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Development, state of the art and future trends in design and production of heavy plates in X80 steel-grades

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Abstract

This paper gives an overview of the development of steel grades in the X80 strength-level at the 5.1 m heavy plate mill of Mannesmannröhren Mülheim (MRM). For reasons of increasing cost effectiveness in pipeline-construction, high strength low alloy line pipe steel grades were developed. MRM in close co-operation with Salzgitter Mannesmann Forschung (SZMF, former MFI) and their predecessors contributed to this development from the very beginning. Commercial manufacturing of steel plates in the X80-strength-level at MRM began more than 20 years ago. These developments and optimisations are described in this paper, considering various contracts and present projects.

Introduction

MRM is specialised in the production of heavy plates for longitudinal welded large diameter pipes. These plates are produced in the thermomechanical-controlled process (TMCP). On MRM`s 5.1 m 4-high rolling stand, commercial manufacturing of steel plates in the X80-strength-level began in the early eighties. The brand name for this early X80 was GRS 550 (“Großrohrsonderstahl 550” which means large diameter pipe special steel 550).
These developments resulted in plate manufacturing for the world`s first X80 pipeline in 1985. A 3.2 km long section of GRS 550 was incorporated into the Megal II pipeline. In 1992, the

approximately 250 km long Werne-to-Schlüchtern Natural Gas Pipeline in Germany was also made of GRS 550 [1].

Since then, about 300,000 Mt of plate were produced and delivered in the X80-strength-level according to European, American and international standards (figure 1).

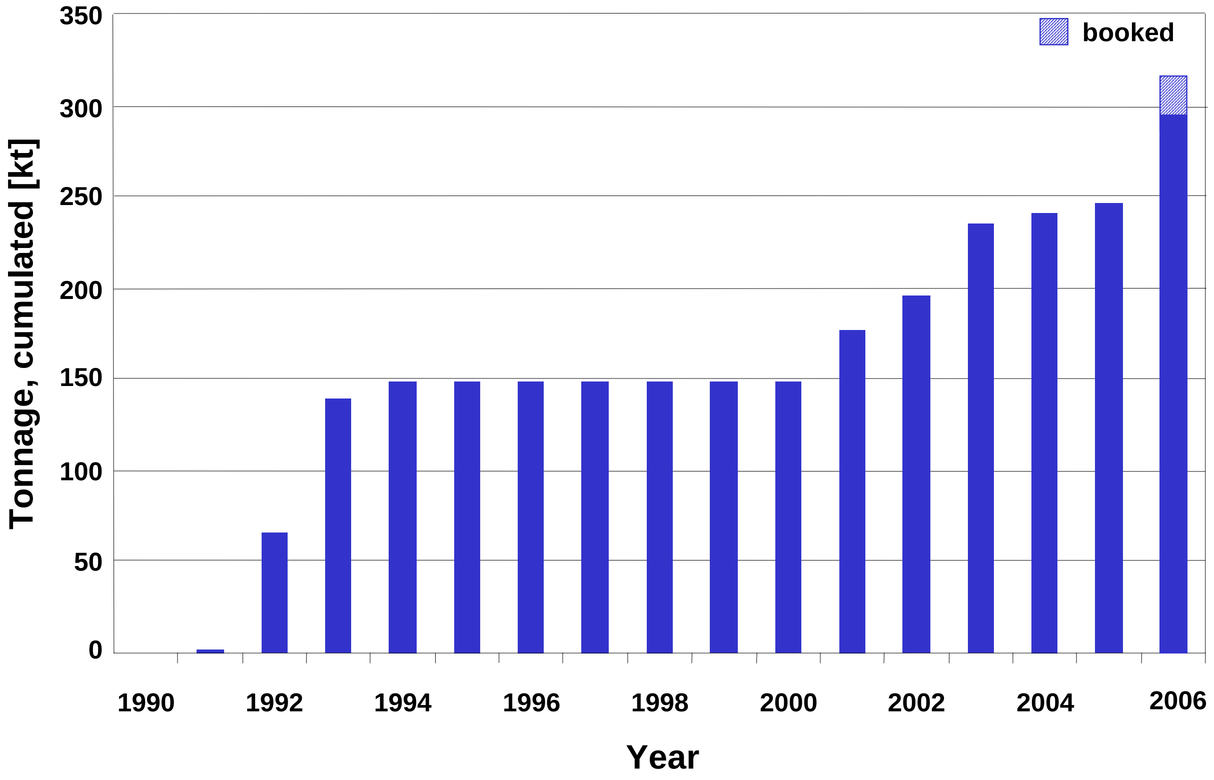


Figure 1: X80 deliveries by MRM (cumulated)

These plates were made for natural gas and hot steam pipeline projects, pressurised natural gas containers and structural pipe applications. The development and the experience in the production of grades of even higher strength like X100 and X120 strongly supported further optimisation [2].

Figure 2 shows the time frame for the development of high strength steel grades at MRM.

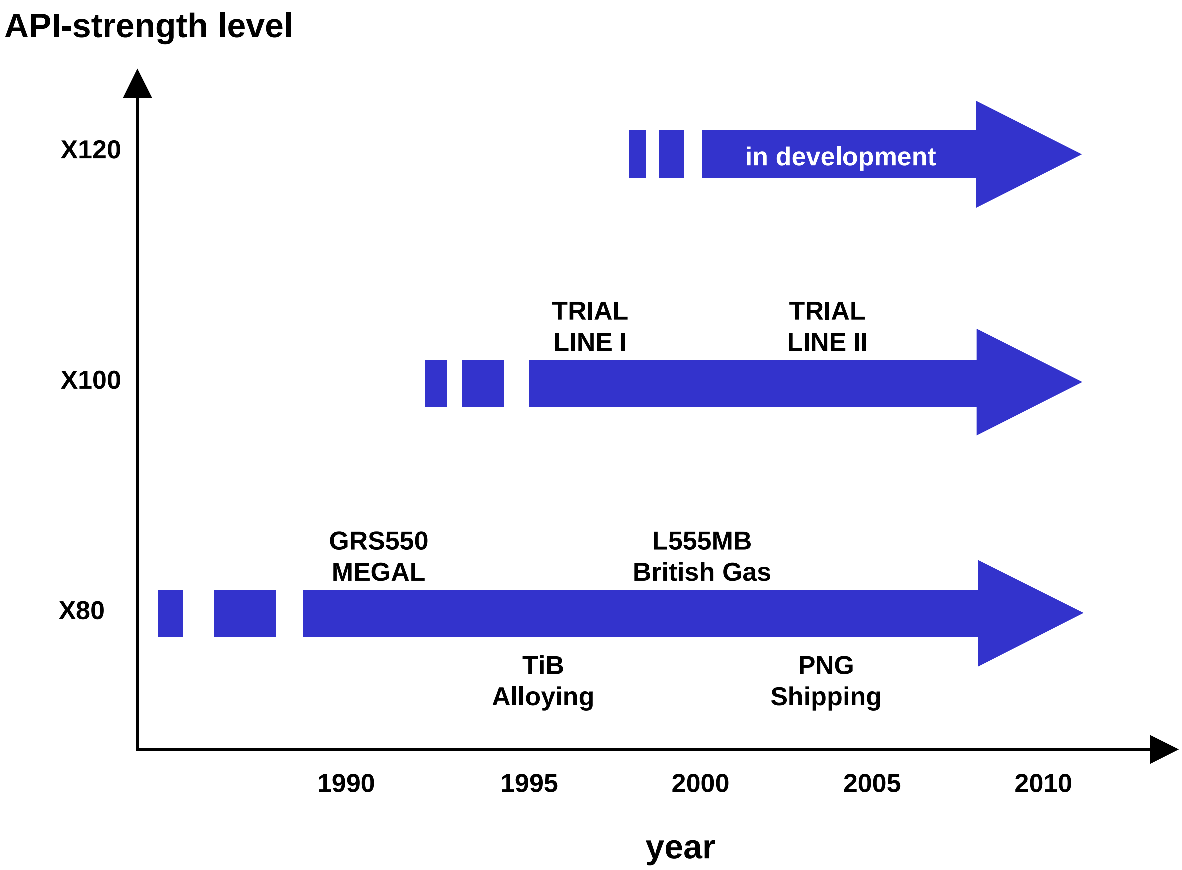


Figure 2: Development of high strength steel grades at MRM

Today, MRM produces plates for pipes in a strength level of X80 with the same reliability as lower grades.

From 1990 till today, customer requirements and specifications have changed considerably. For example, low temperature properties became more important and the wall thickness increased. Further developments were made to lower the carbon equivalent in order to improve weldability .

These developments have been conducted with MRM`s largest customer Europipe (joint venture of Salzgitter AG and Dillinger Hüttenwerke AG), a manufacturer of longitudinally welded large diameter pipes. The geometry range covers plates up to 40 mm thickness and 3.830 mm wall thickness (48 inch tube diameter, figure 3).

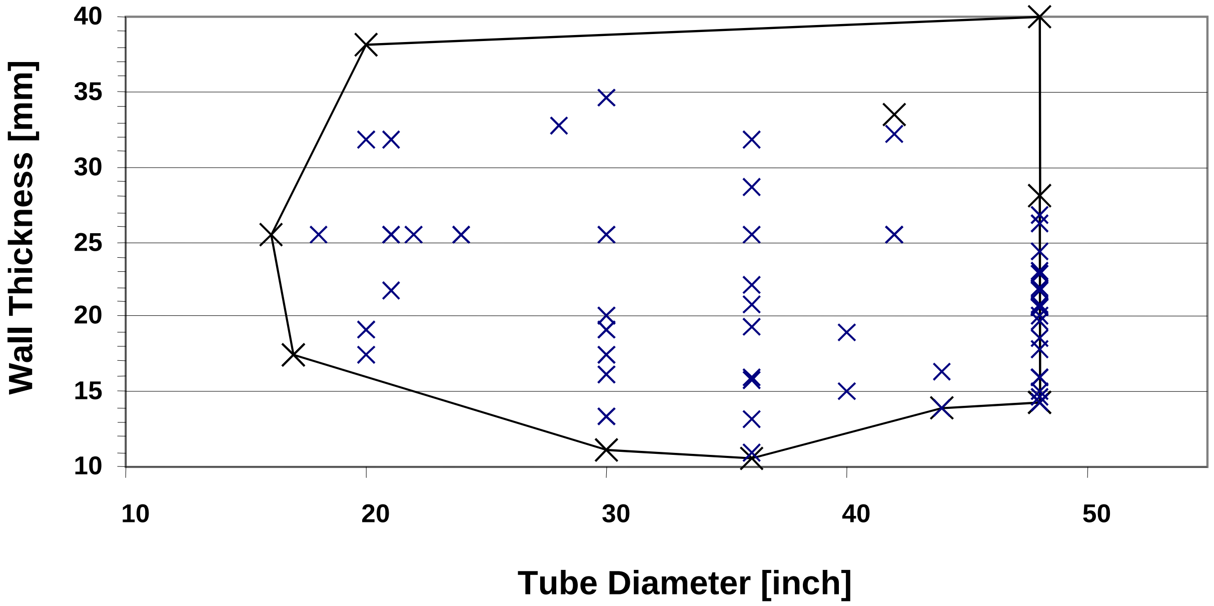


Figure 3: Geometry of deliveries in the X80-strength-level

Projects and Developments

The current American and European standards allow the production of plate in the X80-strength level with standardised concepts as the required material properties are very similar.

The production process from steel to plate is schematically shown in figure 4. Process parameters of plate rolling base on the 2-phase thermomechanically controlled rolling process plus accelerated cooling.

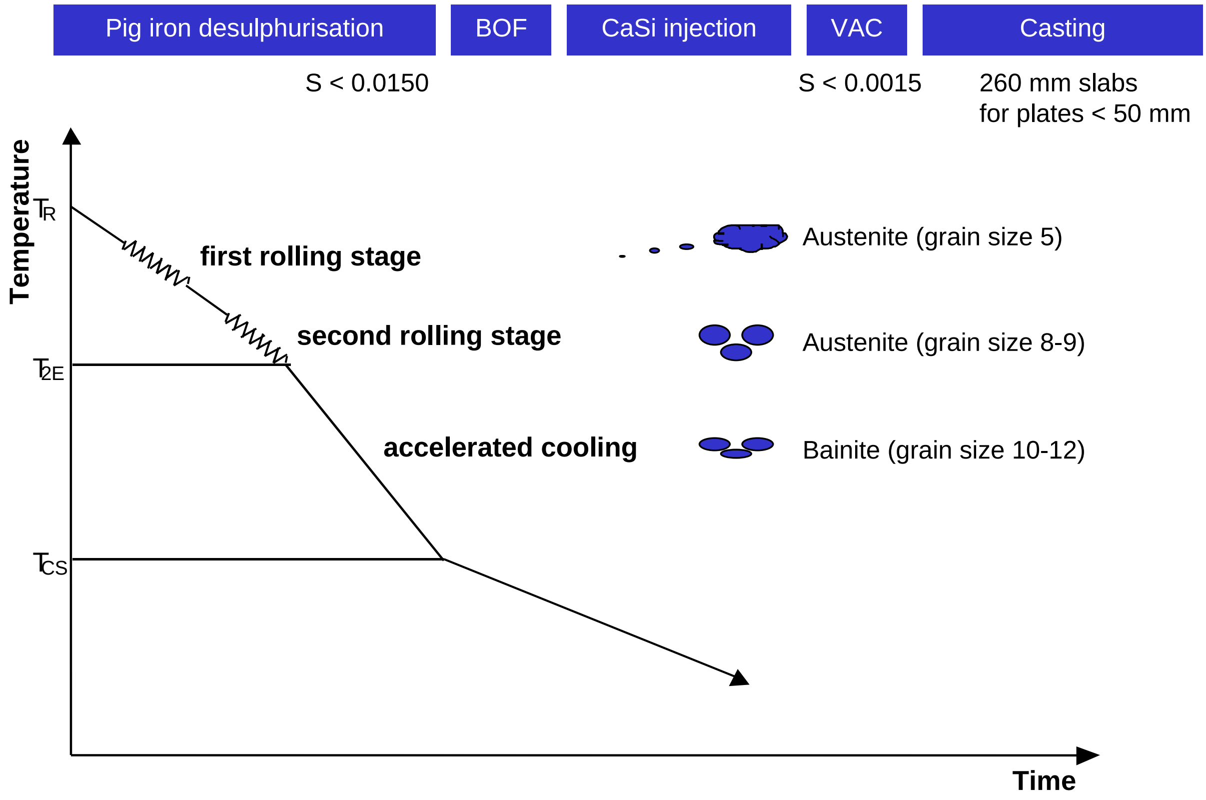


Figure 4: Process from steel to high strength heavy plate

Figure 5 shows the change of chemistry in the development of modern X80 steel grades. In the eighties and early nineties, the GRS-development started with high carbon contents of 0.1 weight %, manganese contents of 1.95 weight % and a titanium-niobium alloying concept for 18,3 mm wall thickness. Charpy V-notch requirements were e.g. 70 J at –20 °C and 95 % shear fracture area was required in the BDWT-test at –10 °C.

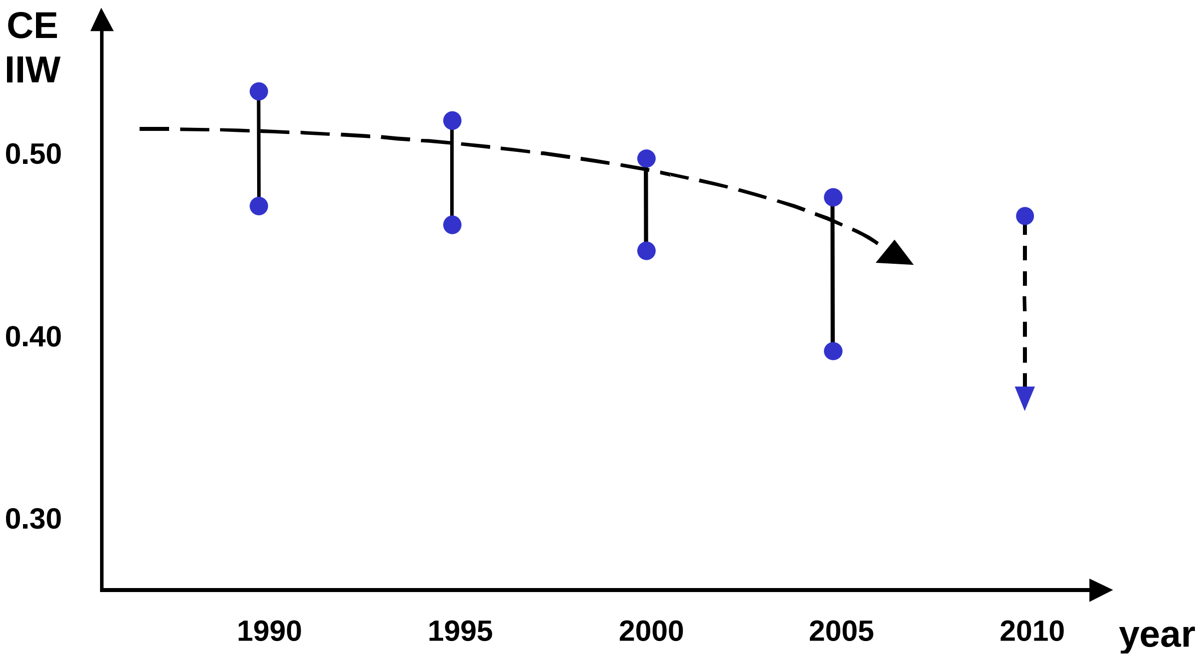


Figure 5: Change of chemistry in the development of modern X80 steel grades

Objectives for further developments were:

- increasing wall thickness
- improvement of toughness properties,
- low design-/ test-temperatures
- improvement of weldability.

In 2001, plates for a hot steam transportation pipeline in grade C550 were produced at MRM (25.4 mm wall thickness). Material requirements at room temperature (RT) and 354 °C are listed in table 1.

	RT	354°C
Yield Strength	561 – 641 MPa	min. 520 MPa
Tensile Strength	min. 640 MPa	min. 645 MPa
A“	min. 23 %	min. 23 %

Table 1: Requirements on plate in C550 for a hot steam project

The strength properties with rising temperature showed a slight decrease from room temperature to about 150 °C, the toughness properties remain relatively constant. A maximum of strength properties was found at about 300 °C, going along with a slight decrease in toughness properties. Above 400 °C, both strength and toughness properties changed significantly [3]. Figure 6 shows the increase of strength properties on plate between room temperature and 354 °C.

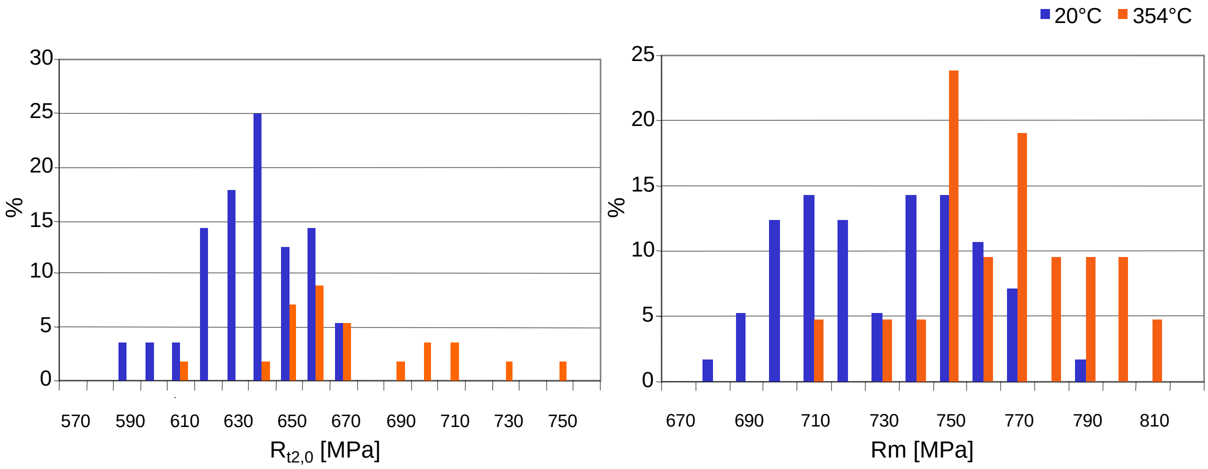


Figure 6: Strength properties of C550 material at room temperature and 354 °C

The required Charpy V-Notch values of 40 J at –25 °C and 80 J at 354 °C and the BDWT-requirements of min. 85 % shear fracture at –15 °C were met safely.

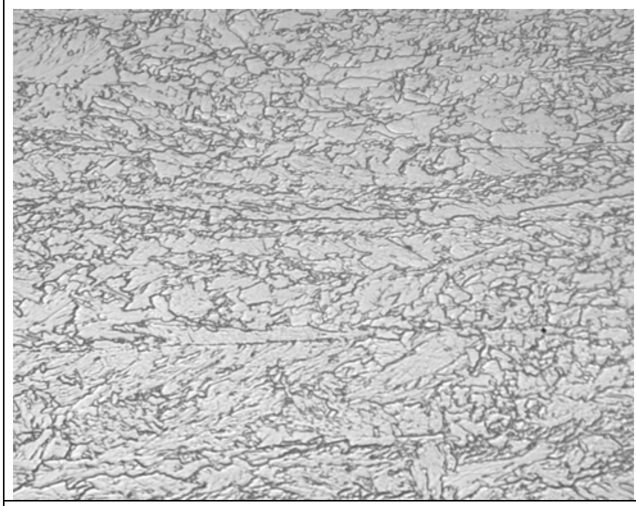
In 2005, a mill trial production of L555-plates for Pressurised Natural Gas (PNG)-Containers was performed (wall thickness 33.5 mm). These containers may be used in future for mid distance transport of gas by ship.

The toughness properties of >150 J (Charpy-V-Notch) at -55 °C were met safely with a product-analysis shown in table 2.

C	Si	Mn	Other	Ti	PCM
0,03	0,22	1,9	Nb, Cu, Cr, Ni	0,02	0,17

Table 2: Chemical Analysis PNG-Tanker (weight-%)

Figure 7 shows the typically achieved microstructure. A minimum bainite content of 85 % is necessary to meet the specified tensile strength requirements of L555 (figure 8).



500:1

Bainite 95% Ferrite 5%

Figure. 7: Microstructure of the investigated steel

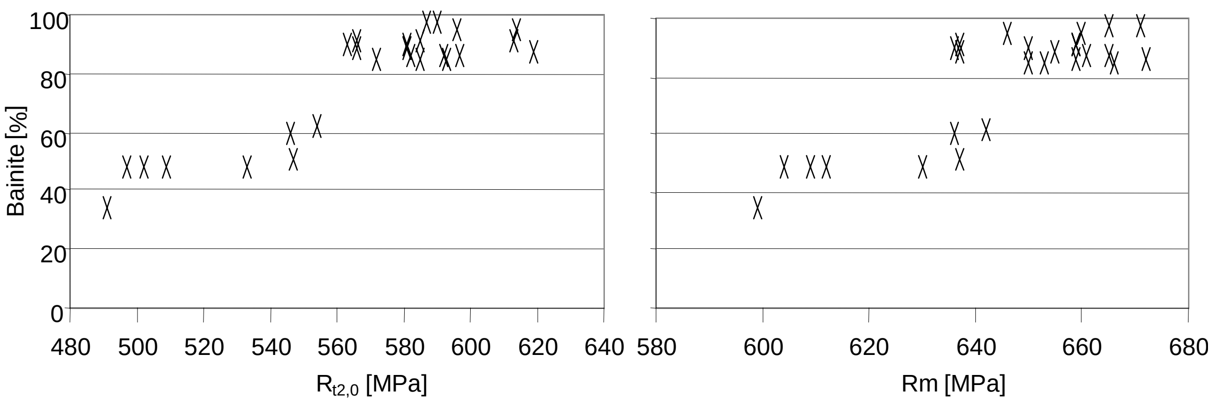


Figure 8: Influence of microstructure on strength properties

For a large order of L555 MB, various alloying concepts were tested in lab and mill trials for wall thickness` between 14 and 22 mm. The chemical analysis is given in table 3.

C	Si	Mn	Other	Nb	Ti	PCM
0,06	0,30	1,9	V, Cr, Cu, Ni	0,06	0,02	0,21

Table 3: Chemical Analysis L555 MB (weight-%)

The use of Molybdenum can be avoided in special cases by applying particularly tight production parameters in a narrow production window in the TMCP, figure 9.

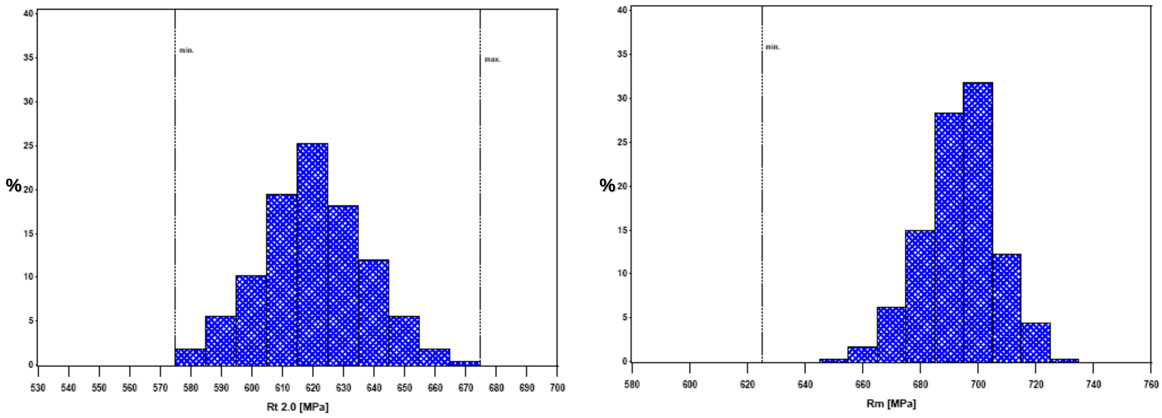


Figure 9: Yield and tensile strength of L555 MB in 22 mm wall thickness

An effective promotor of the required bainitic microstructure is boron. Alloyed in small amounts (< 40 ppm), boron segregates to the austenite grain boundaries and retards the austenite ferrite transformation. The production window for bainitic steels is widened significantly.

Boron also has a high affinity to carbon and nitrogen. The undesired formation of coarse $Fe_{23}(CB)_6$ precipitates can be prevented by the reduction of the carbon level below 0.06 %.

The formation of boron-nitrides can be prevented by adding titanium. Usually, a stoichiometric Ti/N ratio is desired. Niobium inhibits the nucleation and growth of ferrite and helps in the homogenous distribution of boron to austenite grain boundaries. Remaining solute carbon is combined with niobium [4-8].

A large mill scale trial investigation on a low carbon NbTiB microalloyed X80-steel with 35 mm wall thickness was performed in 2004 [9]. An almost fully bainitic structure can be produced at cooling rates between 10 and 15 K/s (figure 10).

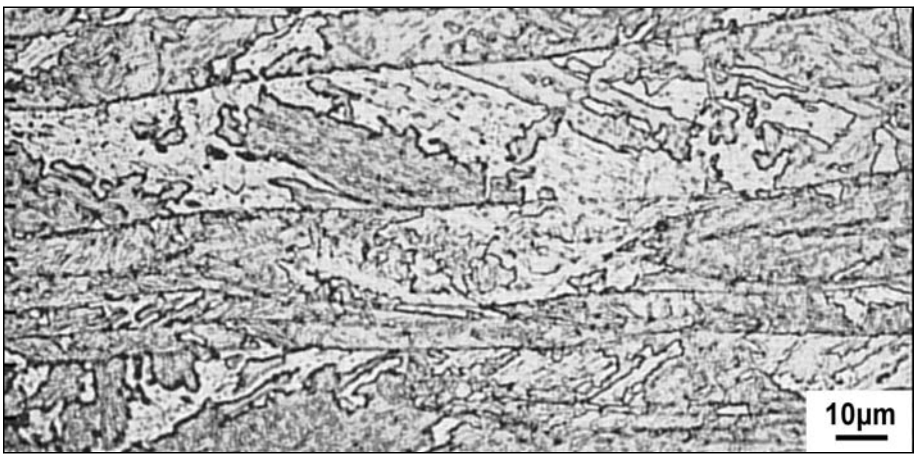


Figure. 10: Microstructure of the investigated NbTiB-steel

The chemical composition used in this trial, see table 5, allowed a safe X80 production.

C	Si	Mn	Other	Nb	Ti	PCM
0,04	0,30	1,9	Mo, B	0,05	0,02	0,18

Table 4: Basic chemical composition (weight-%)

Optimising rolling parameters, even higher steel grades can be achieved, figure 11.

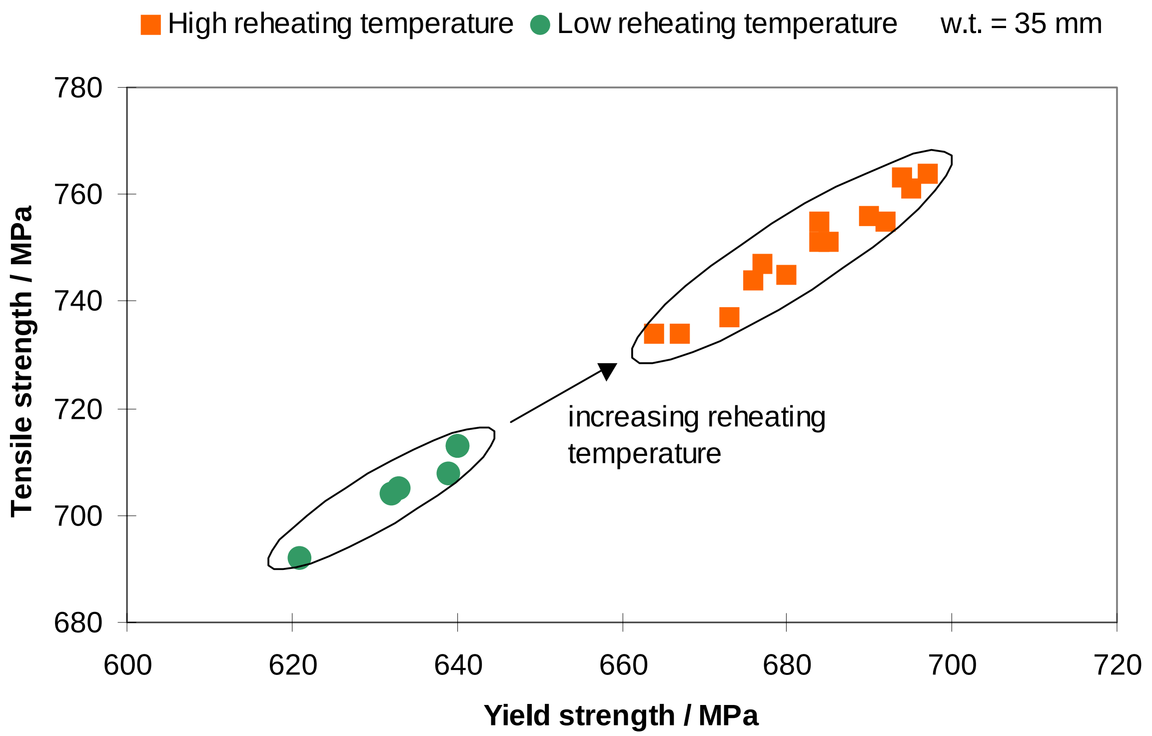


Figure 11: Influence of reheating temperature on strength properties

Research continues for further improvement of high toughness properties for high wall thicknesses at low temperatures. The shape control of the stress-strain-curve is of special interest. Base material optimisation is driven by harsh requirements on weld and heat affected zone properties. Last but not least, X80 for sour application remains a goal for the future.

Summary

In more than 20 years experience in the production of heavy plate in the X80 strength level, MRM together with SZMF played a leading role in establishing high strength steels for pipeline construction. Based on close cooperation between manufacturer and research, MRM successfully delivered heavy plate for various projects with very different requirements on plate.

About 300,000 Mt of plate were produced and delivered by MRM according to European, American and international standards. These plates were made for natural gas or hot steam pipeline projects, pressurised natural gas containers and structural pipe applications. The development and the experience in the production of grades of even higher strength like X100 and X120 strongly supported further optimisation.

Today, heavy plates for longitudinally welded pipes in the X80-strength level are produced by MRM with the same reliability as lower grades.

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