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RECENT QUALITY ACHIEVEMENTS ON STEEL PLATE FOR LINE PIPE

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ABSTRACT

From the viewpoint of a plate manufacturer the status of steel plate quality for line pipe applications is discussed. Technologies of the steel shop and the plate mill to create high class material are presented, as well as alloying and accelerated/intermediate cooling concepts. The levels of consistency that can be reached are illustrated on recent contracts. This includes sour gas resistant line pipe steels, applications for low temperatures and the extension of these features towards high strength grades.

INTRODUCTION

Steels for gas and oil pipelines are in evolution and the attainable levels in strength, toughness and sour gas resistance grow permanently. This paper presents recent progress on line pipe steels for onshore and for offshore application. The focus is on plate making which is the business of Dillinger Hüttenwerke (DH).

To create high grade line pipe steel demands state-of-the-art production facilities and optimized concepts for the Thermo-Mechanical Control Process (TMCP). The latest technologies available at DH will be briefly reviewed.

DH delivers plate to a number of pipe mills which differ in their processing facilities, such as UOE or three-roll bending; with or without expansion. The effect of plate to pipe forming on the pipe properties is therefore respected already in the concept of the plate.

More stringent control in manufacturing is needed owing to constraints imposed by limit state design, by new pipelay techniques and generally by growing customer requirements with narrow tolerances in strength, toughness/BDWTT and HIC resistance.

The paper collects results of a number of recent orders with special requirements which serve to exemplify the current status.

MANUFACTURING TECHNOLOGY

The steel shop at DH is charged with hot metal from two blast furnaces and operates two 185 t BOF converters with bottom stirring. Using the recently added vacuum tank degassers, it is possible to treat all heats under vacuum [1]. Secondary metallurgy includes further steps such as cleanness stirring and calcium treatment. By this processing, lowest contents in sulphur, hydrogen, nitrogen and total oxygen are reached [2].

Three continuous slab casting machines are available. As a specific feature at DH all casters are of vertical type with bending and straightening after solidification [3]. This principle ensures high cleanness, since non-metallic particles can float up and separate to the meniscus easily while inclusion accumulation bands, as characteristic for curved machines, are entirely averted [4]. Further, the absence of bending deformation with liquid core prevents intercolumnar cracking. Macro-segregation is suppressed by intensive strand cooling and through soft reduction with dynamically adjustable segments.

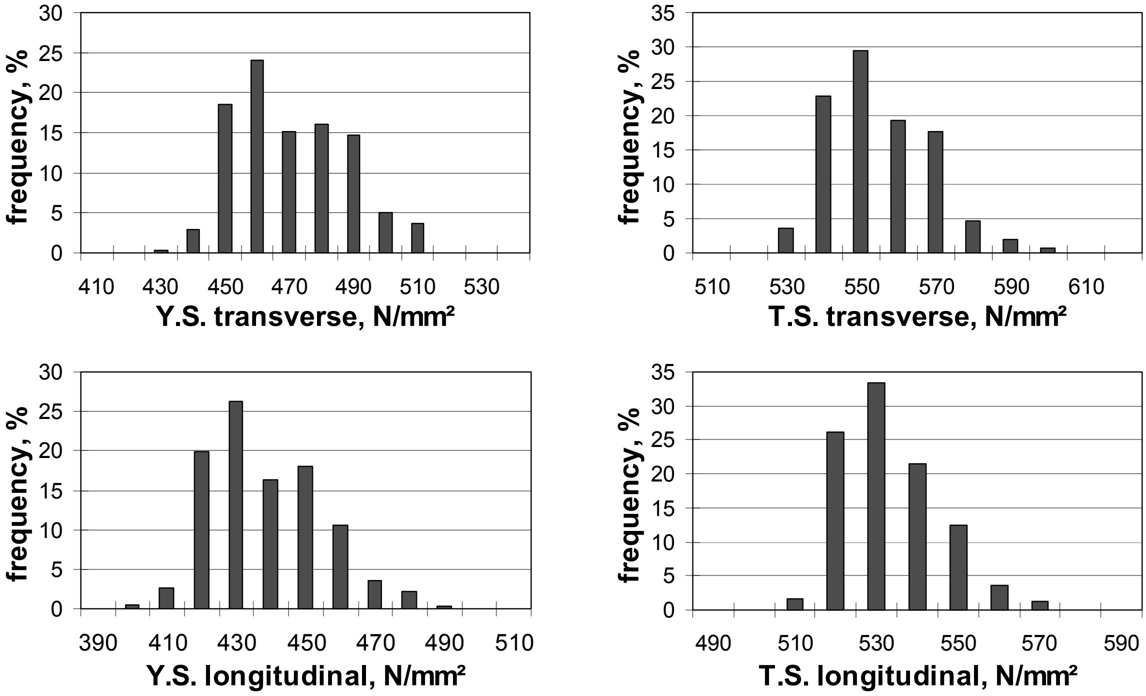

Figure 1: Tensile properties of 23.8 mm X60 plates for the Devils Tower Deepwater Project

The new slab caster CC5 can cast slabs of up to 400 mm thickness. This permits to realize plate thicknesses out of continuously cast slabs that were impossible with the previous maximum slab thickness of 300 mm.

The Thermo-Mechanical Control Process is applied to produce steel plates from slabs, see [5] - [8]. With this technology the desired strengths can be achieved with low alloying addition, to reduce cost and maintain good weldability. Slabs are first heated in pusher type or bogie hearth furnaces and are then rolled on the two four-high stands. For Accelerated Cooling (ACC), a 30 m long Multi Purpose Interrupted Cooling (MULPIC) unit is available directly after final rolling, which can also be used for intermediate cooling.

A TM schedule is an elaborate sequence of rolling stages at prescribed temperatures interrupted by cooling periods and cooling after finish rolling either on air or in a water cooling line. The principle of TM is to reduce the austenite grain size and consequently the final ferrite grain size. A modified type of ferrite with high dislocation substructure can be created by further strengthening through finishing in the two-phase region. With ACC, microstructures of very fine ferrite and bainite can be obtained.

PROJECTS WITH SPECIFIC REQUIREMENTS

Devils Tower Deepwater Project

Devils Tower is a currently developed oil and gas field in the deep waters of the Gulf of Mexico. The export pipeline connects the field (water depth 1750 m) with shallow water locations at the shelf edge. The steel for the pipes is X60 with a diameter of 18". They will be laid with the reel lay technique by a newly built deepwater pipelay vessel.

A lean CMnNb steel was selected with a specifically designed TM multistage rolling schedule, which includes intermediate cooling in the rolling mill. DH has produced 36 000 t of TMCP plates for the deepwater pipelines in early 2002. The wall thickness was between 22.2 and 28.6 mm.

Figure 1 presents relative frequencies of the tensile properties obtained in transverse and longitudinal direction. Specific for this case are the very small windows of only 100 N/mm² (14.5 ksi) for yield and tensile strengths of the plates, both in transverse and in longitudinal direction. Such narrow tolerances are important for reeling, which requires strict tensile constraints for pipes (and consequently also for plates) owing to the considerable cold plastic deformation during the lay process of the pipes.

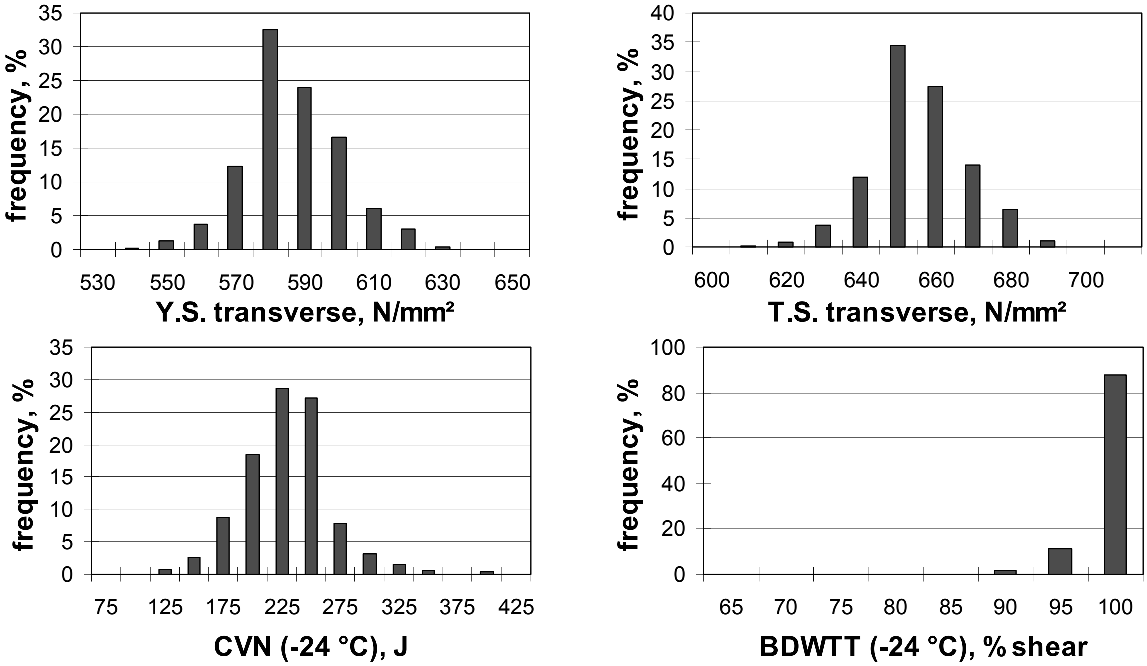

Figure 2: Distribution of mechanical properties on plate with thickness of 20.8 mm and grade X70 for the Gulfstream project

Gulfstream

Gulfstream is a pipeline project in the United States to deliver natural gas to electric power stations in Florida. The transmission line runs from Mobile, Ala. through the Gulf of Mexico to Manatee County, Fla. The project included a total of 450 000 t of heavy wall pipes with outer diameter of 30 and 36". The wall thickness was between 11.2 and 31.4 mm and the steel grades were X65 and X70 for sweet service.

DH has produced more than 200 000 t of steel plates for this project. They were processed in different pipe mills, with UOE as well as three-roll bending without expansion. As the Bauschinger effect depends on the pipe making process, the plate properties had to be tailored accordingly.

Figure 2 shows the tensile properties achieved on 20.8 mm thick plates in transverse direction. They meet the X70 specifications on pipe without expansion, both in longitudinal and transverse direction. A special TM-procedure was defined for this purpose; Nb, V, and Ti were used as micro-alloying elements.

Figure 2 also gives Charpy-V-Notch toughness (CVN) and Batelle Drop Weight Tear Test (BDWTT) properties. They show a very narrow distribution which guarantees homogeneous and predictable behavior in the pipe mill and during construction and operation.

Alliance

The ALLIANCE project in Canada refers to a natural gas pipeline system from north-eastern British Columbia and north-western Alberta to the mid-west United States. Part of the line lies in colder areas where the design temperature is -30°C. This demands BDWTT with shear fracture requirements and CVN values at rather low temperatures. The plates were produced for a pipe mill without expansion. The low C steel was alloyed with Mn, Ni, Nb, V and Ti.

Table 1: Results on plates for low temperature application, average values and standard deviation, 22.2 mm, X70

	Y.S. N/mm²	T.S. N/mm²	A_{2in} %	CVN (-57 °C) J	BDWTT (-45 °C) % shear
Mean	582	634	41	141	76
Std. dev.	7	7	3	19	9

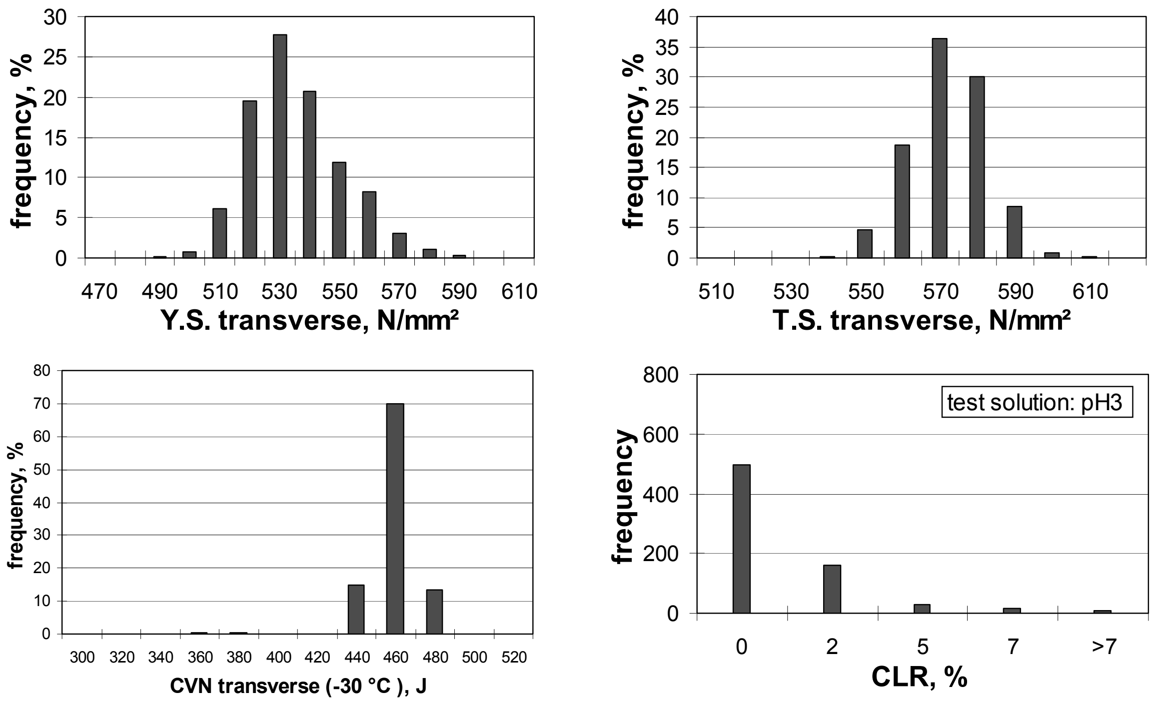

Figure 3: Mechanical and HIC test result, NACE TM0284 solution A (average of 3 sections). Shell NOGGS project, 19.4 mm X65 plates

Properties in transverse direction are given in Table 1. The standard deviations confirm a very homogeneous distribution. High yield strength on plate, close to the range of X80 values, was set to compensate yield strength losses from plate to pipe due to the Bauschinger effect which is more pronounced in a pipe mill without expander. The impact and BDWTT properties for low temperature operation are remarkable.

<u>Shell Nigeria OGGS</u>

The Nigerian offshore gas gathering system (OGGS) aims at eliminating gas flaring at high volumes by connecting various production plants with a 265 km long gas pipeline and will be West Africa's longest offshore pipeline. The steel is X65 which has to satisfy pH3 sour gas requirements. Special steel making measures were applied [9], resulting in low levels of S and P in combination with limited addition of Ca and Mn. As micro-alloying elements, Nb and V have been used, and the plates were treated with ACC.

Dillinger Hütte and GTS have produced about 105 000 t of plates for this order with thickness of 19.4 and 23.3 mm. Figure 3 shows mechanical properties together with results of HIC testing in terms of the Crack Length Ratio (CLR). The figure confirms low ranges of scatter of all properties.

<u>X70 for low temperatures</u>

While Alliance involved lower temperature properties and Shell Nigeria was strict on HIC resistance, demands on both aspects have been set on plates which were delivered for use in Alaska. The wall thickness was 11.9 mm and the plates were HIC tested per NACE TM0284 with solution B.

Figure 4 summarizes results of plates for this order. In particular the BDWTT values and the Charpy impact energies at -55 °C are worth mentioning.

<u>X80</u>

The market for high strength grade X80 grows, as manifested by recent orders. DH has produced X80 steel plates with thickness in the range from 14 to 25 mm for pipeline projects, e.g. in UK for TRANSCO, former British Gas. Trials indicate that line pipe steel with even higher thickness is

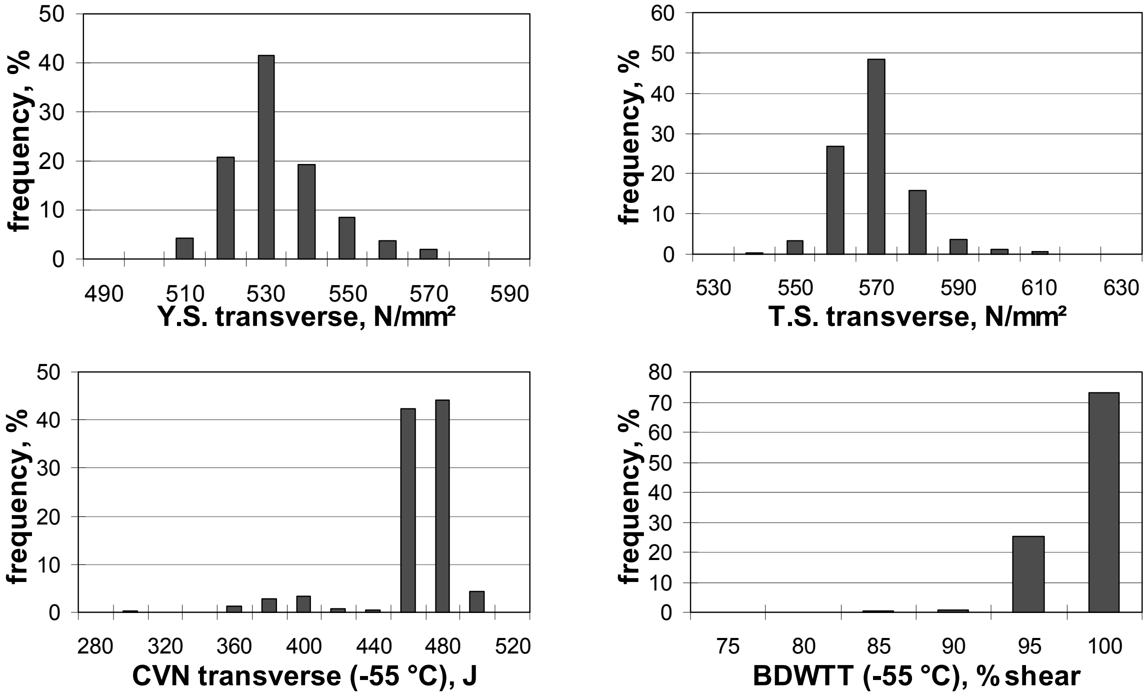

Figure 4: Distribution of mechanical properties for 11.9 mm plates for X70 HIC plates for Alaska

feasible with good toughness; more details will be reported in Ref. [5].

Another application of X80 plate is the production of riser and conductor pipes with higher wall thickness for which DH has delivered plates up to 44 mm in thickness. The steels were Ni and Mo added and micro-alloyed with Nb and Ti; the carbon equivalent CE_{IIW} was 0.44. The process was based on TMCP rolling and accelerated cooling with high cooling rate and low cooling temperature. For riser and conductor pipes it is possible to produce plates for pipes with good longitudinal properties even after post-weld-heat-treatment (PWHT) at 600°C and with restrictions in hardness and requirements for elongation A_5 transverse. Plate results of an X80 order for pipe production without expansion and with PWHT are shown in Figure 5.

SUMMARY AND CONCLUSIONS

The paper has gathered prominent examples of plate orders for line pipe steels which enhance the previous spectrum of achievable properties in various aspects. Such steel plates are manufactured with leading edge steelmaking technology and advanced thermo-mechanical processing on high power rolling equipment, if necessary in combination with accelerated and intermediate cooling.

Rolling and cooling schedules are tailor-made according to the project, using a wide know-how data base. Changes of the material during different pipe forming processes, too, are considered in plate design. Lean chemistries warrant good weldability.

The examples show that standard line pipe grades such as X60 are today produced with very narrow tolerances for specific demands, e.g. as needed for the reel-lay technique. X70 is now mastered routinely for sweet service with tight ranges in tensile properties, and has matured also for sour service. Remarkably low design temperatures for operation in cold areas are realized by adequate alloying and process design. Sour gas resistance is safely achieved, and even the triple combination of high strength, low service temperatures and HIC resistance can be implemented with X70. The next step, X80, is emerging as a product on the market. Development efforts will now focus on the grade X100 as a higher strength material for increased pressure lines and, generally, with expected economic benefits.

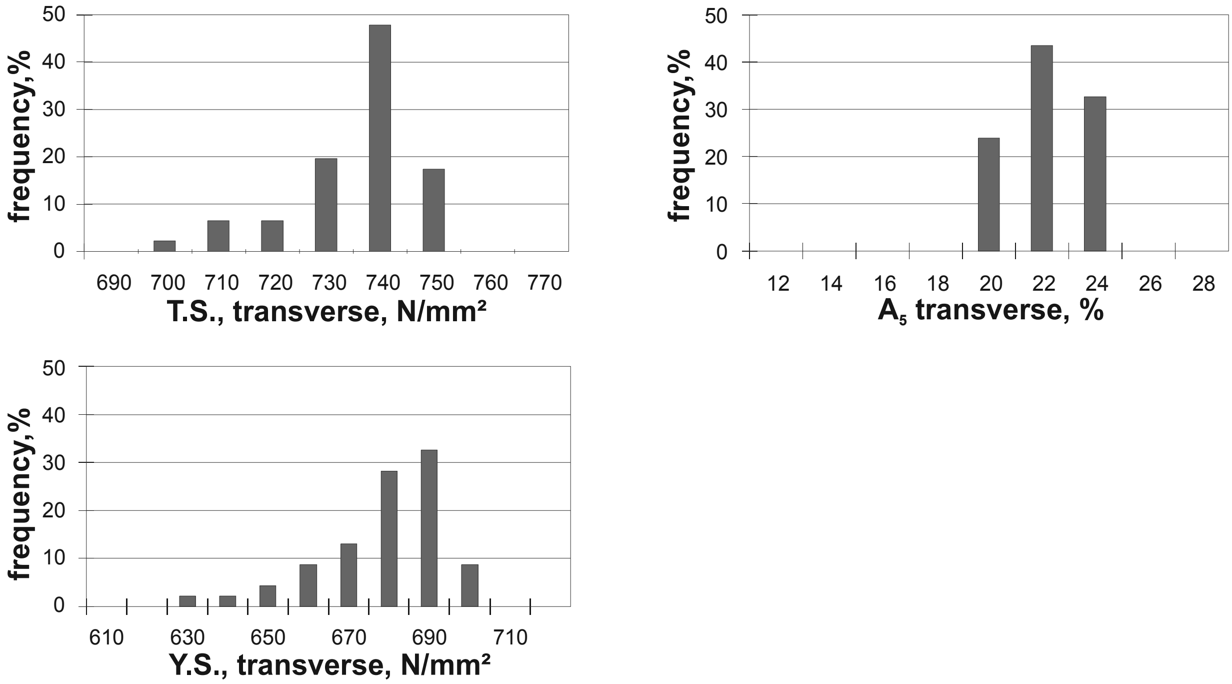

Figure 5: Mechanical properties in transverse direction of plates for X80 for pipe production without expansion and PWHT with wall thickness of 38 mm

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