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Production results and new development trends for high strength, high toughness offshore linepipe steels

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To achieve high strength, high toughness levels according to customers project specifications, Dillinger Hüttenwerke is using specific variants of the thermomechanical control process (TMCP). By the application of these variants steels for sweet service with heavy wall for subsea as well as for sour service with BDWTT requirements can be produced.

Important elements of the metallurgical approach are low carbon chemistry with well defined usage of microalloying elements, a reproducible high level of cleanliness and homogeneity of microstructure with a sophisticated combination of rolling and cooling variants.
Some challenging projects for sweet gas linepipe steels especially for subsea purpose up to grade X 80 and production results of high strength steels for sour service up to grade X 65 are presented. Especially the demands of some customers for sour service steels will be discussed, giving some production results of actual projects.

Future development trends i. e. X 100 sweet service will be discussed. First full scale trial results are presented.

1. INTRODUCTION

The composition of oil or gas, the surroundings of the fields and the need for operational safety have led to complex linepipe specifications.
Three major challanges have to be met:

- "High pressure", internal from the gas or external from the water pressure , depending on the laying depth for subsea linepipes. This leads to a requirement for a steel with high strength and high toughness.
- "Gas or oil composition" leads to a requirement for a sweet or sour service Steel.
- "Environmental and laying conditions" lead to special requirements like low temperature toughness and weldability which presupposes a well balanced lean composition and a sophisticated process design in the plate mill.

2. MANUFACTURING FACILITIES AND THE PROCESS DESIGN

To satisfy the actual requirements of specifications new strategies for production have been developed at Dillinger Hüttenwerke also respecting limit state design for pipelines which has reduced safety factors and therefore requires a tighter control in manufacturing /1/.

In the steel plant the secondary metallurgy with the vacuum treatment and the continuous casting with a dynamic soft reduction and a maximum slab thickness of 400 mm is the prerequisite of sophisticated subsea pipeline projects. The features of the new double-strand caster /2/ are presented in figure 1. The max. thickness has been increased to 400 mm, having been limited to 300 mm up to now but the principle of vertical casting with bending after full solidification has been maintained.

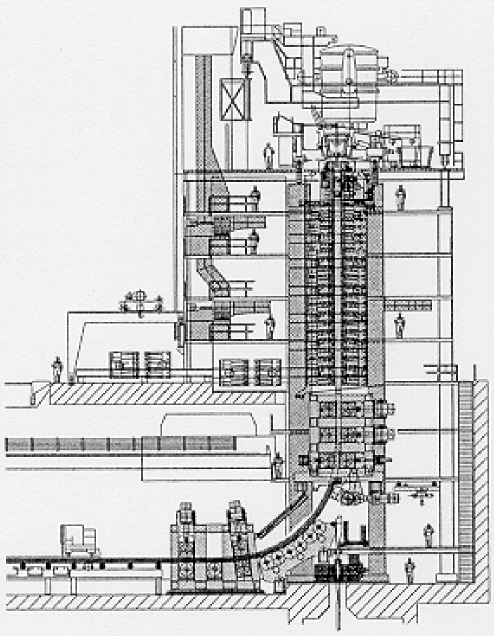


Figure 1: Layout of CC-machine for slab thickness 400 mm

To assure the fulfillement of the required internal quality in terms of segregation levels, internal cracks, porosity and cleanliness it was considered important to bend and rebend the strand without liquid portions in the core. Macro-segregations are suppressed by intensive strand cooling and by soft reduction technique based on under load adjustable roller apron /3/.

The Thermomechanical Control Process (TMCP) /4/ is applied to produce steel plates with the desired yield strength level without an exaggerated addition of alloying to avoid additional costs and impairment of weldability.

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

An appropriate selection and combination of the process steps during plate making and their on-line control (figure 2) are prerequisites for the fulfilment of the whole specification.

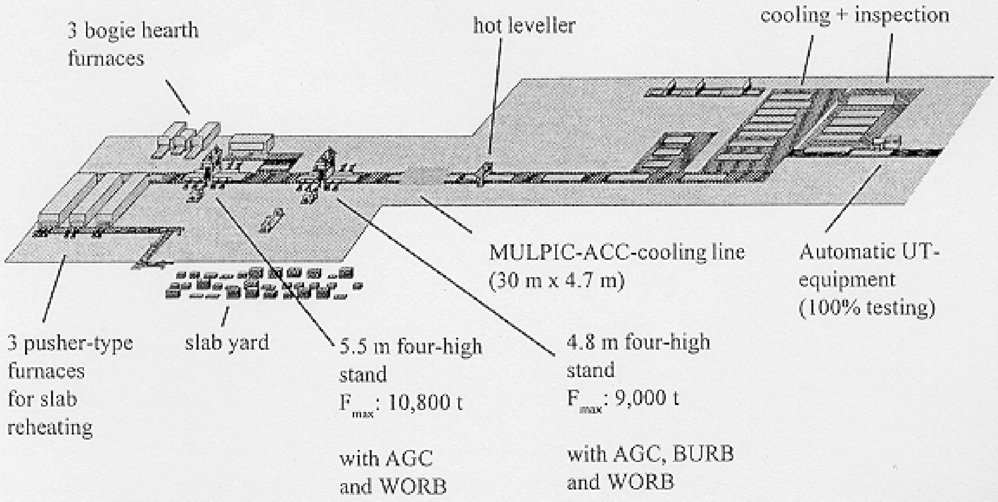


Figure 2: Layout of hot part of the plate mill

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

The TM rolling process includes a large variety of realization possibilities from the manufacturer's point of view, which is shown in figure 3.

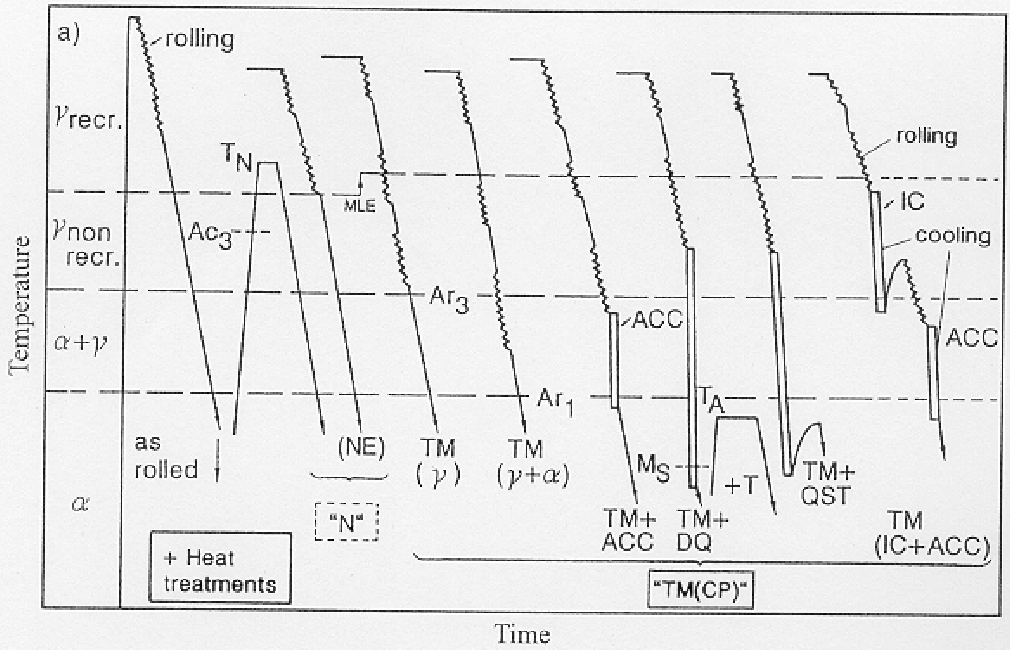


Figure 3: TMCP-processing variants

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 (figure 4). 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.

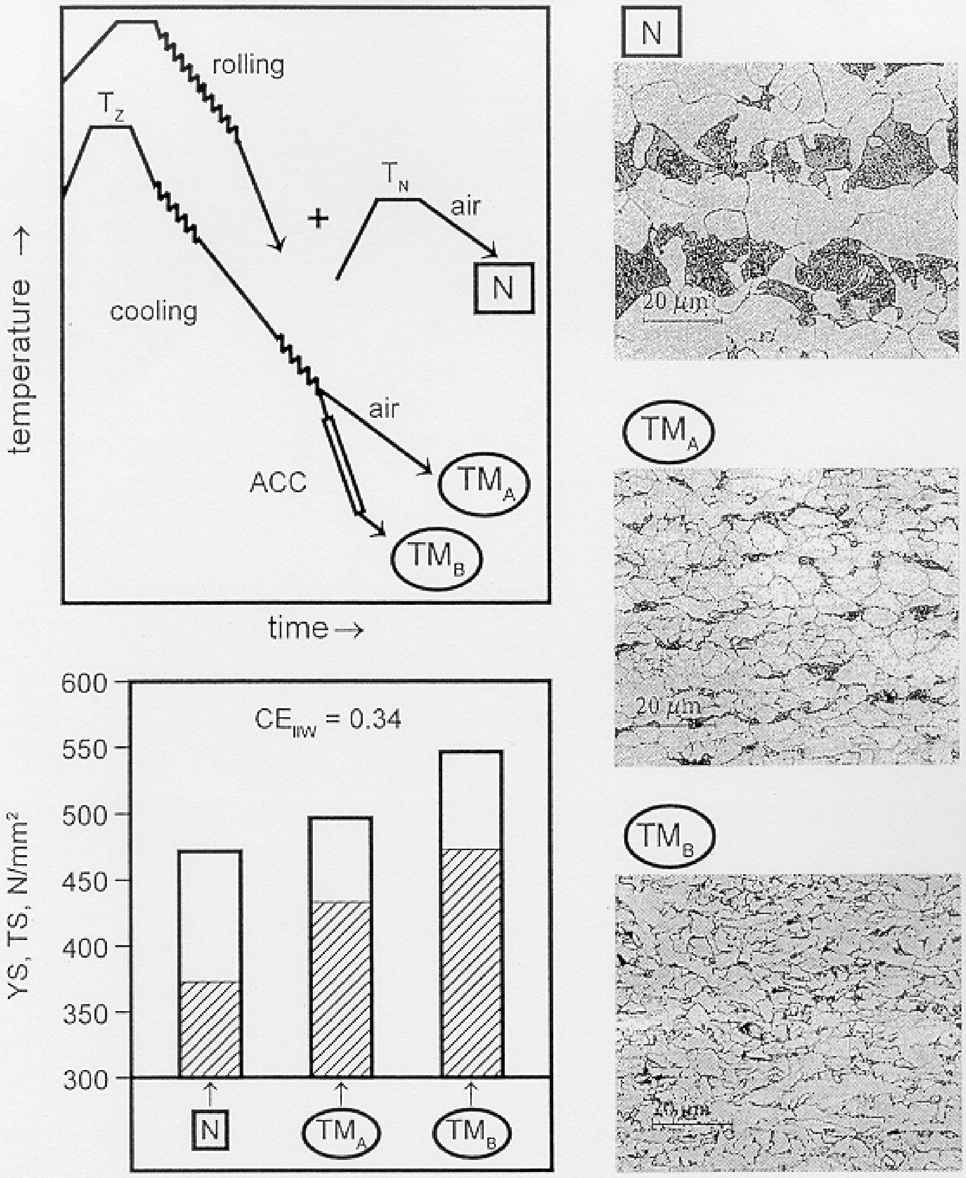


Figure 4: Comparison of N- and TM-processing variants (route, microstructure, properties)

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.

3. APPLICATION EXAMPLES FOR X65 SUBSEA LINEPIPE STEELSESIGN

In the following some application examples for X65 subsea grades are presented.

Typical for intermediate and heavy wall subsea linepipe steels were INTERCONNECTOR- and NORFRA-projects with wall thicknesses of 22,2 mm up to 30 mm and the ELDFISK-project with wall thickness of 36,5 mm respectively.

All these steels were produced at DH using a lean CMnNbV alloyed steel type with a special process design.

Typical results for plate and pipe are illustrated in figure 5 for INTERCONNECTOR, figure 6 for NORFRA and figure 7 for ELDFISK-project /1/.

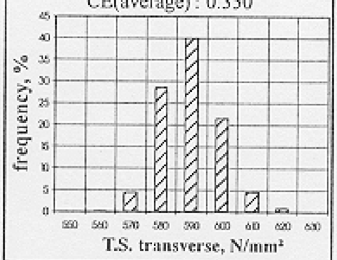
Project: INTERCONNECTOR, X65 sweet, 22.2 mm, 40"	
Plate (TMCP)	Pipe (UOE)
CE(average) : 0.350 	X65 tr + long YS_{tr} (average) : 477 N/mm² TS_{tr} (average) : 596 N/mm² BDWTT (average): 98 % shear

Figure 5: Project INTERCONNECTOR, results

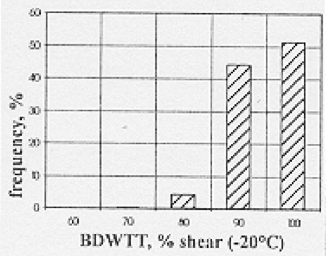
Project: NORFRA, X65 sweet, 25.8 mm, 42"	
Plate (TMCP)	Pipe (UOE)
CE(average) : 0.355 	X65 tr + long YS_{tr} (average) : 487 N/mm² TS_{tr} (average) : 588 N/mm² BDWTT (average): 95 % shear (-10°C)

Figure 6: Project NORFRA, results

Project: ELDFISK, X65 sweet, 36.5 mm, 24"	
Plate (TMCP)	Pipe (UOE)
CE(average) : 0.348	X65 tr + long YS_{tr} (average) : 522 N/mm^2 TS_{tr} (average) : 618 N/mm^2 HV10(average), body: 208

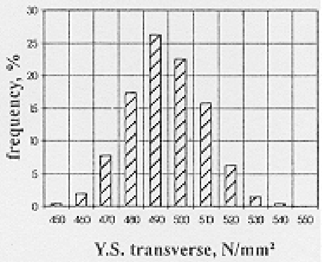


Figure 7: Project ELDFISK, results

The only project in the north sea with pH = 3 sour service demands was the SOUTH-ARNE-project for DANGAS. The steel for that X65 subsea linepipe project was produced with wall thicknesses from 14,2 mm to 22,1 mm based on DNV rules '96. The process design is based on a typical design for sour service steels with a multistage rolling combined with intermediate and accelerated cooling after final rolling. Typical results on plate and pipe are illustrated in figure 8.

Project: SOUTH-ARNE-HYDRO, X65 sour (pH 3), 14.2 mm, 24"	
Plate (TMCP)	Pipe (UOE)
CE(average) : 0.289	X65 tr + long YS_{tr} (average) : 524 N/mm^2 TS_{tr} (average) : 607 N/mm^2 BDWTT (average): 100% shear (-10°C) CLR (spec.) : ≤ 15%

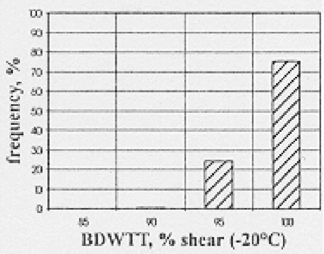


Figure 8: Project SOUTH-ARNE-HYDRO, results

Based on the experience from the described projects the further development of X65/X70 grades with subsea requirements and for sour service is going on to answer the future demands of the customer.

4. X70 AND X80 STEEL GRADE FOR SWEET SERVICE

X70 linepipe steel grades up to 56" diameter is a well known standard all over the world for design temperatures equal or higher than -10°C /5/.

One of the challanging X70 projects last year was the ALLIANCE-project in Canada/USA, where for a part of the line the design temperature was defined at -30°C. This design criteria led to low temperature requirements regarding BDWTT and impact toughness as described in table 1.

Table 1: Requirements profile for plate and type of alloying for low temperature X70

Yield strength:	≥ 545 N/mm² ÷ 648 N/mm²	
Tensile strength:	≥ 565 N/mm² ÷ 696 N/mm²	
CVn transv.	-57°C; ≥ 71/59 J	
BDWTT transv.	-45°C: ≥ 75 / 50 % shear	
Type of alloying:	C:	~ .07 %
	Mn:	~ 1.65 %
	Nb+V+Ti:	≤ .14
	Ni:	~.20 %

Statistical results are shown in table 2 for wall thickness 22.2 mm. A very homogeneous distribution with a low standard deviation can be observed.

Table 2: Statistical results on 22.2 mm X70 low temperature grade

thickness	Y.S.	T.S.	Y/T	A2"	CVn tr. (-57°C)	DWTT (-45°C)
22,2 mm	N/mm²	N/mm²	%	%	J	% shear
av.	582	634	91,8	41	141	76
1s	7	7	0.8	3	19	9
n	10	10	10	10	10	20

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 account. 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 38 mm with small diameters less or equal 28" the development and, - today -, the production of such TMCP-steel plates plays an important role /4/.

The basic alloying of such a grade X80 was a composition with Ni and Mo and microalloying elements like Nb and Ti with a carbon equivalent CE_{IIW} of about 0.44 %. The process was based on TMCP-rolling and accelerated cooling with high cooling rate and low cooling temperature /6/.

Thus it is possible to produce plates for pipes with longitudinal properties even after a post-weld-heat-treatment (600°C) and with restrictions in hardness and elongation for riser- and conductor-pipes. The maximum wall thickness of the grade X80 according API-specification produced at Dillinger Hüttenwerke now is 38 mm. As an example the plate results of X80 order with wall thickness of 38 mm are shown in figure 9.

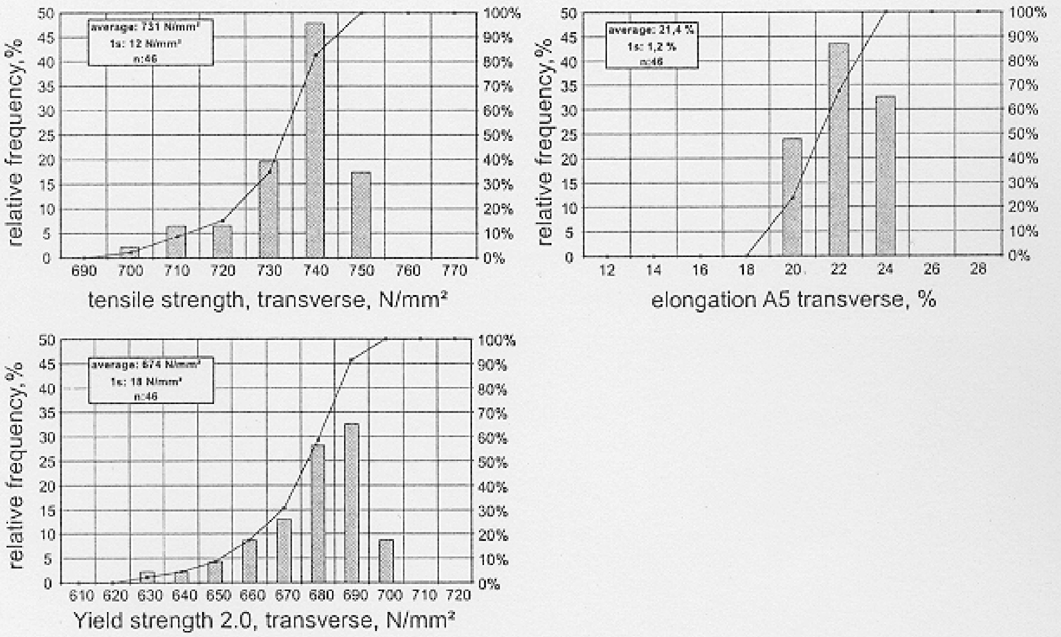


Figure 9: Mechanical properties of grade X80 with wall thickness of 38 mm

5. DEVELOPMENT TRENDS FOR X100 STEEL GRADE

Based on development and production results of grade X80 the next step was the development of grade X100.

In the last years, different types of production design were tested /7/.

Based on these results DH/Europipe decided to participate on the ECSC STEEL RTD PROGRAMME - Fracture properties of API X100 gas pipeline steels /8/.

DH/EP produced X100 pipes with slight variations in plate processing to obtain well defined different toughness levels according to the requirements of a full scale burst test programme. ChV-toughness values (average) ranging from 150 J in the initation pipe up to about 280 J in the outermost pipes were obtained. The analysis of the fracture appearance after the full scale burst test on the test pipes involved in the fracture propagation showed a fully ductile behaviour for all pipes.

A second burst test and a project report related to the safety issues by determining a range of fracture properties using both laboratory and full scale tests will be finalized end of the year 2000 with the aim of defining appropriate safety criteria.

6. SUMMARY

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

- Actual status of steel manufacturing facilities and TMCP rolling design for linepipe grades at DH.
- The design for TM X65 subsea linepipe steels has been illustrated on projects like INTERCONNECTOR, ELDFISK and NORFRA for sweet service linepipe steels and SOUTH-ARNE HYDRO for X65 pH3 sour service linepipe steels.
- The experience on low temperature X70 and the actual status of grade X80 for riser and conductor pipes has been reported.
- Actual development trends for the grade X100 were illustrated.

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