High strength line pipe for project cost reduction

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Introduction

In view of the ever-increasing pipeline length and operating pressure, Europipe's efforts in the development of high-strength steels make a significant contribution to pipeline project cost reduction. On the one hand cost reduction subjects by use of high strength steels are caused by wall thickness reduction having a significant impact on quantity of material, transportation and welding costs. On the other hand high strength steels make possible to operate pipelines with higher pressures resulting in larger quantities of transported gas.

Over the past 25 years, severe demands have been placed on the pipe manufacturer with respect to the development and processing of materials to linepipe. Generally, longitudinally welded large-diameter linepipe is used for the transportation of oil and gas, because it offers the highest safety in pipeline operation and represents the most economic solution. From the point of view of pipeline economy, the pipe must favourably respond to laying in the field and permit high operating pressures for the pipeline. These requirements imply that the pipeline steel has to possess high strength and toughness and that the pipe shall have optimised geometry.

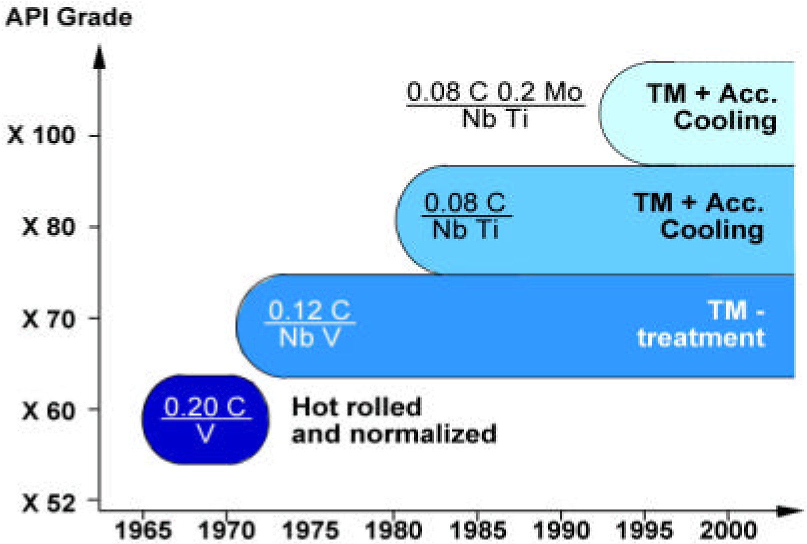

Figure 1: History in Line Pipe Steels (Large Diameter Pipe)

The development of high strength steels is shown in figure 1. In the seventies, the hot rolling and normalising was replaced by thermomechanical rolling. The latter process enables materials up to X70 to be produced from steels that are microalloyed with niobium and vanadium and have a reduced carbon content. An improved processing method, consisting of thermomechanical rolling plus subsequent accelerated cooling, emerged in the eighties. By this method, it has become possible to produce higher strength materials like X80, having a further reduced carbon content and thereby excellent field weldability. Additions of molybdenum, copper and nickel enable the strength level to be raised to that of grade X100, when the steel is processed to plate by thermomechanical rolling plus modified accelerated cooling.

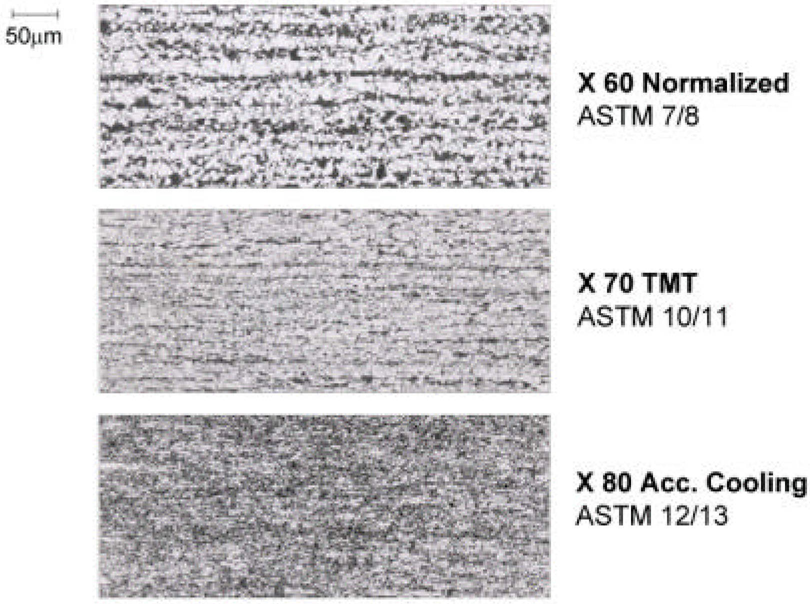

Figure 2: Typical microstructures of normalized, TM-treated and acc. cooling steels

Figure 2 shows typical microstructures of three types of linepipe steel. Banded ferrite and pearlite and coarse ferrite grain size (ASTM 7–8) are the characteristic features of conventionally rolled and normalised X60 steels. The microstructure of TM rolled X70 steels is more uniform and the ferrite grains are finer (ASTM 10–11). The most uniform and extremely fine microstructure is attained by accelerated cooling that follows thermomechanical rolling, as shown for the X80 steel. The improved properties of this steel can be attributed to its ferritic-bainitic microstructure.

High Strength Linepipes

Over the past two decades, Europipe has carried out extensive work to develop high-strength steels in grades X80 and X100 to assist customers in their endeavour to reduce weight and pipelaying costs.

Development to X80

The developments in alloy design since 1984 can be seen in the results (1) on pipe produced commercially for the Megal II, CSSR and Ruhrgas projects (Figure 3).

In 1984, Europipe produced grade X80 line pipe to be installed for the first time in history in the Megal II pipeline. A manganese-niobium-titanium steel, additionally alloyed with copper and nickel, was used for the production of the 13.6 mm wall pipe. Subsequent optimisation of production parameters enabled the CSSR order to be executed using a manganese-niobium-titanium steel without the additions of copper and nickel. This has simultaneously led to an improvement (i.e. reduction) in the carbon equivalent of the steel used.

Order	Pipe geo-metry	C	Si	Mn	P	S	Al	Cu	Cr	Ni	Mo	Nb	Ti	N	IIW	PCM
Megal II	44" x 13.6mm	.081	.42	1.89	0.11	.0016	.038	.18	.04	.18	.01	.044	.018	0052	.430	.206
CSSR	56" x 15.6mm	.085	.38	1.85	0.14	.0017	.030	.03	.05	.03	.01	.044	.019	0060	.409	.197
Ruhrgas	48" x 18.3mm	.09	.40	1.94	0.18	.0011	.038	.03	.05	.03	.01	.043	.017	0040	.435	.213

Order	Pipe geo-metry	Yield strength MPa		Tensile strength MPa		Elongation 5d (%)		CVN, 0°C (Joule)	
		$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s	$\bar{x}$	s
Megal II	44" x 13.6mm	603	21	737	22	22	2	182	30
CSSR	56" x 15.6mm	607	18	716	10	23	2	183	29
Ruhrgas	48" x 18.3mm	592	14	729	16	21	1	176	32

Figure 3: Chemical composition and mechanical properties of GRS 550 pipe

The first pipeline using GRS 550 (X80) in its entire length was the Ruhrgas Werne-to-Schlüchtern pipeline project in Germany with 250 km length in 1992. Europipe supplied all pipe of 48” diameter with up to 19.3 mm wall thickness including induction bends. Since the strength decreases as the wall thickness increases, it was necessary to raise the carbon and manganese levels marginally. The concentrations of all other elements remained unchanged.

The table shows also the mean values of the mechanical properties measured on the pipes produced for the three orders. The measured tensile and the impact energy values conformed fully to the specification requirements in all cases. The standard deviation for the yield and tensile strength values is very low. The impact energies measured on Charpy V-notch impact specimens at 0°C is very high, resulting in an average value of about 180 J. The 85% shear transition temperatures determined in the drop weight tear (DWT) tests are far below 0°C.

Figure 4 gives an idea of the Ruhrgas pipeline project (2). After welding, non destructive examination and field joint coating, the girth welded segments were lowered onto the prepared trench bottom. By using GRS 550 TM with a thinner wall instead of StE 480.7 TM about 20000 t of pipe material could be saved (145000 t instead of 165000 t), which had a strong impact on material and pipe laying costs concerning transportation and welding.

Figure 4: First large scale use of GRS 550 TM (X80) Pipe Line Material Ruhrgas Werne-to-Schlüchtern Line

Welding parameter and consumables for X80 girth welds are shown in Figure 5. For root pass and hot pass cellulosic electrodes were used. Filler passes and cap passes were welded with basic electrodes.

Typical impact energy values for different welding technics and processes were compared during development of X80 HSLA steel. As can be seen in figure 6 the lowest toughness values were achieved by welding filler passes with cellulosic electrodes. Modern automatic Gas-Metal-Arc-Welding techniques result in sufficiant toughness values and transition temperatures as they are at down hill welding with basic electrodes.

Pass		Filler		Current [A]	Voltage [V]
		AWS type	dia. [mm]		
Cellulosic	Root Pass	E7010-A1 or E6010-G	4.0	120/160	24
	Hot Pass	E7010-A1 or E6010-G	5.0	180/200	24
Basic	Filler Passes	E10018-G	4.0 4.5	190/210 230/250	20 20
	Cap Pass	E10018-G	4.0	190/210	20

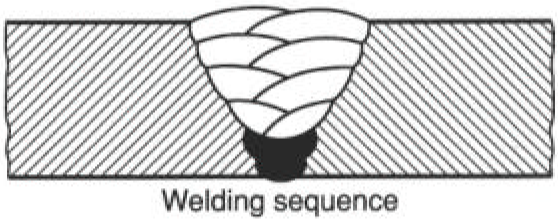

Figure 5: Welding parameter for GRS 550 TM (X80)

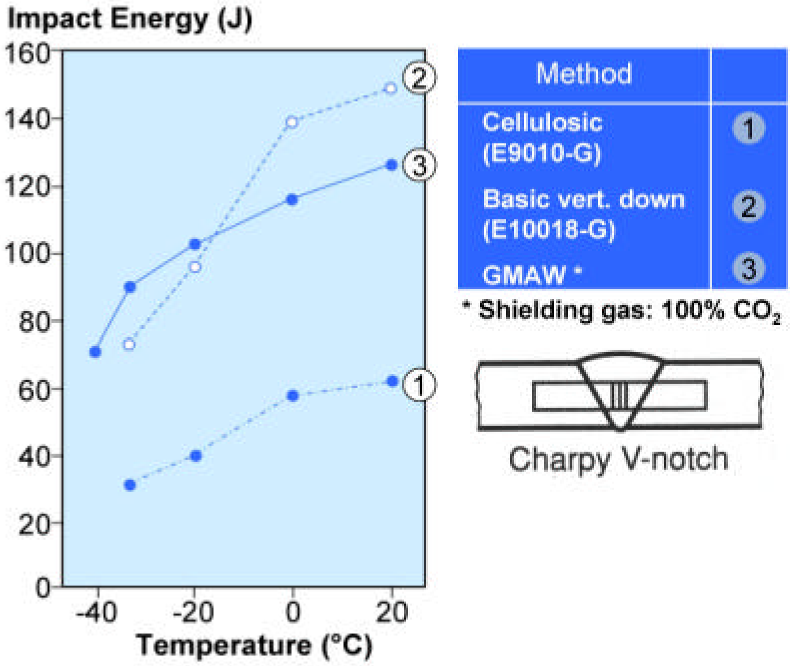

Figure 6: Typical toughness of weld metals suitable for girth welding of GRS 550 TM (X80) line pipe

To show manufacturability of heavy wall X80 Europipe commercially produced 36" diameter pipe with 32.0 mm wall thickness of which the mechanical properties are fixed in Figure 7. The manganese-niobium-titanium steel used here has a sufficiently high ratio of titanium to nitrogen and is additionally alloyed with molybdenum. The low carbon equivalent ensures good field weldability. The elongation values (A2") are particularly high. The Charpy V-notch impact energy measured at -40°C is in excess of 200 J and the shear area of DWTT specimens tested at –20°C is greater than 85%. The forming and welding operations carried out on this high strength steel did not cause any problems.

Mean chemical composition [wt.%]														
C	Si	Mn	P	S	Al	Cu	Cr	Ni	Mo	Nb	Ti	N	IIW	PCM
.07	.27	1.86	.015	.0010	.036	.02	.03	.02	.15	.040	.023	.0057	.419	.186

Specimen orientat. (and type)	$R_{t0.5}$	R_m	R_t/R_m	A2"	Charpy V-notch (1/1), transverse, -40°C				DWTT, -20°C	
	MPa	MPa	%	%	J	J	J	Aver. J	S.A. %	S.A. %
Transverse (flat bar)	559	685	82	47	222	219	231	224	85	90
Transverse (round bar)	579	674	86	46						

Figure 7: Production results on 36" O.D. x 32.0 mm W.T. API Grade X80 line pipe

One of the latest projects using X80 was a UK pipeline for BG Transco in 2000. The results on Europipe's production tests, performed in the context of certification of the pipe, are shown in figures 8 and 9. All values of the tensile and impact tests conform to the requirements of X80. The standard deviations of tensile testing are 15 MPa for yield strength, 13 MPa for tensile strength, 0.02 for yield to tensile ratio and 1.8% for elongation. Average values of impact testing were 227 J for base metal and 134 J for weld metal.

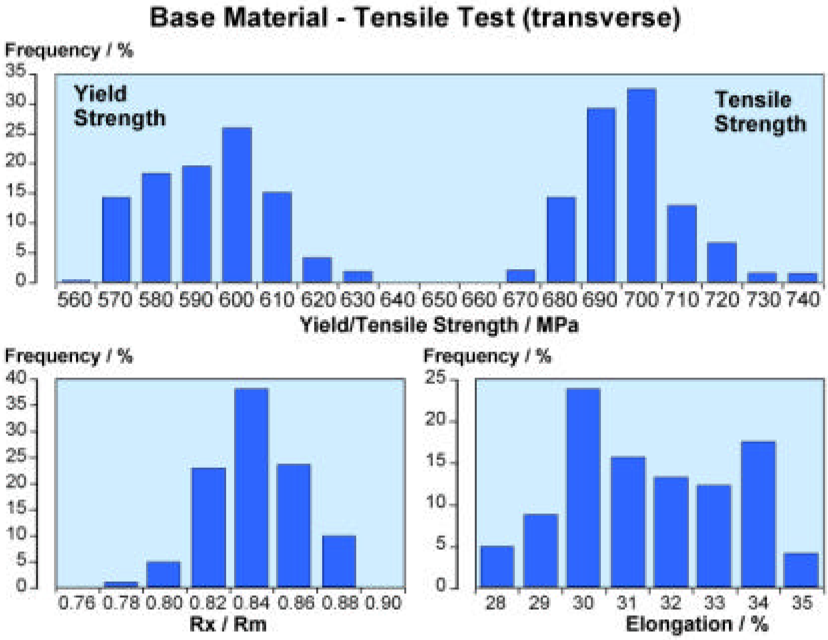

Figure 8: Strength properties of X80 Pipes (48" O.D. x 15.1 mm W.T.

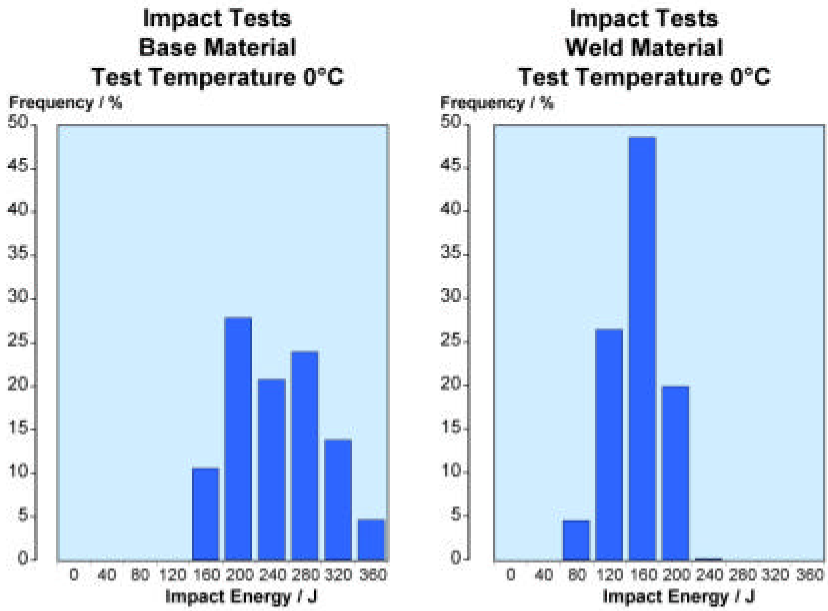

Figure 9: Impact properties of X80 Pipes (48" O.D. x 15.1 mm W.T.)

<u>Development to X100</u>

To cope with market requirements for enhancing strength Europipe put its effort to the develpment of grade X100. No technological breakthroughs, such as TM rolling and accelerated cooling which increased the strength and toughness respectively, but only improvements in the existing technology were involved in the production of grade X100 plate. As a result, the production window is quite narrow. Heat treatment of plate or pipe is obviously not advisable.

As can be seen in figure 10, Europipe took three different approaches with respect to the selection of chemical composition and cooling conditions (3).

Approach A, which involves a relatively high carbon content, has the disadvantage that the crack arrest toughness requirements to prevent long-running cracks, may not be fulfilled. Moreover, this approach is also detrimental, e.g. to field weldability.

Approach B, which is practically the same as direct quenching with fast cooling rates down to a very low cooling-stop temperature, results in the formation of uncontrolled fractions of martensite in the microstructure, which have a detrimental effect on toughness properties of base metal and leads additionally to the softening in the heat affected zone. This effect cannot be adequately compensated for extremely low carbon contents, without adversely affecting productivity. Moreover, it is very difficult to produce pipe with adequate uniformity of strength properties. This difficulty cannot be attributed solely to the Bauschinger effect associated with the variation in local deformation occurring during the heavy straightening operation needed in the case of thin section plate, which distorts heavily during direct quenching.

Experience gained meanwhile indicates that Approach C is the best choice. This approach enables the desired property profile to be achieved through an optimised two-stage rolling process in conjunction with a reduced carbon content, a relatively high carbon equivalent and optimised cooling conditions. The special potential of the existing rolling and cooling facilities contributes significantly to the success of this approach.

Approach C, which involves a low carbon content, ensures excellent toughness as well as fully satisfactory field weldability, despite the relatively high carbon equivalent of the chemical composition. The chemical composition should therefore be considered acceptable for the purpose of current standardisation.

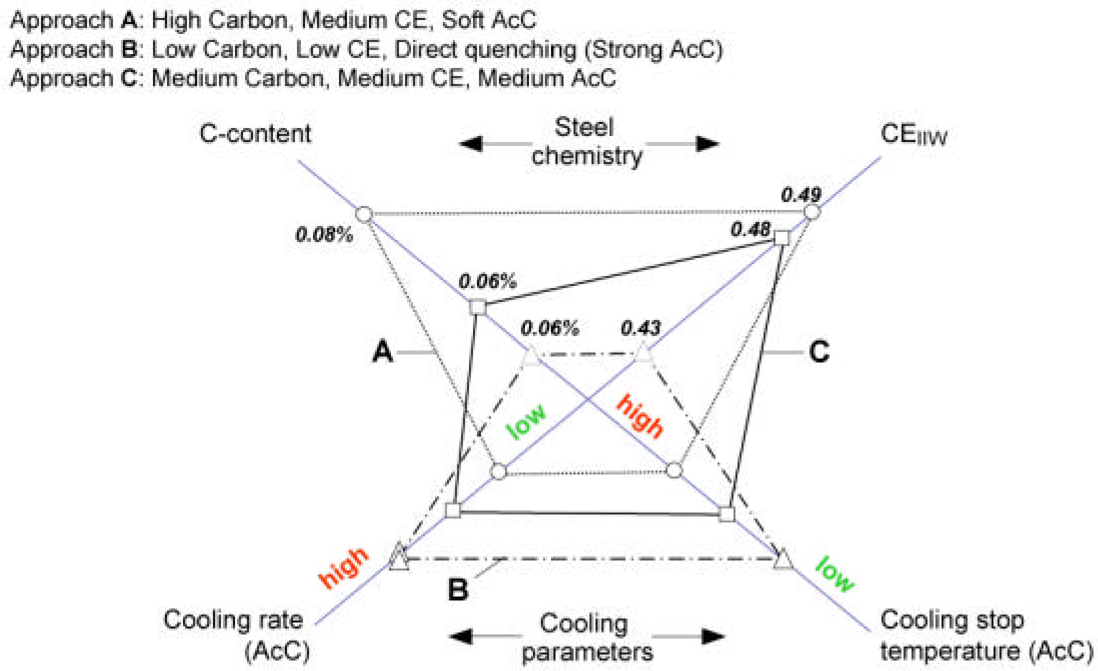

Figure 10: Modification of steel chemistry and cooling parameters to achieve the strength level of API X100

Large-diameter grade X100 pipes were produced on a trial basis for several times. The pipes are intended for use as test pipes to determine the behaviour of grade X100 material in full-scale burst tests (figure 11), which are conducted as part of several ECSC-funded research projects (4).

Figure 11: Full scale burst tests on X100 line pipe

The mechanical properties determined on the pipes (Figure 12) are quite appreciable, although they do not fully conform to the requirements currently specified for lower-strength material grades. The current requirements particularly for yield to tensile ratio and elongation, which are applicable to material grades up to X80, are too severe to be fulfilled for grade X100 on a statistical basis. This difficulty is attributable to the basic finding that as the strength increases, the yield to tensile ratio increases and the elongation decreases. The X100 material produced responds favourably to manual and mechanised field welding, a finding which can be attributed to its reduced carbon content (5).

For reasons of technical feasibility and cost-effective production, it is necessary in the context of grade X100 to reassess and redefine some of the requirements for the mechanical properties, considering the anticipated service conditions for the pipe.

Dimensions	30" x 19.1 mm		30" x 15.9 mm		56" x 19.1 mm		36" x 16.0 mm	
	(Heat I)		(Heat II)		(Heat III)		(Heat IV)	
	round	flat bar	round	flat bar	round	flat bar	round	flat bar
Yield strength $R_{0.5}$ (transverse)	739 MPa	665 MPa*	755 MPa	681 MPa*	737 MPa	643 MPa*	752 MPa	649 MPa*
Tensile strength R_m (transverse)	792 MPa	785 MPa	820 MPa	816 MPa	800 MPa	805 MPa	816 MPa	811 MPa
$R_{0.5}/R_m$	93 %	84 %	92 %	83 %	92 %	80 %	92 %	80 %
Elongation	A_5: 18.4 %	A_2": 32.5 %	A_5: 17.1 %	A_2": 27.7 %	A_5: 18 %	A_2": 30 %	A_5: 18 %	A_2": 28 %
CVN (-20°C)	235 J		240 J		200 J		270 J	
DWTT-transition temperature	- 15°C		-25°C		-20°C		~ -50°C	

* Specified minimum values not met due to the Bauschinger effect

Figure 12: Mechanical properties of X100 (Pipe body)

In the mean time pipes with 12.7mm, 16.2mm and 25.4mm wall thickness were produced to be tested in a further ECSC Demopipe project to demonstrate full scale usage.

Conclusion

The predicted growth in energy consumption in the coming decades necessitates severe efforts for transporting large amounts of natural gas to the end user. Large-diameter pipelines serve as the best and safest means of transport. This paper gives an overview of the current requirements of high strength steels and the associated developments. The technical possibilities were described. Also for the future additional substantial improvements can be realised.

The enormous pressure on the price of natural gas forces the pipeline operator to explore all the possibilities to reduce the cost of a pipeline project in the future. The pipe manufacturer can assist him in his endeavour by supplying high quality pipe. The effect of pipe quality on project costs will be more substantial when the pipeline is constructed to the limit state design. For an offshore pipeline in the North Sea, the project team could reduce the project costs especially for transportation in several stages by optimising the pipe diameter, that led to a cost reduction of 5%, increasing the material grade, that led to 4%, and using of limit state design, that led to 6% reduction.

Finally, the pipe manufacturer makes his contribution to reducing operational costs of a pipeline over its life by investigating the fatigue, corrosion and ageing behaviour of pipe and pipe materials. These properties have a significant bearing on the integrity of a pipeline and consequently the operating costs. These properties are currently being extensively studied. The knowledge gained these studies can be made available to assist the pipeline operator when planning a new pipeline project or when estimating the residual life of an ageing pipeline.

For reasons of technical feasibility and cost-effective production, it is necessary in the future to reassess and redefine some of the materials requirements for pipe, considering the anticipated service conditions for the pipe. Europipe likes to initiate close co-operation between the pipeline designer, operator, laying contractor and the pipe manufacturer in this respect that would be conducive to finding good solutions in modern pipeline construction.

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