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X80 line pipe for large-diameter high strength pipelines

H.-G. Hillenbrand	EUROPIPE GmbH
C. J. Heckmann	Mannesmann Forschungsinstitut GmbH
K. A. Niederhoff	Mannesmann Forschungsinstitut GmbH

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X80 line pipe for large-diameter high strength pipelines

By H.-G. HILLENBRAND[1], C. J. HECKMANN[2] and K. A. NIEDERHOFF[2]

[1] *EUROPIPE GmbH, Ratingen, Germany*
[2] *Mannesmann Forschungsinstitut, Duisburg, Germany*

Abstract

This paper gives an overview on manufacturing and field welding of high-strength steel grade X80 line pipe. Aspects of the production of induction bends are also discussed. Large projects have already been implemented with satisfactory results. Manual combined-electrode welding and mechanised gas metal arc welding (GMAW) as field welding methods for pipeline construction are well-established. This is also true for welding consumables, which have been well-tuned to match the pipe material in strength. The pipe material X80 is suitable for unrestricted use in onshore applications.

1. Historical Review

The ever increasing demand for energy world wide requires the construction of high-pressure gas transmission lines with the greatest possible transport efficiency, so that the cost of pipeline construction and gas transportation is minimised. This is particularly true when large distances are to be covered. The trend is therefore towards using line pipe of larger diameter and/or increasing the operation pressure of the pipeline. This, in turn, necessitates the use of higher strength steel grades to avoid large wall thickness that would be otherwise needed.

Also, in some long distance lines, where an increase of the capacity is not required, a reduction of wall thickness (no change of diameter and pressure) can be an economic incentive for applying X80 pipe. This is going to be more and more implemented in Australia using HFI (ERW) pipes and in Canada using spiral pipes of grade X80 (hot strip material from Steckel mill).

The development started about 30 years ago along with the introduction of thermomechanical (TM) rolling practices, and will continue in future. It was mainly governed by the large-diameter pipe manufactures **[1-5]**, due to the fact that TM-treatment (with or without accelerated cooling) can optimally be applied for plate only. Therefore, the availability of high strength hot strip material for manufacturing spiral and ERW pipes seems to be limited to grade X80. It is also limited with respect to the available maximum wall thickness (**Fig. 1**).

Today it is possible to produce grade X100 (TM) line pipe from plate and lay it under field conditions, maintaining all safety-related criteria **[6-7]**.

In the early 70s, grade StE 480.7 TM (X70) was introduced for the first time in Germany for the use as line pipe in construction of gas transmission pipelines. Since then, grade X70 material has proven a very reliable material in the implementation of numerous pipeline projects. The material has been optimised in the course of further development of TM rolling, and can be welded trouble-free with cellulosic electrodes providing care is taken to avoid hydrogen induced cold cracking.

Following satisfactory experience gained with StE 480.7 TM and X70 in the subsequent period, grade X80 (GRS 550) line pipe came into use for the first time as a 3.2 km pipeline section in 1985 on a trial basis (**Fig. 2**). Subsequently, the material was used in the construction of several additional trial sections. In 1992/93, Ruhrgas AG constructed the world's first ever pipeline of 250 km length in this material, again in Germany **[5, 8]**. The reason why Ruhrgas AG selected this material was the reduction in pipe wall thickness needed in the construction of the pipeline designed to operate at 100 bar pressure.

The yield strength values specified in various standards (DIN 17172, API 5L, EN 10208-2/ISO 3183-2) for the different high strength line pipe steels differ only slightly (**Fig. 3**) between 550 MPa (DIN 17172) and 555 MPa (EN 10208-2). To ensure that pipes are not supplied with excessive yield strength in individual cases, the current versions of API-5L, EN 10208-2/ISO 3183-2 specify an allowable scatter range of 120 MPa for yield strength. The yield strength measured on the transverse tensile specimens is required to lie in this range. The intention of specifying an upper limit for the yield strength was to enable the weld metal strength to be better matched to the pipe material. The specified yield strength range of 120 MPa applies to all line pipe grades that are included in these standards.

Significant differences are noticeable in the specified minimum tensile strength among the different standards. For instance, the minimum required tensile strength of GRS 550 (StE 550.7 TM to DIN 17172) is 70 MPa higher than that of API 5L grade X80. Therefore, this material was quite close adapted to a thought API 5L grade X90.

2. Development and Production Results of X80

2.1 Large EUROPIPE projects

The first large scale X80 line pipe was ordered by the German Ruhrgas running from Werne-to-Schlüchtern. This pipeline passes through the states of North Rhine-Westphalia and Hessen in Germany. The geometry of the pipe to be used was 48" O.D. x 18.4 and 19.3 mm wt. EUROPIPE supplied 145,000 t of pipe in the years 1992 and 1993 for this project. Furthermore, line pipe bends (QT-treated) were produced for the first time in this material grade by the Mannesmannröhren-Werke.

In 2001 and 2002 further X80 pipes were manufactured for a project in UK. Several parts of the gas pipeline network were ordered to a total length of 42 km in the past. Further quantities being about 70 km are also booked for this and next year.

A challenging project of 2001 was a hot steam pipe line system for CNRL in Canada **[9]**. The longitudinally welded pipes were qualified for operation temperatures up to 354 °C. The high temperature properties with respect to creep were tested, and the results indicated sufficient creep resistance.

2.2 Steel making

The basic work towards the development of the high strength grade X80 and GRS 550 materials was already completed by us in 1985. On the basis of extensive laboratory investigations and mill trials, a MnNbTi steel was found to fulfil the necessary requirements. The strengthening mechanisms in this steel type have been described elsewhere **[3]**. The base composition of the steel used consisted of 0.09 % Carbon, 1.9 % Manganese, 0.04 % Niobium and 0.02 % Titanium. Additions of Copper, Nickel or Molybdenum were not necessary in the case of pipe wall thickness up to 25 mm. Alloying with Boron was not permitted.

Because of the higher specified minimum tensile strength of 690 MPa, the carbon content and carbon equivalent are slightly higher in the case of GRS 550 than in the case of X80 for a given wall thickness. Nevertheless, a carbon equivalent according to IIW formula of less than 0.44 % could be assured. A Ti/N ratio of greater than 3.5 is necessary for the MnNbTi alloying system to be effective. The Titanium content of the steel must be less than 0.025 % so that there is no detriment to the toughness in the HAZ of the longitudinal weld seam. As a consequence, the Nitrogen content during steel making was only allowed to vary up to a maximum of 50 ppm. Therefore, an adequate vacuum treatment of the melts is necessary. **Fig. 4** shows the Titanium and Nitrogen contents found in the ladle analyses of the casts for the Ruhrgas order.

2.3 Plate Production

The effect of rolling and cooling parameters on the mechanical properties of MnNbTi steels has been described in detail in previous publications **[1-5]**. As an example the 18.3 mm thick GRS 550 plates for the Ruhrgas order were rolled under the following conditions, which were maintained within narrow limits:

- Slab reheating temperature 1168 °C ± 10 °C
- Intermediate thickness 100 mm
- Finish rolling temperature 772 °C ± 8 °C
- Cooling start temperature 760 °C ± 10 °C
- Cooling stop temperature 560 °C ± 11 °C
- Cooling rate 15 °C/s

Accelerated cooling of the plate from finish rolling temperature has a remarkable effect on the microstructure and hence, on the mechanical properties of the steel. To obtain an almost fully bainitic microstructure, it is necessary that the accelerated cooling should be started before the transformation of austenite into ferrite begins. **Fig. 5** shows typical temperature profiles along the length of the plate before and after accelerated cooling. The two curves shown in each case represent the temperature profiles for the top and the bottom sides of the plate.

Numerous additional investigations carried out in the plate mill have shown that the variation in strength could be controlled in a narrow range of only 10 MPa along the plate width and only 20 MPa along the plate length within each plate. These results document that the rolling and accelerated cooling techniques are fully matured, which, coupled with the steel composition selected, ensure that the material readily complies with the strength and toughness requirements specified.

2.4. Pipe Production

The parameters for the pipe manufacture of the Ruhrgas order were selected, drawing upon the experience gained in the course of the production of the pipe for the previous trial sections (Megal II, CSFR) **[4]**. The results of testing carried out at that time for single-case approval by the German technical regulator, TUEV, which became necessary because the material grade was not standardised, could be applied to the present case since there was no decisive difference in pipe geometry and since the chemical compositions were almost identical. The yield and tensile strength values measured for the pipe in circumferential direction are shown in **Fig. 6**. As seen in the figure the specified minimum values were comfortably achieved. The strength values were determined using round bar tensile specimens, since the strain hardening behaviour of the bainitic material leads to a large Bauschinger effect. The higher the strength level, the greater the Bauschinger effect. In other words, the proof stress values measured on flattened rectangular specimens taken from the pipe do not correlate well with the true proof stress values of the pipe wall. It should also be noted that the yield strength of high strength pipeline material shows an unisotropic behaviour. Using round bar specimens, the yield strength of an X80 material is about 30-40 MPa higher in circumferential direction than in longitudinal direction. Therefore it is easier to realise girth weld overmatching requirements. The tensile strengths in both directions are comparable.

The impact energy values measured on the base material were in excess of 95 J, thereby exceeding the minimum value recommended by the EPRG for crack arrest. The ductile-to-brittle transition temperatures measured on the individual DWTT specimens were well below the specified test temperature of 0 °C.

Fig. 7 shows the chemical composition of the longitudinal seam weld metal deposited by the two-pass SAW method. Also shown in the figure are the impact energy values measured at 0 °C, which is the commonly specified test temperature in Germany. The weld metal has a high Manganese content and is additionally alloyed with Molybdenum. This Ti-B-free weld metal represents a good compromise with respect to toughness and mechanical strength. The average impact energy values measured varied between 100 and 200 J.

The strength of the seam weld was checked by means of flattened transverse weld specimens, with the weld reinforcement removed by machining. All specimens broke in the base material, i. e. outside the weld region. Thus, all the tensile strength values measured reflect the strength of the base material and were above the specified minimum value of 690 MPa.

One of the latest projects using X80 was a UK pipeline for Transco in 2001 **[10]**. The results on EUROPIPE's production tests, performed in the context of certification of the pipe, are shown in **Fig. 8 and 9**. All values of the round bar tensile tests and impact tests conform to the requirements of X80. The standard deviations of tensile testing are 15 MPa for yield strength and 13 MPa for tensile strength. Average values of impact testing were 227 J for base metal and 134 J for weld metal.

To give an example of the manufacturability of heavy wall X80 pipe, EUROPIPE commercially produced 36" diameter pipe with 32.0 mm wall thickness. 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 (CE_{IIW} = 0.42) ensures good field weldability. The Charpy V-notch impact energy measured at -40°C was in excess of 200 J and the shear area of DWTT specimens tested at –20°C was greater than 85%. The forming and welding operations carried out on this high strength steel did not cause any problems.

2.5. Production of Induction Bends

The induction bending machine at Mülheim works of Mannesmannröhren-Werke AG is designed so as to enable bends to be produced from pipes with outside diameters up to 64". In the course of the execution of the Ruhrgas order 600 large diameter pipe bends of various angles were produced from GRS 550 QT pipe for the first time in 1992 and 1993. The double submerged-arc welded line pipe being used for the production of the bends was 1220 mm OD and 22 mm in wall thickness. The bending radius was 6,000 mm (corresponding to approx. 4.9 times the pipe diameter) for all bends. The bends contained no straight pipe portions at the ends.

The induction bending operation has been carried out on a computer-aided bending machine specially designed for this purpose. Heating is done by means of a ring-shaped inductor. The pipe next to the heated zone, which is subjected to bending, is quenched with water by means of a ring nozzle. The heat condition of the heated zone being inductive bent corresponds to that of full austenitization heat treatment. Following bending operation, the bends were tempered full length in a furnace at 620 °C ±10 °C.

Thus, the finished bends were delivered in the quenched and tempered condition. For this reason, the base material for bends exhibits an increased alloy content compared to the straight line pipe. The bends contain Molybdenum additions and a slightly increased carbon content.

Fig. 10 shows the average chemical composition of the bend body material. This figure also includes the mechanical properties measured in the course of the production of the bends and the specified requirements. It is clear from the data in the figure that the measured values were comfortably above the specified minimum values. The IIW carbon equivalent of the chemical composition of the bends was 0.46 % in average and thus good field weldability of the bends was ensured.

The weld metal of the longitudinal seam was alloyed with Nickel and Molybdenum. The submerged-arc welds were performed using high-basic flux. In the quenched and tempered condition, the requirements for the weld metal toughness were readily fulfilled (Fig. 10). Also the strength of the weld was quite satisfactory.

Finally, it should be mentioned here that X80 bends made from ERW or spiral pipe have not been produced so far. In any case the material should be able to be quenched and tempered, therefore the material will differ from straight pipe. For thin wall X80 line pipe also X70 induction bends with thicker wall can be used.

3. Weldability

Before GRS 550 (StE 550.7 TM to DIN 17172) was first used on an industrial scale in 1985, the cold cracking behaviour of the material had been studied extensively by means of laboratory and full-scale tests [4]. **Fig. 11** shows the minimum preheating temperature for avoiding heat affected zone (HAZ) hydrogen cracking determined for different steel compositions of pipeline steels in the implant test on welds deposited with cellulosic vertical-down electrodes. It is evident from this figure that a preheating temperature of only 100 °C is necessary to deposit welds in GRS 550 (X80) without any risk of cold cracking in the HAZ. Unlike the conditions for the implant test, girth welds on large diameter pipe deposited during actual pipe laying are not allowed to undergo interruptions with cooling to room temperature after only the root pass has been deposited. It would therefore be possible to use lower preheating temperatures than those determined in the implant test **(Fig. 12)**. Even the most critical weld, No. 2 in Fig. 12, which was deposited completely without interruption using cellulosic electrodes at a preheating and interpass temperature that was deliberately maintained at a low value of only 50 to 60 °C, was free of cold cracking. Hence, there is no increased threat of cold cracking in the HAZ compared to X70 line pipe material.

This has been also demonstrated by the practical experience gained with the Ruhrgas pipeline construction.

The high-strength basic girth weld metal (AWS electrode E10018-G) itself, however, has been found to be somewhat more sensitive to cold cracking than the girth weld HAZ of X80 material. Therefore, it is recommended to control that the preheating and interpass temperatures are maintained at about 80 to 100 °C minimum. If this requirement is fulfilled and if it is ensured that the basic electrodes are kept dry, there will be no threat of cold cracking in the weld metal as well as in the HAZ of base material.

As the diffusible hydrogen content (HD) in deposited weld metal of mechanised gas metal arc welding lies below 3 ml/100 g, a preheating temperature of 80 °C (freedom from condensed water) is quite sufficient. Extended interruptions associated with intermittent cooling should however be avoided also in the case of gas metal arc welding.

4. Field welding methods

4.1. Manual vertical down welding

Considerable changes had to be made to the manual welding method required in the construction of large-diameter pipelines in high strength materials as X80, GRS 550 and higher for the following reasons. The material StE 550.7 TM to DIN 17172 (GRS 550) has the same yield strength (550 MPa) as grade X80 to API 5 L, but a specified minimum tensile strength which is 70 MPa higher than that of grade X80. The material could therefore be considered as grade X90 from the point of view of tensile strength. Because of this high tensile strength, it was not possible for the weld metal deposited by the cellulosic electrode to fulfil the requirement for the specified minimum tensile strength and to have simultaneously satisfactory toughness and satisfactory resistance to cold cracking. This problem was solved by the use of a combined-electrode manual welding method (**Fig. 13**). In this method, the root pass and the hot pass are deposited with well-established cellulosic electrodes of lower strength grade, and filler and cap passes with a high strength basic vertical-down electrode of the AWS type E 10018-G. It is thus possible to ensure an unchanged high front end progress during pipelaying. This method is well-established now and regarded as sufficiently tried for large-scale practical use **[4, 8, 11]**.

4.2. Mechanised gas metal arc welding (narrow-gap, vertical-down)

All established mechanised gas metal arc welding methods (GMAW) developed for use in onshore pipeline construction can be employed. Gas metal arc welding, however, encounters certain limitations in the case of onshore pipe laying in difficult terrain. It should be carefully considered also in the case of frequent interruptions (roads, rivers, etc.) whether it would be more economical to apply manual welding. **Fig. 14** shows, by way of example, the welding procedure that was employed to construct parts of the 250 km long Ruhrgas pipeline.

5. Strength behaviour of girth welds (overmatching)

As the strength of line pipe material increases, weld metals of increased strength and sufficient toughness are required. For the reasons mentioned in earlier publications (inadequate toughness, susceptibility to cold cracking of the weld metal), the cellulosic electrode cannot be improved beyond the AWS type E 9010-G with the highest strength **[12-14]**. Therefore, it was necessary to resort to basic vertical-down electrodes to deposit filler and cap passes by manual welding. As well as the extensive service experience gained, the results of recent wide plate tests, which involved welds with artificial planar defects in the HAZ, indicated that the high-toughness weld metal deposited with the basic vertical-down electrode of the AWS type E 10018-G is tuned to match the pipe material strength optimally. This applies also to the welding consumables needed for making welds by mechanised gas metal arc welding.

6. Final remarks

HFI welded pipe is limited in diameter, wall thickness and material grade (X 80 maximum). One reason is the restriction of hot rolled strip production. The use of a better hot strip rolling process like Steckel mill enables helical seam weld X80 pipe to be produced with a larger wall thickness of up to about 16 mm. By comparison, longitudinal SAW seam welded X80 line pipe is available with wall thickness from 10 mm to 35 mm at outside diameters from 20 inches to 56 inches. This pipe is particularly suitable for operation at the highest pressures. The pipes produced by the various methods overlap in the lower part of the size range. The quality level of the pipes can be considered to be the same. Price wise each product has its optimum range. In overlapping sizes a specification should allow all products.

While it is not possible to produce HFI welded and helical seam welded pipes in grades higher than X 80, longitudinal seam welded grade X 90 line pipe has been already produced on a commercial scale. Materials meeting the requirements for grade X 100 have already been produced. EUROPIPE is partner in some JIP to develop X100 line pipe.

Grade X 80 pipe in most cases is more economical than X70. Consistently predictable and reproducible mechanical properties and good field weldability can be achieved without difficulty.

In the case of grade X 100, questions regarding its cost-effectiveness cannot be answered in general terms yet, because other aspects such as the need for crack arrestors etc. might arise with this material.

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Figures

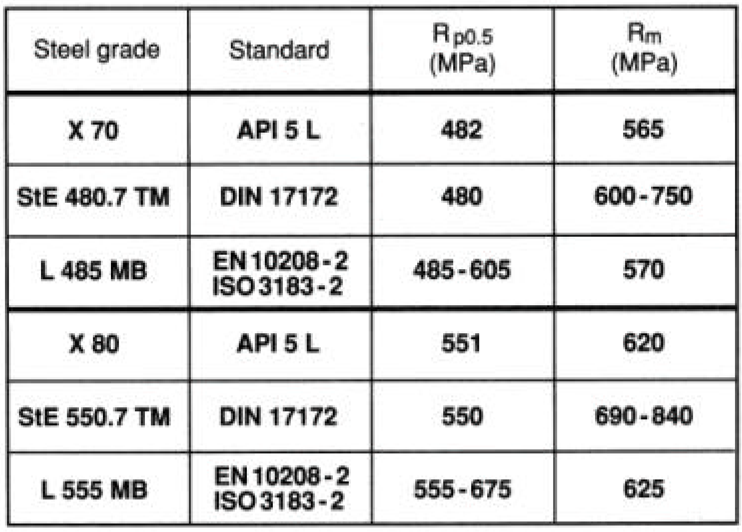
Process	**Diameter**	**Wall thickness**
Longitudinally welded large-diameter pipe	20 “ to 64 (56) “	ca. 10-35 mm
Spirally welded large-diameter pipe	20 “ to 64 “	ca. 6-16 mm *)
HFI (ERW) welded pipe	= 24 “	ca. = 10 mm

**) Hot strip material from Steckel mills*

Figure 1: Limitation of Dimensions to be manufactured in grade X80 on different production routes

Project	**Dimension**	**Quantity**	**Realization**
MEGAL II, Germany	1118 x 13.6 mm	3.2 km	1985
4th Transit Gas Pipeline, Czechoslovakia	1420 x 15.5 mm	1.5 km	1985
Empress Eats Compressor Station Alberta; Canada	42” x 10.6 mm	126 welds	1990
Werne-Schlüchtern Pipeline, Ruhrgas, Germany	48” x 18.4 and 19.3 mm	250 km; 145.000 to	1992/1993
NOVA Pipeline; Matzhiwn project, Alberta, Canada	*Spiral pipe*, 48” x 12.1 mm	ca. 54 km	1994
Trans Canada Pipeline	*Spiral pipe*, 48” x 12.0mm & 16.0mm	ca. 118 km	1997
Transco/UK	48” x 15.1 mm and 21.8 mm	42 km	2001
Canadian Natural Resources, Canada	24” x 25.4mm	18 km; hot steam onshore pipeline	2001

Figure 2: Reference list of X80 onshore projects in large-diameter pipe world-wide



Steel grade	Standard	$R_{p0.5}$ (MPa)	R_m (MPa)
X 70	**API 5 L**	**482**	**565**
StE 480.7 TM	**DIN 17172**	**480**	**600-750**
L 485 MB	**EN 10208-2** **ISO 3183-2**	**485-605**	**570**
X 80	**API 5 L**	**551**	**620**
StE 550.7 TM	**DIN 17172**	**550**	**690-840**
L 555 MB	**EN 10208-2** **ISO 3183-2**	**555-675**	**625**

Figure 3: Specified strength for high strength line pipe steel grades

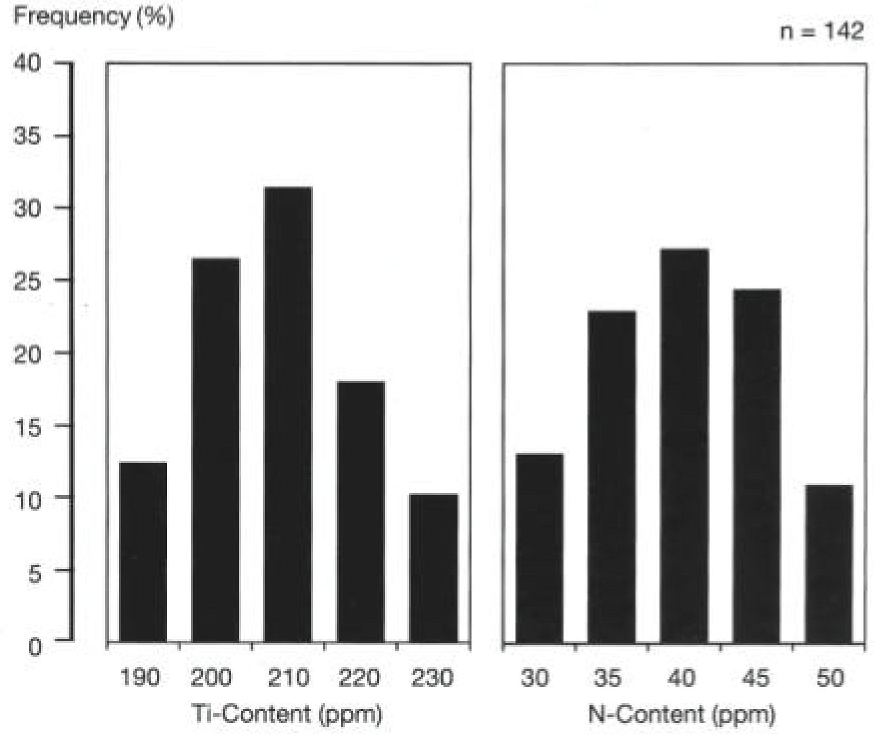


Figure 4: Distribution of Titanium and Nitrogen contents of the base material of the pipes produced (Ladle analyses)

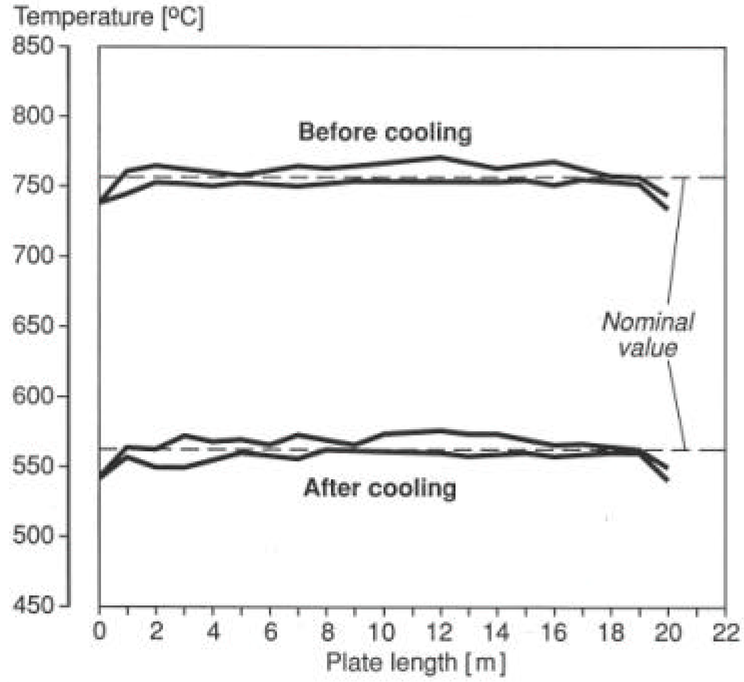


Figure 5: Temperature profiles measured before and after accelerated cooling

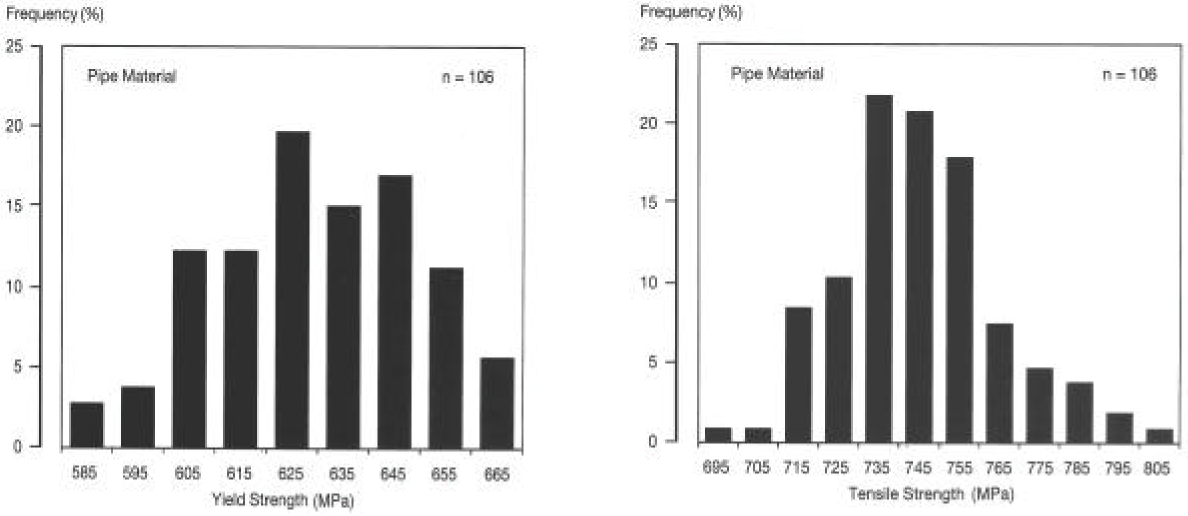
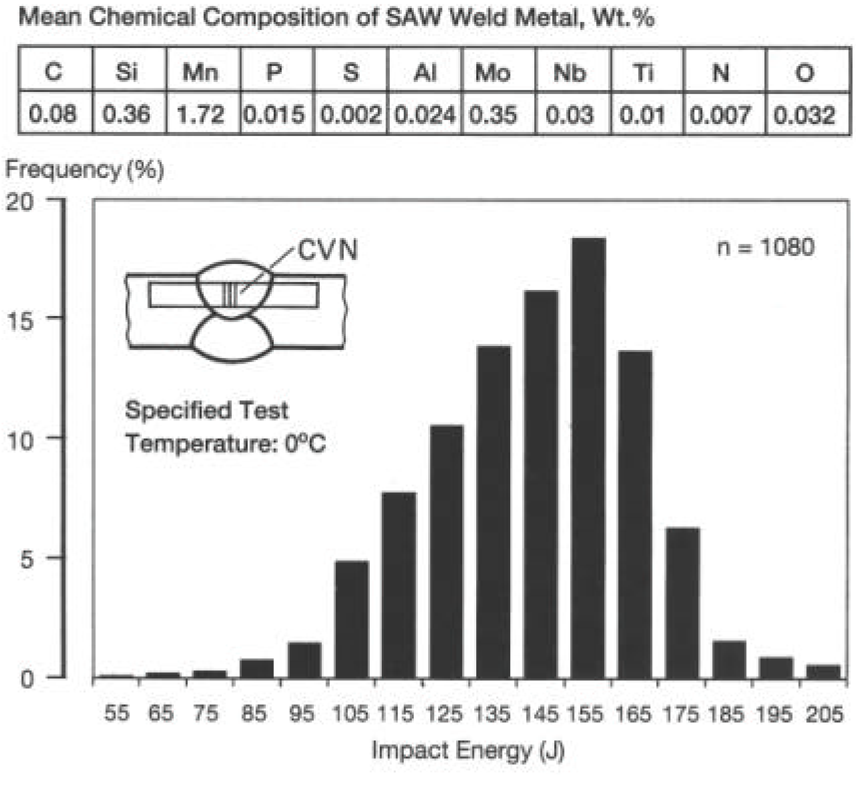


Figure 6: Distribution of transverse yield strength (Rt0.5) and tensile strength (round bar specimens to DIN 50125)



Mean Chemical Composition of SAW Weld Metal, Wt.%

C	Si	Mn	P	S	Al	Mo	Nb	Ti	N	O
0.08	0.36	1.72	0.015	0.002	0.024	0.35	0.03	0.01	0.007	0.032

Figure 7: Mean chemical composition and distribution of impact energy values measured on ISO V-notch specimens for the SAW longitudinal seam weld metal

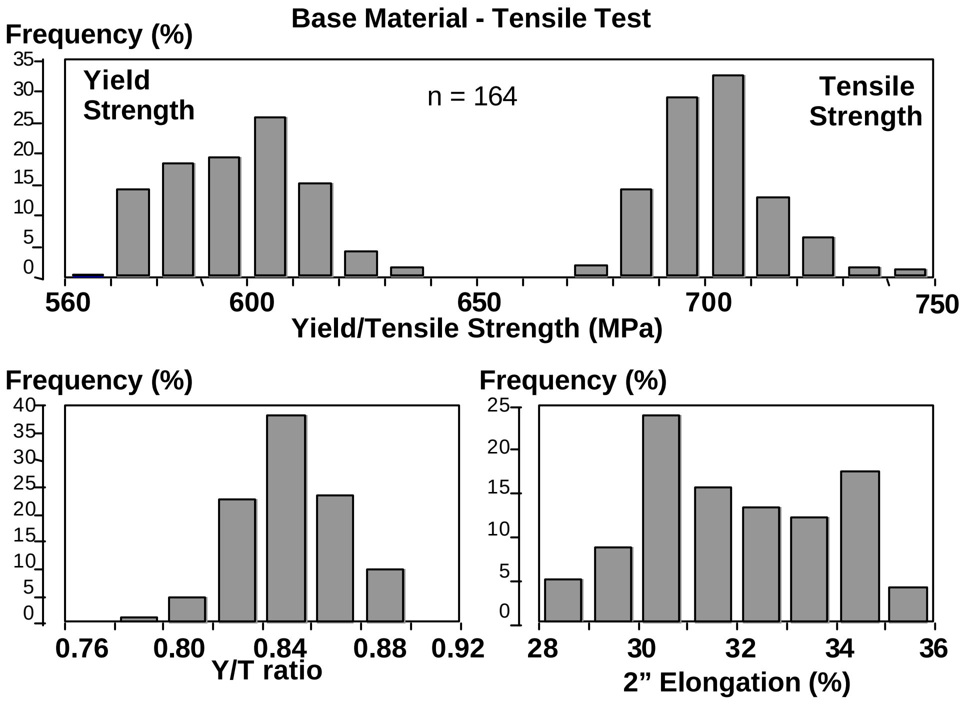


Figure 8: Strength properties of X80 Pipes (48” OD x 15.1 mm WT); Transco pipeline

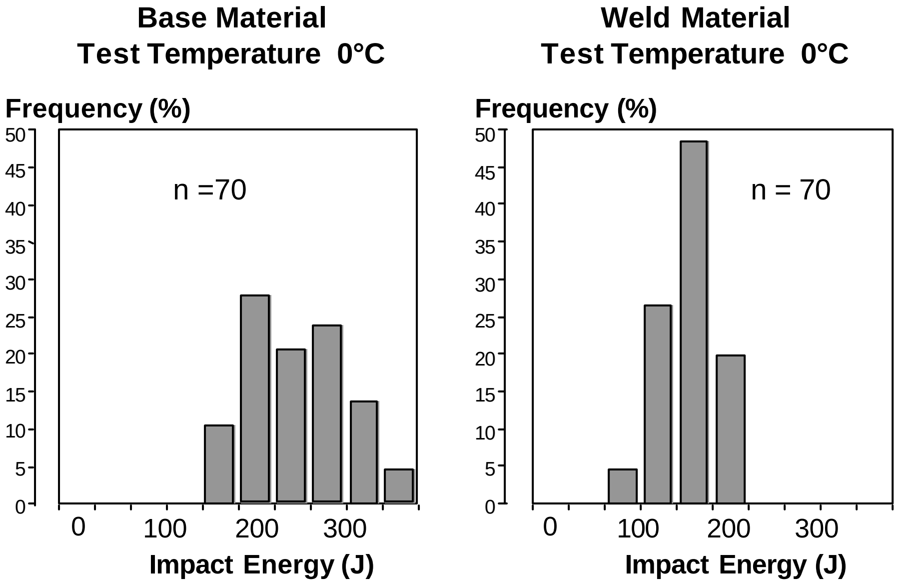
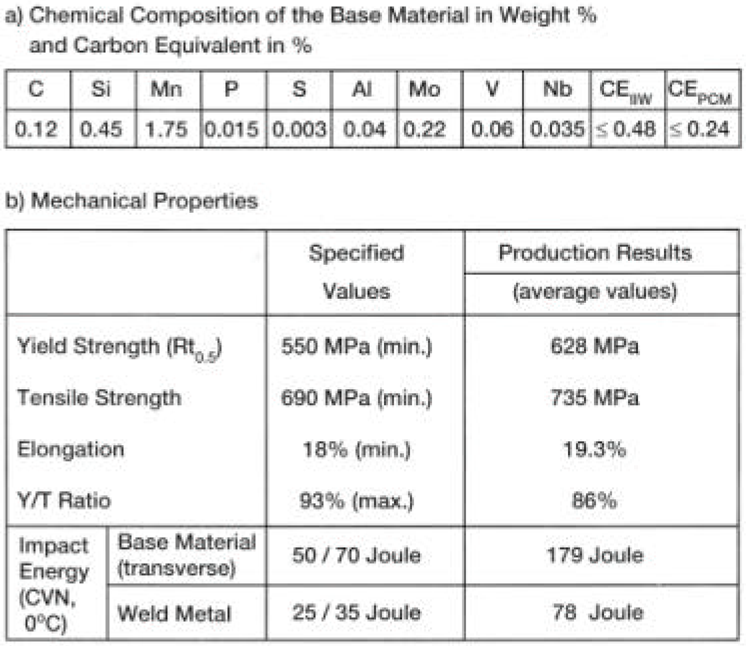


Figure 9: Impact properties of X80 Pipes (48” OD x 15.1 mm WT); Transco pipeline



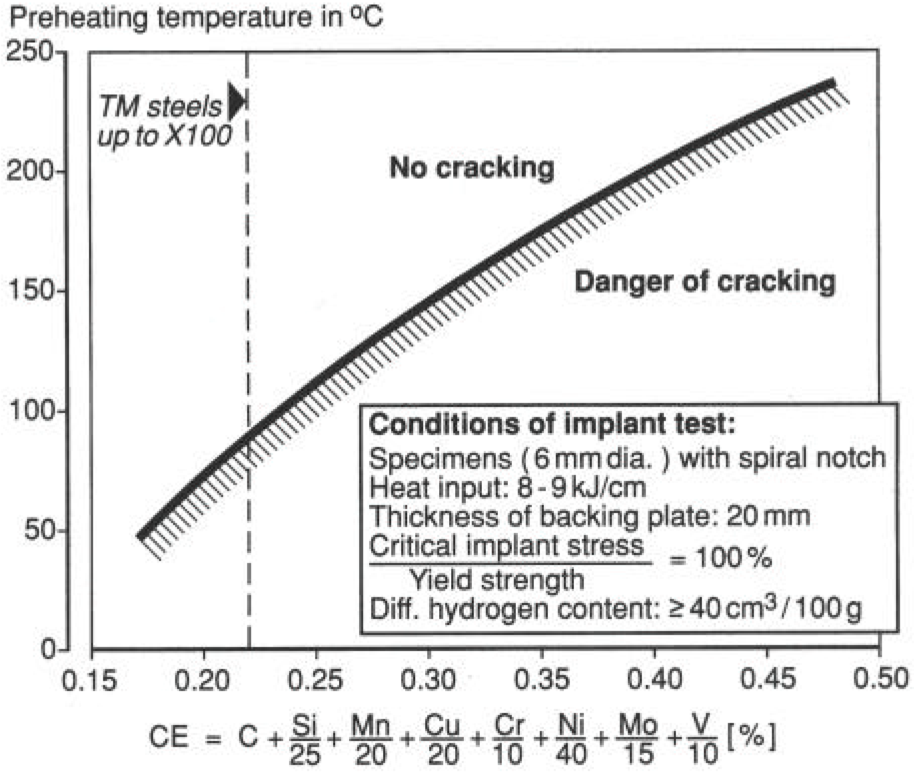
a) Chemical Composition of the Base Material in Weight %
and Carbon Equivalent in %

C	Si	Mn	P	S	Al	Mo	V	Nb	CE_{IIW}	CE_{PCM}
0.12	0.45	1.75	0.015	0.003	0.04	0.22	0.06	0.035	≤ 0.48	≤ 0.24

b) Mechanical Properties

		Specified Values	Production Results (average values)
Yield Strength ($Rt_{0.5}$)		550 MPa (min.)	628 MPa
Tensile Strength		690 MPa (min.)	735 MPa
Elongation		18% (min.)	19.3%
Y/T Ratio		93% (max.)	86%
Impact Energy (CVN, 0°C)	Base Material (transverse)	50 / 70 Joule	179 Joule
	Weld Metal	25 / 35 Joule	78 Joule

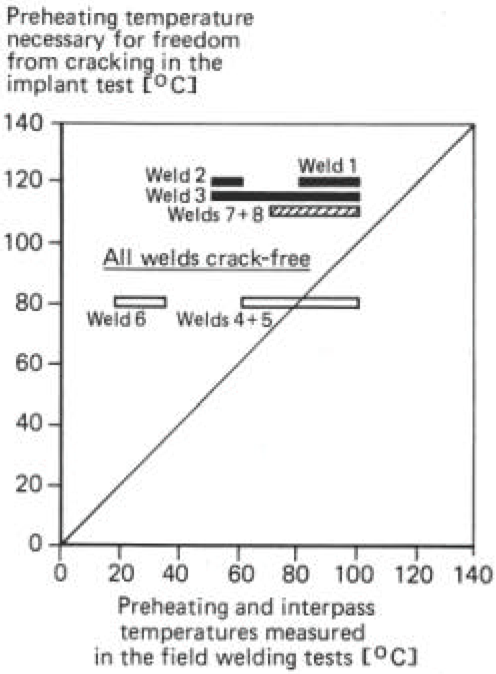
Figure 10: Chemical composition and mechanical properties of the GRS 550 QT (Grade X80) line pipe bends



$$CE = C + \frac{Si}{25} + \frac{Mn}{20} + \frac{Cu}{20} + \frac{Cr}{10} + \frac{Ni}{40} + \frac{Mo}{15} + \frac{V}{10}\ [\%]$$

Figure 11: Preheating temperature for crack resistance as a function of the C-equivalent - Welding with cellulose coated electrodes –

Implant test: Plates 20mm thick
Heat input: 8-9kJ/cm



Field welding test: Pipes 1220 x 17mm			
Weld	Electrode	Heat input [kJ/cm] Root	Heat input [kJ/cm] Hot pass
1	Cellulosic (V-down) ▬ HD 40	9	10
2		9	9
3		6/7	9
4	Basic (V-down) ▭ HD 5	8	8
5		7	10/11
6		7	10
7	Cellulosic/ basic mixed weld (V-down) ▨ HD40/HD5	6	9
8		8	10

	Time between root and hot passes
Cellulosic	Approx. 5min.
Basic	7 to 9min.

Figure 12: Comparison between the preheating temperatures required in the laboratory and those required in the field for ensuring crack-free welds in X80 steel

Pass		Filler AWS type	Filler dia. mm	Current A	Voltage V
Cellulosic	Root pass	E7010-A1 or E6010	4.0	120/160	24
	Hot pass	E7010-A1 or E9010-G	5.0	180/200	24
Basic	Filler passes	E10018-G	4.0 4.5	190/210 230/250	20 20
	Cap passes	E10018-G	4.0	190/210	20

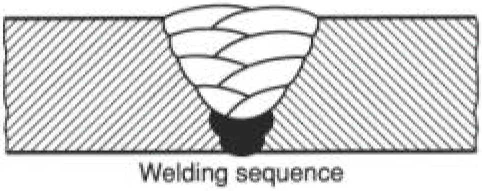
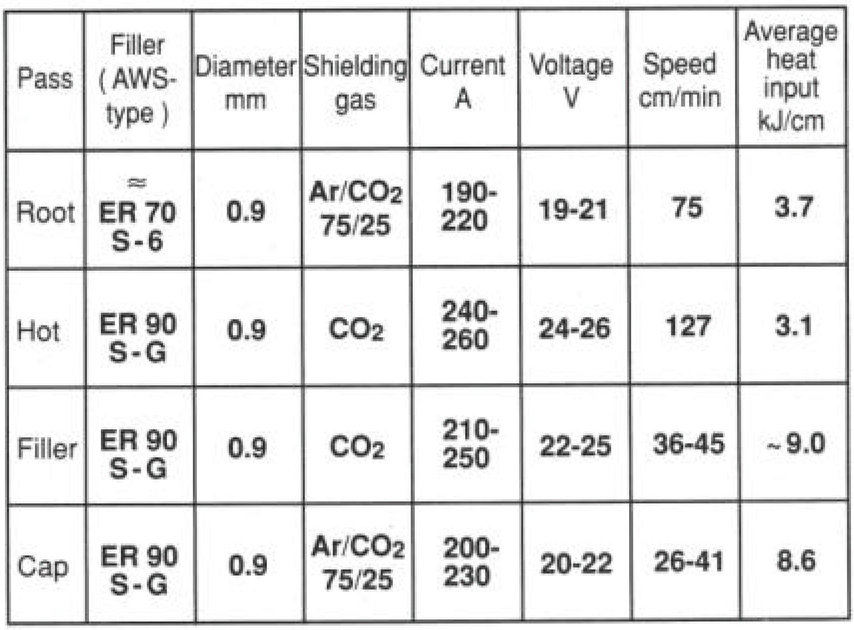


Figure 13: Manual downhill welding procedure for high-strength line pipe steel



Pass	Filler (AWS-type)	Diameter mm	Shielding gas	Current A	Voltage V	Speed cm/min	Average heat input kJ/cm
Root	≈ ER 70 S-6	0.9	Ar/CO_2 75/25	190-220	19-21	75	3.7
Hot	ER 90 S-G	0.9	CO_2	240-260	24-26	127	3.1
Filler	ER 90 S-G	0.9	CO_2	210-250	22-25	36-45	~9.0
Cap	ER 90 S-G	0.9	Ar/CO_2 75/25	200-230	20-22	26-41	8.6

Figure 14: Typical girth welding procedure for mechanized gas metal arc welding of X80 line pipe (CRC-Procedure)