High strength steel plates for linepipe in grades up to X100

A. Streisselberger, J. Bauer, P. Flüss, H.-G. Hillenbrand*, P. Cordon**

Dillinger Hütte GTS, Dillingen, Germany
**Europipe GmbH, Ratingen, Germany*
***Berg Steel Pipe Corporation, Panama City, USA*

ABSTRACT

The production of high strength high toughness steel plates for gas linepipes based on complex customer specifications needs an intensive development work towards an optimized processing route.
To achieve high strength and toughness levels according to the requirements defined by the customer, Dillinger Hüttenwerke is using specific variants of the thermomechanical control process (TMCP) to achieve these objectives without costintensive alloying in order to assure good weldability.
The decisive elements of the metallurgical approach are low carbon chemistry with well defined usage of microalloying elements, reproducibility of high level of cleanliness and homogeneity of microstructure.
Based on the experience of standard linepipe-production in the range of Grade B to X70 with plate thicknesses up to 40 mm within the last 15 years, the development of grades X80 and X100 for sweet service and X70 for sour service is actually an important objective both for plate and pipe mills.

Some challenging projects from the recent years for sweet gas linepipes especially for arctic regions and for subsea lines up to grade X70 and production results of high strength steels for sour gas service up to grade X65 are presented.

Results of X80 production for linepipe, riser pipe and construction pipe are reported together with results regarding X100 development and mill-scale production.

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INTRODUCTION

The exploitation and transportation of oil and gas under severe and riskful conditions requires a high sophisticated design and careful selection of construction material.

The Thermomechanical Control Process (TMCP) is applied to produce steel plates with the desired yield strength level without an exaggerated addition of alloying to avoid costs and impairment of weldability.
Some challenging projects from recent years are described to illustrate the systematic development work and the exploitation of the sophisticated equipment, which will be explained first of all.

To achieve the desired, i.e. specified properties of TMCP material the design has to be based on an adjustment of steel composition /1/ to the sequence of all process steps during plate making.

An appropriate selection and combination of the process steps during plate making and their on-line control (Fig. 1) are prerequisites for the fulfilment of the whole specification.

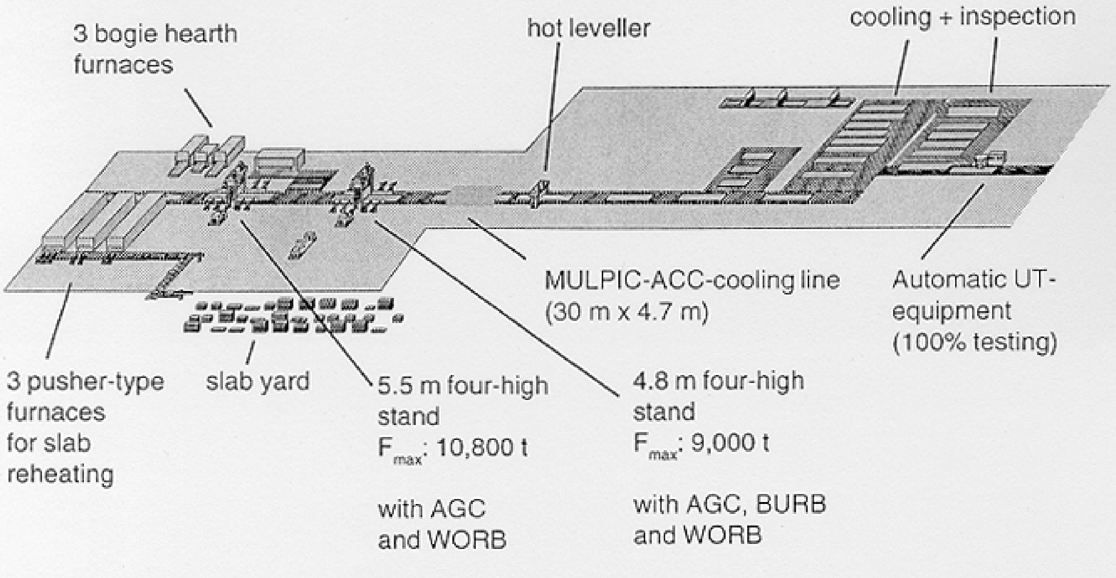

Figure 1 - Layout of hot part of the plate mill

For TMCP the principal steps to be mentioned and highlighted are the reheating of slabs in the pusher type or bogie hearth furnaces, the multi-stage TM-rolling at the 2 four-high-stands according to a well defined schedule of rolling passes, and the use of accelerated cooling (ACC) in the 30 m long MULPIC [Multi purpose interrupted cooling] equipment directly after final rolling, in some cases combined with an intermediate cooling /2/.

The TM rolling process includes a large variety of realization possibilities from the manufacturer's point of view, which is shown in Fig. 2.

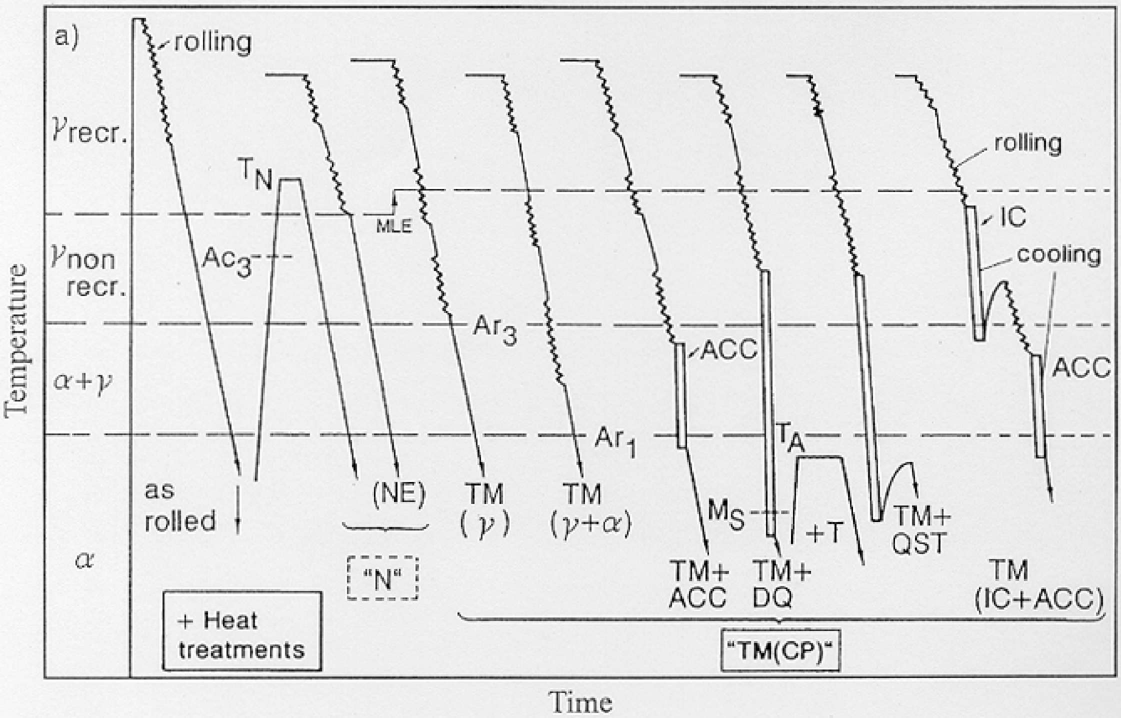

Figure 2 - TMCP-processing variants

The desired properties of the TM-rolled plates are obtained by a special time and temperature sequence including

- a defined number of rolling stages at prescribed temperature ranges interrupted by cooling periods and
- cooling after finishing rolling either on ambient air or in a water cooling line.

The metallurgical result of TM-rolling is a reduction of the austenitic grain size and subsequently of the final ferritic grain size compared to N-treatment (Fig. 3). A modified type of ferrite with a high dislocation substructure may be produced for further strengthening of the steel through finishing in the $\gamma+\alpha$-region. A mixed microstructure of very fine ferrite and bainite is obtained by accelerated cooling.

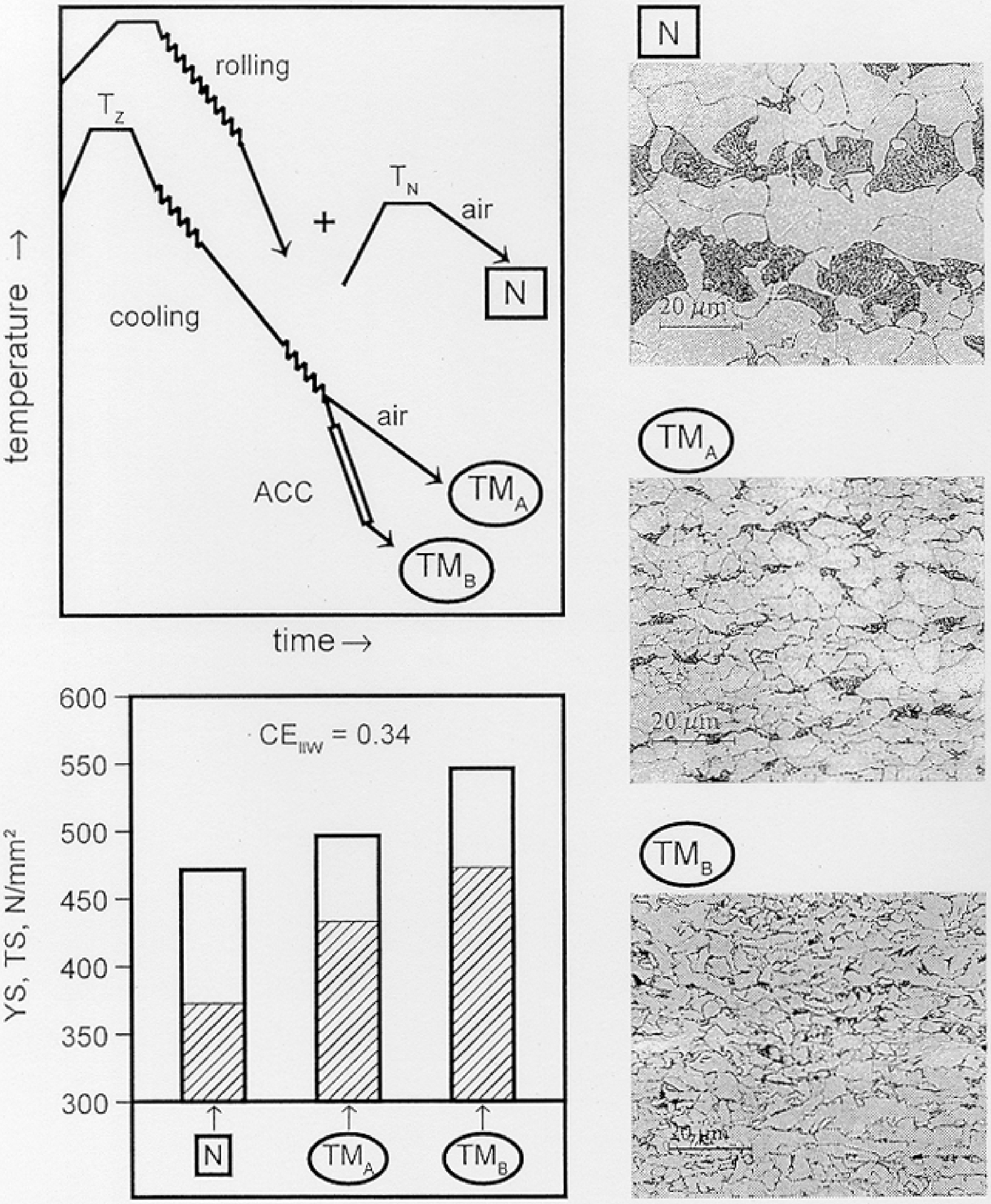

Figure 3 - Comparison of N- and TM processing variants
(route, microstructure, properties)

Concerning the mechanical and the fabrication properties, the result is an increased strength and toughness level and improved weldability due to the lean chemical composition.

To assess the properties from plate testing, the change of material properties during fabrication of the pipes and the service behaviour has to be taken into account. A balanced combination of all these features should be the aim of an optimized material specification and its verification during the whole production cycle. To illustrate the systematic development work, some challenging projects from recent years /3/ together with new results of X80/X100 production are reported in this paper.

FROM RECENT YEARS PROJECTS TO ACTUAL LINEPIPE STEEL DEVELOPMENT

TM-steel plates for North Sea application

Typical „North Sea“ properties on yield and tensile strength in longitudinal as well as in transverse direction combined with high toughness requirements of 150 J at -30°C and BDWT-test with 85/75 % shear fracture at -20°C were specified for X65 line pipe grade plates in wall thicknesses from 25 mm to 32 mm /4/.

More than 150.000 to of steel plates for projects like NORFRA, ZEEPIPE Phase II, TROLL Phase I and EUROPIPE II were delivered to the large diameter pipe mills.

Based on a lean CMnNbV-steel composition a TM-multi stage rolling including MULPIC cooling was applied. As an example, some results of tensile-, Charpy-V- and BDWTT-testing are shown in Fig. 4 and 5.

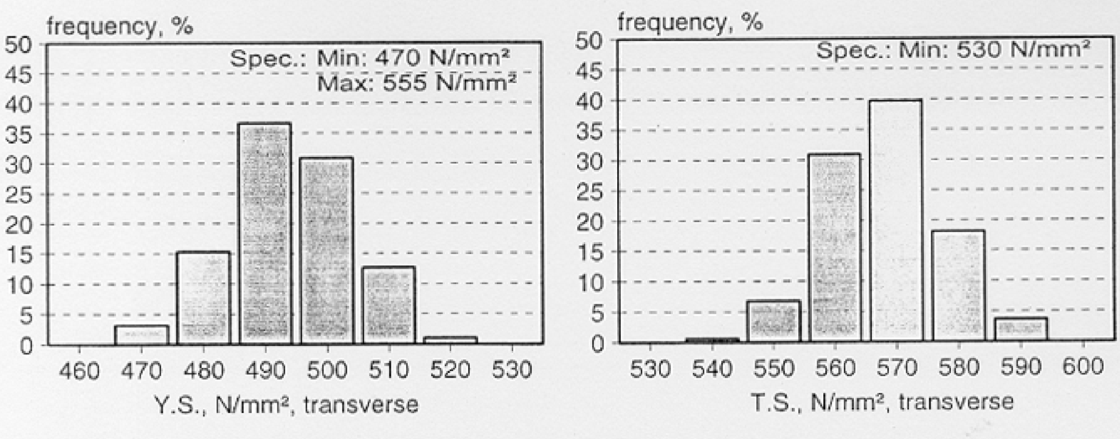

Figure 4 - ZEEPIPE Phase II, X65, 28.7 mm, tensile properties (plate)

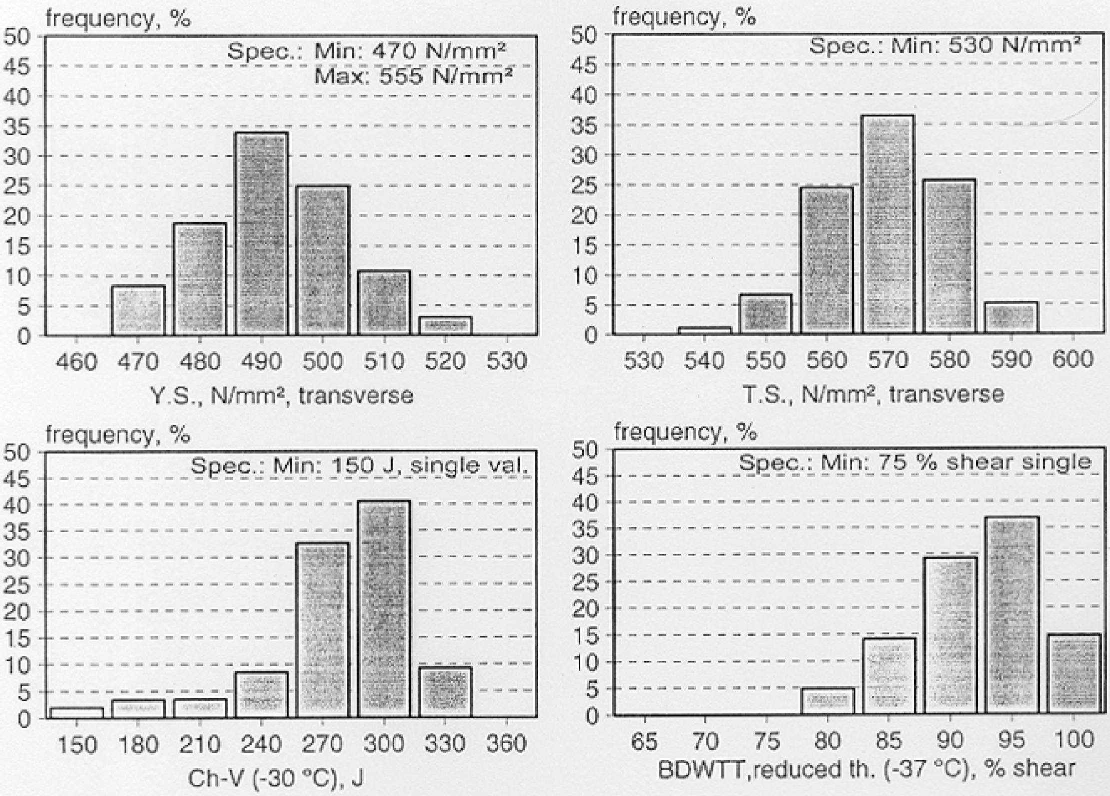

Figure 5 - TROLL Phase I, X65, 31.3 mm, mechanical properties (plate)

All the properties have been fulfilled with a satisfying standard deviation, which demonstrates the good reproducibility of the production process.

For riser pipes the wall thickness is increased because of risks for working people, the platform itself and the environment, respectively. Nevertheless the requirement profile is the same as for the linepipe. The decisive elements for the realisation of the specified properties are based on the approach for linepipe grade combined with an additional alloying of e.g. Cu or Ni. Test results of that steel type produced by a multi-stage TM-rolling process including cooling at the MULPIC-equipment are illustrated in Fig. 6.

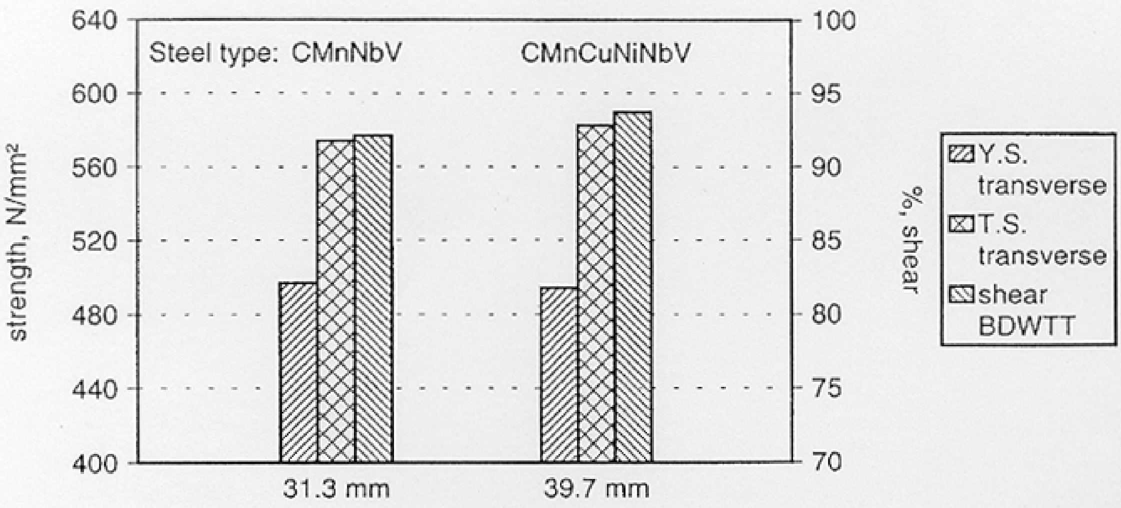

Figure 6 - Comparison of average properties of X65 plates in 31.3 and 39.7 mm

TM steel plates for sour service requirements

The production of linepipe grades for sour service needs an optimized combination of modern steelmaking and casting and TMCP rolling technology /5/.
The strategy for X60/X65 sour service steel is shown in Fig. 7. Steels following this design have been used in projects for companies and regions like BP, QATAR, NIOC, ELF, ABU DHABI or DANGAS.

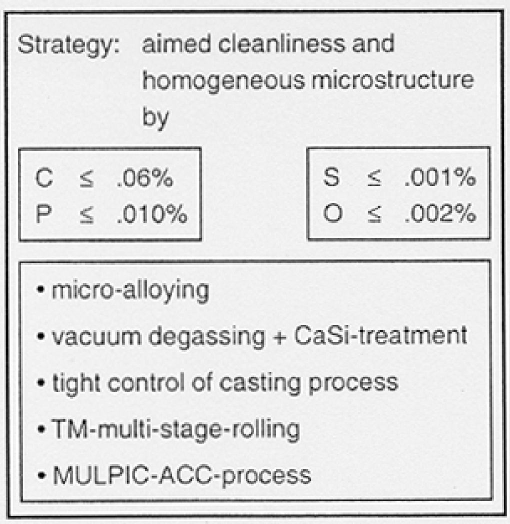

Figure 7 - Strategy for X60/X65 sour service steel

The rolling process for these plates with a combination of DWTT-, HIC- and SSCC-requirements respectively is a multi-stage TM-rolling combined with intermediate cooling and a final accelerated cooling. As an example for that technology, pipe results of a X65 HIC grade (test solution pH = 3) with wall thickness of 25.4 mm are illustrated in Fig. 8. The reproducibility both of the plate rolling and pipe forming process is good as it can be observed looking to the narrow scatter band of tensile and toughness properties.

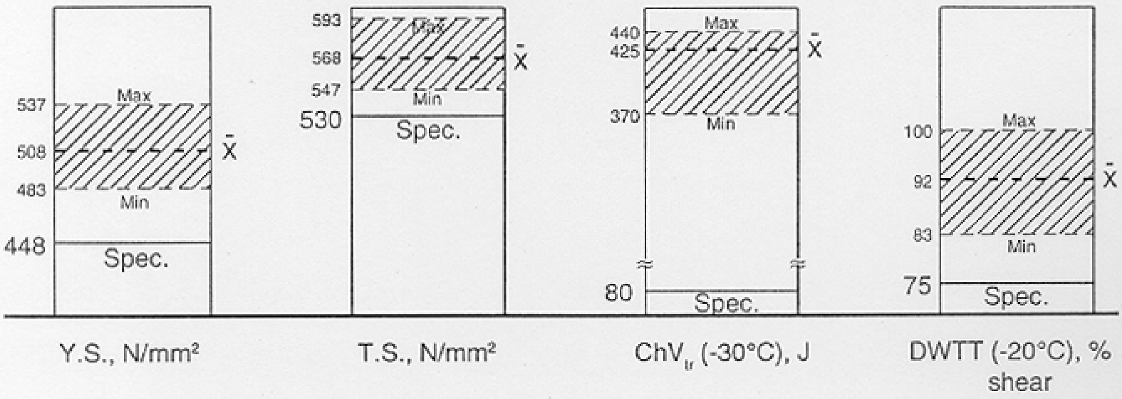

Figure 8 - Pipe test results of X65 HIC grade (pH = 3) with wall thickness of 25.4 mm

High grade TM steel plates for sweet service

One of the challenging projects last year in USA was the X70 SHELL DESTIN project for sweet service. The pipes were produced by BSPC in wall thicknesses of 17.8 mm for the main part of the project. Using a low carbon NbV-microalloyed steel type combined with a well defined 3 stage TM-rolling including cooling, the plates were prepared to fulfill the X70 requirement profile for the pipes.

The results on pipe are illustrated in Fig. 9 as a frequency distribution for tensile properties. A very homogeneous distribution with a low standard deviation can be observed. One of the essential features of this project is the fact that the pipe mill did not use an expansion after pipe forming. The resulting yield strength losses from plate to pipe due to Bauschinger effect had to be taken into due consideration. This effect requires yield strength on plate close to the range of X80-values to fulfill X70 properties on pipe. The presented distribution of values gives evidence for a satisfying property level on pipe.

Respecting the need of the US market for high strength grade X80 used for riser- and conductor pipes in wall thickness up to 25.4 mm with small diameters less or equal 28" the development and, - today -, the production of such TMCP-steel plates plays an important role.

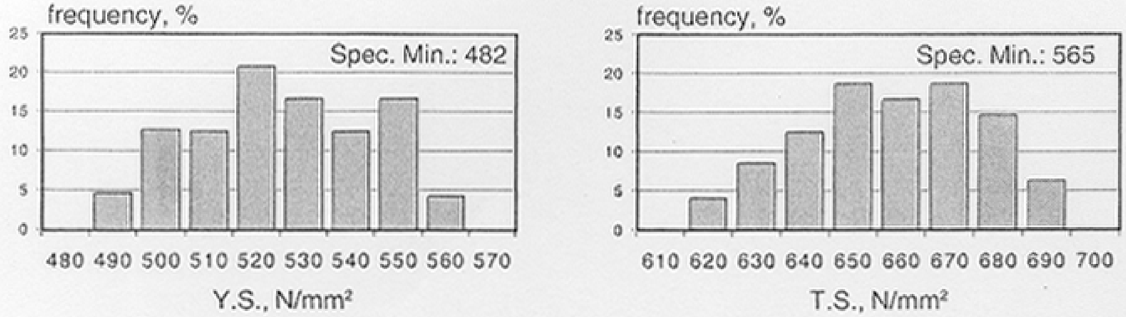

Figure 9 - Frequency distribution of tensile properties for X70 pipes with wall thickness of 17.8 mm

Based on the fact that also pipe mills without an expansion equipment are asked to produce the above mentioned products, a production route for steel plates was defined using the feed back of these pipe mills as element of design base.

The average results on pipe for X80 grade with wall thickness of 22.2 mm are plotted for strength and toughness properties in Fig. 10 using a microalloyed chemistry with addition of solution hardening elements like Mo or Ni and a TMCP processing route including accelerated cooling. The frequency distribution shows a very narrow scatter band fulfilling in any case the required properties, even without using expanding.

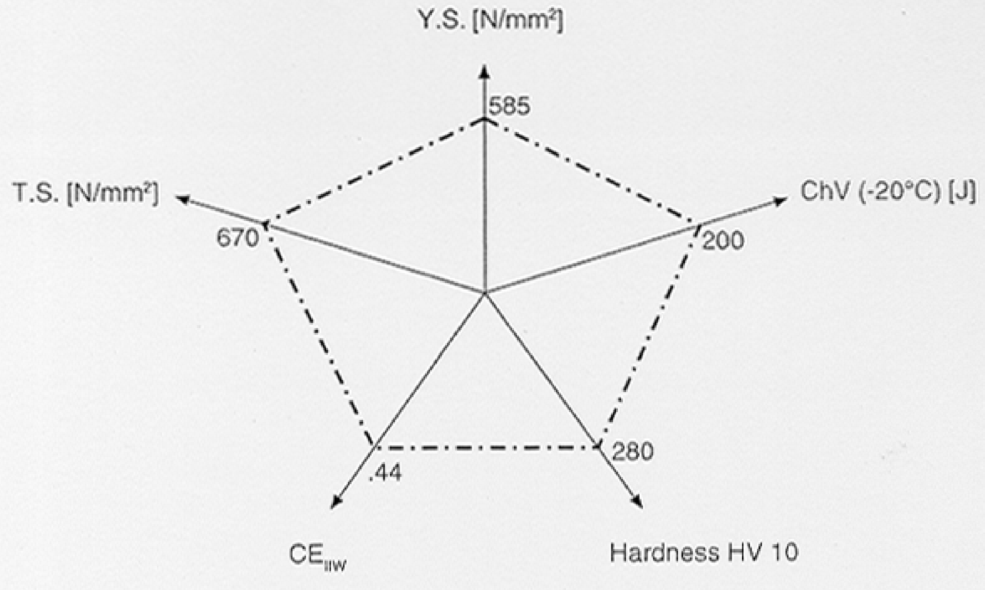

Figure 10 - Average property profile of X80 pipes with wall thickness of 22.2 mm

TM steel plates for linepipe grade X80/X100

Using the experience of grade X80 production it was only a next step to enter into the development of the grade X100.

To fulfill the requirements on plate [YS greater than 700 MPa and minimum TS of 770 MPa] different types of production design were tested in the last years /6/. The analysis of all concepts is a CMn-steel alloyed with Cu, Ni, Mo, Nb and/or Ti. The basis of the TMCP approach was a multistage rolling schedule with finishing in the austenitic region (above Ar_3) and an accelerated cooling with high cooling rates. As it can be seen in Fig. 11 the carbon equivalent and the cooling parameters can be balanced in a correct combination. With a low carbon equivalent it is necessary to cool at a higher cooling rate and to a lower final cooling stop temperature. With a higher carbon equivalent a lower cooling rate and a higher final cooling temperature it is possible to achieve the properties of X100. The facilities and possibilities of the mills, the forming behaviour of the plates and the weldability of the pipes are other aspects which have to be taken into consideration for the balance of the above mentioned parameters.

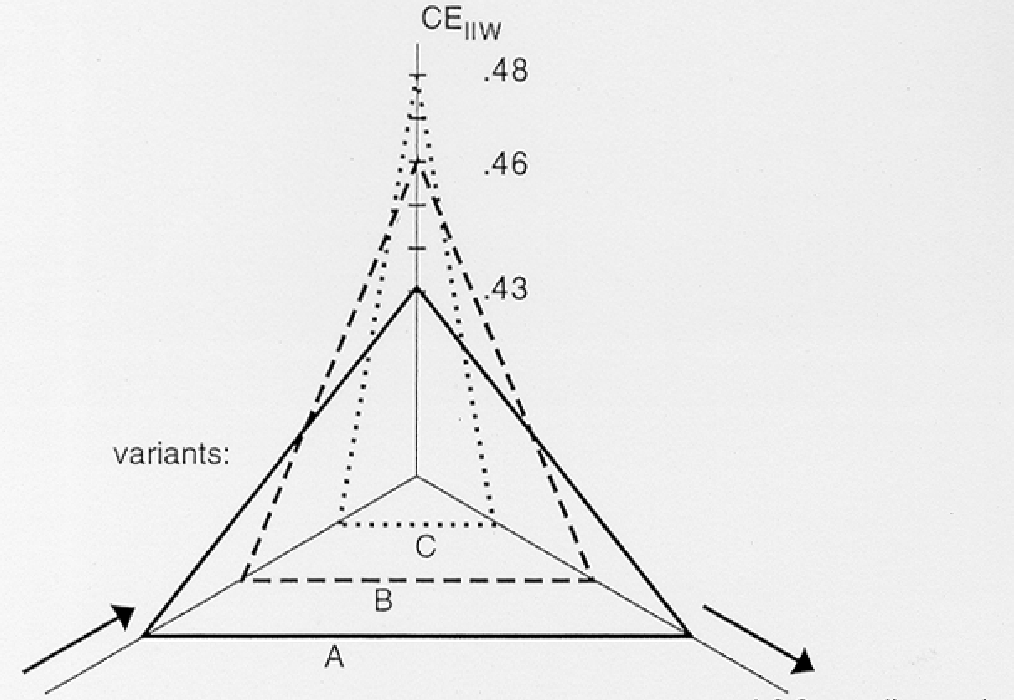

Figure 11 - Possibilities (3 variants) of combination of steel chemistry and processing parameters to achieve same strength level (API X100)

SUMMARY

Summarizing, the following application examples have to be listed as contribution to the actual status of linepipe steel development and production:

- The design for TM steel plates for North Sea application has been illustrated on projects like ZEEPIPE Phase II and TROLL Phase I showing the necessity of the well balanced combination of chemistry and rolling process parameters.

- The strategy for the production of TM steel plates for sour service requirements has been shown for a X65 HIC grade illustrating the good reproducibility of steel making, casting, TM-rolling and pipe forming process.

- The experience of production of X80 grades led to the development of future aspects X100 grade taking into consideration the possibilities of rolling mills and their equipment.

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