heat input by the inside and the outside welding in the root position of the Heat Affected Zone (HAZ) may lead to formation of local brittle zones in the HAZ.

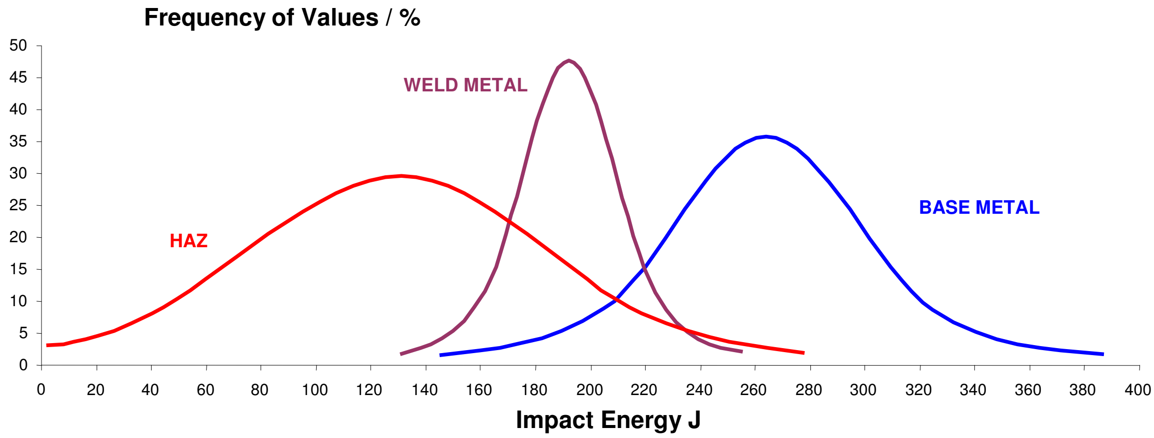

Figure 5: Statistical distributions of impact energy values at –10°C for base metal, weld seam and HAZ (mid wall position; WT:16.1 mm; OD 1216.5 mm; L555MB)

Figure 5 shows statistical distributions of impact energy values for base metal, weld seam and HAZ. These distributions are based on 56 mean values of item 001. The tests have been performed at -10°C on specimens of mid wall position which is similar to root position at this wall thickness.

GRADE X100

Development and Demopipe Project

To cope with the market requirements for enhanced pipe strength, EUROPIPE put its effort to the development of grade X100. No technological breakthroughs in TMCP rolling and accelerated cooling had been necessary. Only optimisation of the existing technology was required for the production of grade X100 plate. As a result, the production window became narrower. Heat treatment of plate or pipe was obviously not necessary.

Since 1995 six small mill production trials have been completed in a wall thickness range from 12,7 mm up to 25,4 mm and diameters between 30" and 56". In total four trials were done in a cooperation together with CSM, supported by ECSC /5/. An overview of the activities is given in **Table 3**.

Table 3: EUROPIPE's development actions for X100 pipes

Year	Action
1994	First request of some clients to supply pipe with grades ≥ X100
1995	Lab trials (higher CE, lower acc. cooling) First production of pipe 36" x 19.1 mm
1997	Lab trials (lower CE, higher acc. cooling) Second production of pipe 30" x 15.1 mm
1998	Pipe production for the first X100 full scale burst test , ECSC-project 56" x 19.1 mm (third production)
1999	New lab trials (medium CE, medium acc. cooling), ECSC-project 4th production of pipes for second full scale burst test 36" x 16 mm
2001	Production of pipe 36" x 12.5 to 25.4 mm, ECSC Demopipe project (5th production)
2004	Production of pipe 48" x 16.4 to 18.6 mm for TAP order (6th production)

For the Demopipe project 4 industrial heats were produced and rolled at Dillinger Hütte. It was demonstrated that the same steel composition, which is a medium carbon MoNiNbTi steel shown in **Table 4**, could be used. Only slight changes in the rolling conditions were necessary to guarantee all required mechanical properties for all wall thicknesses.

Table 4: Chemical composition of industrial heats used for Demopipe X100, in wt %.

Heat-No.	C	Mn	Si	Mo	Ni	Cu	Nb	Ti	N	Al
16155	.059	1.93	.35	.30	.24	.020	.046	.019	.006	.031
16156	.055	1.97	.31	.31	.24	.025	.047	.019	.005	.035
16157	.057	1.95	.33	.30	.24	.024	.046	.019	.004	.035
18438	.058	1.91	.31	.30	.24	.018	.048	.019	.005	.030

Due to the fact that different toughness levels were required for the Demopipe project, nearly each plate was rolled with different rolling and cooling parameters /6/. Therefore the mechanical properties, which are shown in **Figure 6**, show a larger scatter than usual.

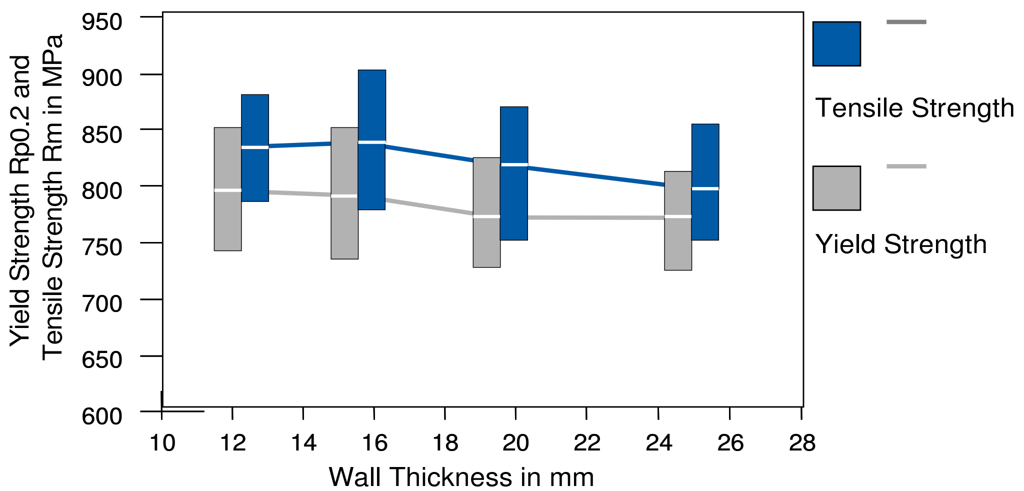

Figure 6: Yield strength and tensile strength of Demopipe pipes

Production L690MC

The first real X100 (L690MC) order was for the TAP project, where 48” pipes were required. About 700 m of pipes with wall thicknesses of 16.4 mm and 18.6 mm were produced, using plate material from Dillinger Hütte and Mannesmannröhren. Mechanical properties of pipe are given in **Table 5**. The results are very comparable. All required properties were achieved.

Table 5: Production results of 690MC order

Properties	Specified values	Production Results	
		48” x 16.6 mm	**48” x 18.4 mm**
Material Source		Dillinger	Mannesmann
YS (Rt 0.5) round bar TS Y/T Ratio	690 -825 MPa 760 - 970 MPa 0.95	741 MPa 786 MPa 0.95	764 MPa 815 MPa 0.94
Impact Energy BM@-10°C	180 / 240 Joule	274 Joule	248 Joule
BDWT	75 / 80 %	98 %	93 %

Grade X120

Development

To fulfil requirements on grade X120, not only steel composition, but also forming technique and welding technology have to be modified in contracts to normal grades.

To produce a steel with a minimum YS of 827 MPa it was shown first in our Research Institute that only Boron- micro alloyed steels can reach the goal /7/. Also Molybdenum, Nickel, Copper and Chromium have to be added. From the first trials, performed in the plate mill at Dillinger Hütte, we could learn that only a very narrow production window in terms of chemistry and rolling and cooling conditions exists /8/.
Nevertheless, a trial production of 30” x 16.1 mm pipes started in 2004.

Modification of pipe forming

One of the great challenges in the pipe forming of ultra-high strength plate with a relatively small wall thickness is the large spring back due to the greater elastic range of a material with high yield strength. Especially the U-forming step is affected by this spring back. It could lead to shells that cannot be inserted into the O-press.

Finite element calculations were carried out to support the optimisation of the U-ing process and the shape of the U-ing punch. The results of the FEM calculations are provided in **Figure 7 (left side)**. The large spring back after an U-ing with a conventional U-press tool is visible here. Such a formed plate can not be inserted into the O-press.

In addition to this the shape of the U-press was modified in the calculations, as can be seen from **Figure 7 (right side)**, to find the best possible parameters for an adapted UOE-process. The newly calculated shape of the U-Press will lead to a reduction of the spring back. The plate could be inserted into the O-Press. Furthermore, it was assured that the ovality and peaking after O-ing were as well set to optimal value to avoid problems with the welding and expansion steps of the pipe production /9/.

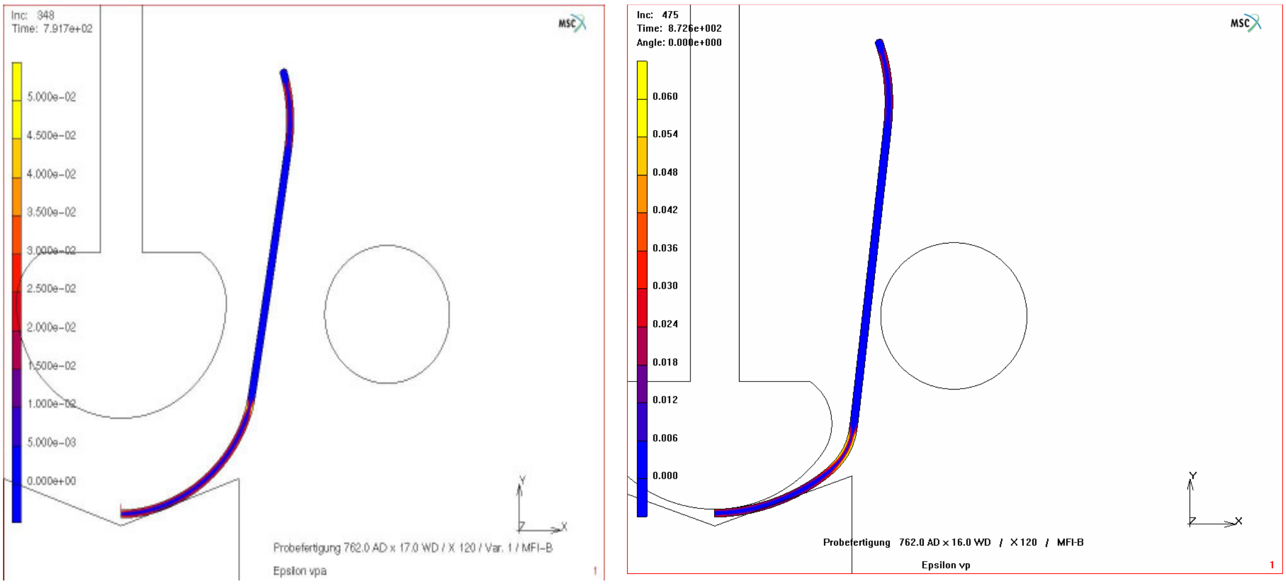

Figure 7: Spring back after U-ing with conventional and modified U-ing punch

Pipe properties

EUROPIPE produced pipes of 30" outer diameter with 16.1 mm wall thickness. With the intention to reach both the upper and the lower limit of a mass production in this trial, plates with the highest as well as the lowest possible strength level were chosen on purpose for pipe forming. The highest possible strength level reached up to 100 MPa more than the target values. The lowest possible level was very close to the target values. This is an appropriate measure to mark out the boundaries for a new material.

Some promising results of these first production tests for the base material of grade X120 are shown in **Table 6**. The yield strength measured in this case was Rp0.2 as for high strength steels like X120 the usually measured Rt0.5 results in values that do not seem to reflect the actual strength level. As also given in Table 6, the yield-to-tensile ratios are lower than 93 %. The fracture and uniform elongation are lower than known for grades X80 or X100.

The Charpy impact energy values in particular are given in **Figure 8**. They were measured on Charpy V-notch impact specimens in a temperature range of -10 °C down to -70 °C. At a testing temperature of -30 °C the values resulted in an average of ≥ 260 J. All individual Charpy toughness values were in excess of 231 J at this temperature.

First results show that for X120 pipe material especially the specific crack propagation energies are lower than for X100 pipes. Therefore, the results of the BDWT tests have to be improved in the next trial production.

Table 6: Mechanical properties of medium high strength variant (flat bar specimens) of X120

Properties		Target values	Mean values Transverse
Yield strength	$R_{p0.2}$	827 MPa	865 MPa
Tensile strength	Rm	931 MPa	944 MPa
Yield-to-tensile ratio	$Rp_{0.2}$/Rm	<93 %	92 %
Elongation	A2"		24.3 %
Uniform Elongation	Au		7.4 %
CVN toughness	@ -30 °C	231 Joule	267 Joule
DBTT		<-50 °C	<-50 °C
BDWT	@ -20 °C	75 %	≥65 %

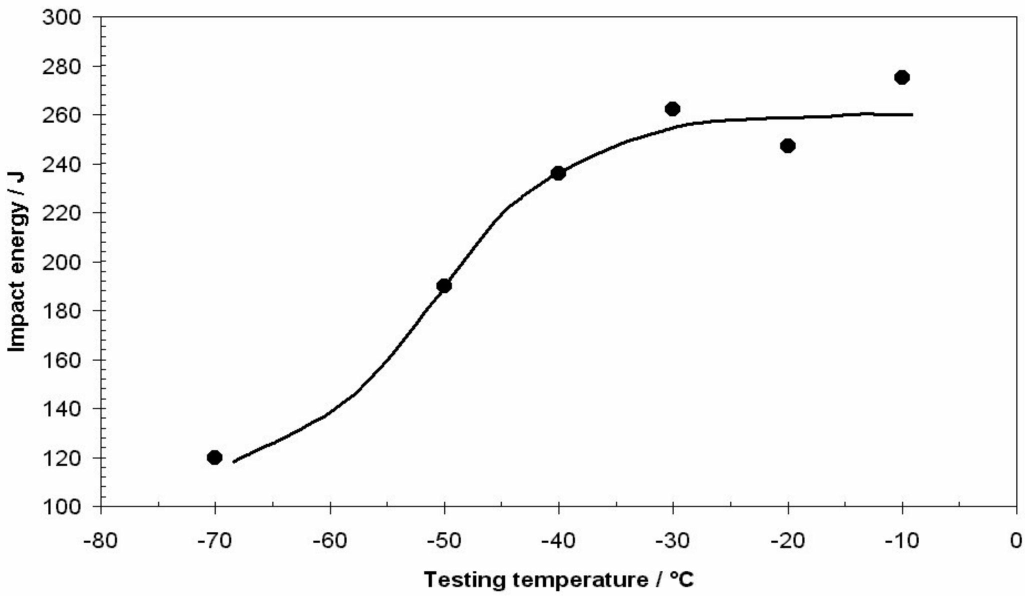

Figure 8: Charpy-V impact test results of pipe base material

Welding technology

From the first welding trials in the laboratory and the mill to nowadays the heat input, which is relatively high during two pass welding, could be reduced from 2 kJ/mm wall thickness to 1.5 kJ/mm wall thickness, due to optimisation of welding parameters and bevel configuration. A small softening zone still occurs but the drop in hardness is reduced to max 10% of the base material hardness values. This leads to the fact that all tense test specimens transverse to the weld break safely in the base material. The development of a low heat input welding process was one step on the way to produce pipes of grade X120.

Another step was the development of the weld seam chemistry and microstructure. As a rule of thumb the two pass SAW seam chemistry can be considered to consist of 2/3 base material and 1/3 welding wire. This must be taken into consideration during developing the welding wire chemistry.

In the beginning of the development several standard solid wires were tested in combination with new developed fluxed core wires. Good results regarding mechanical properties were reached using Boron micro alloyed solid wire in combination with Boron free flux cored wires and fluxes. But the Charpy impact specimens of the weld metal showed partly low values, down to 30 Joule at -30°C. This can be traced back to changes in microstructure from acicular ferrite to bainite/martensite in the weld metal due to high Boron additions /10/. Based on this also low Boron and Boron free solution were developed.

Table 7 shows a typical boron free weld metal analysis which promotes very good toughness properties (80 to 150 Joule at –30°C). Single values below 80 Joule are found during excessive Charpy testing. For HAZ 25/50/25 testing the target of 84 Joule at –30°C can not be met consistently , single values down to 20 Joule at -30°C can appear.

Table 7: Main chemical composition (wt.-%) of X120 two pass SAW weld metal

C	Si	Mn	Cr	Ni	Mo
0.05	0.30	1.80	0.80	2.10	0.70

The strength of the weld metal was measured with tensile specimens that were taken from the longitudinal weld. The all-weld metal tensile properties confirm to the required tensile strength of the base material. However, further development is necessary to improve yield strength.

CONCLUSION

The predicted growth in energy consumption in the coming decades necessitates severe efforts for transporting large amounts of natural gas to end users economically. Large-diameter pipelines serve as the best and the safest means of transport. The use of grade X80 line pipe has already proven to result in substantial cost savings and its development is considered as completed for onshore pipelines. But the economic transport of gas over very long distances requires additional cost cuts. The use of grade X100 and/or X120 could be a solution.

Several pipelines installed in Europe and North America in the past two decades show that the use of X80 line pipe causes no problems with respect to mechanical properties and welding. The development work performed by EUROPIPE during the last decade led to the conclusion that grade X 100 mechanical properties can be reliably achieved on a large scale basis. After several trial productions where the first priority of development has been to find the best balance between strength, toughness and weldability, the last production lot of X100 was delivered for the TAP project, where a full pipeline lifetime will be simulated during a two year test service.

The initial results of the work directed to developing grade X120 are encouraging with respect to the properties of the base material. During this current development the technologies for heavy plate rolling and pipe production as well as the welding process for the longitudinal weld seam were modified or even completely new developed with respect to the new high strength steel grade X120. A first prototype production of pipes in grade X120 led to promising results with respect to the mechanical-technological properties, the weldability and the pipe forming. However, further optimisation of certain aspects, also in collaboration with the end user, is still necessary.

REFERENCES

/1/ G. DEMOFONTI, G. MANUCCI, M. DI BIAGIO, H.-G. HILLENBRAND, D. HARRIS, Proc. 4th Int. Conf. on Pipeline Technology, Ostend, Belgium, (2004), p.467-482

/2/ M. K. GRÄF and H.-G. HILLENBRAND, Proc. 11th PRCI-EPRG Joint Technical Meeting, Arlington, Virginia, (1997), p.3/1-15

/3/ L. BARSANTI, H.-G. HILLENBRAND, G. MANNUCCI, G. DEMOFONTI, and D. HARRIS, Proc. International Pipeline Conference, Calgary, Alberta, (2002), paper 27089

/4/ L. BACCHI, L. BARSANTI, H.-G. HILLENBRAND, E. MUTHMANN, 3R International 44 (2005) Special Edition, p.

/5/ G. DEMOFONTI, G. MANNUCCI, D. HARRIS, H.-G. HILLENBRAND and L. BARSANTI, Proc. Intern. Conf. on the Application and Evaluation of High-grade Linepipe in Hostile Environments, Yokohama, Japan, (2002), p. 245-262

/6/ G. DEMOFONTI, G:MANNUCCI, H:-G. HILLENBRAND, D. HARRIS, 3R International 43 (2004) Special Steel Pipeline Technology, p. 29-33

/7/ J. HECKMANN, D. ORMSTON, F.GRIMPE, H.-G. HILLENBRAND, J.-P. JANSEN, Proc. TMP Lüttich (2004) P. 311-318

/8/ V. SCHWINN, S. ZAJAC, P. FLÜSS, K.-H. TACKE, Proc. High Grade X100, X120 Seminar Beijing (2005), p. 240-250

/9/ H.-G. HILLENBRAND, A. LIESSEM, K. BIERMANN, J. HECKMANN, V. SCHWINN; Proc. International Pipeline Conference, Calgary, Alberta, (2004), paper 0224

/10/ M. HAMADA, S. OKAGUCHI, Y. KOMIZO, N. TAKAHASHI, I. TAKEUCHI, Proc. 4th Int. Conf. on Pipeline Technology, Ostend, Belgium, (2004), p.1077-1088

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