Niobium Bearing Structural Steels
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PROPERTIES AND EXPERIENCES ROLLING HIGH NB STEELS ON CORUS PLATE MILLS

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Abstract

Corus Plate Mills rolled a number of casts of High Nb steel (~0.05% C, ~0.09% Nb) from late 2004 to early 2006, primarily to assess the viability of achieving 25mm X65 with –22°C Battelles. To investigate the potential of these steels, various rolling schedules were applied and to further explore the possibilities a range of other gauges from 15mm to 50mm were also produced.

This paper explores some of the properties obtained and how these were affected by the rolling schedules. Whilst the original objective was not achieved, some excellent strength and toughness combinations in 20mm plate were produced. Additionally, some higher temperature rolling schedules with relatively low post-hold reduction ratios were found to give good Battelles.

The importance of adequate reheating to ensure that Nb precipitates are fully dissolved prior to rolling was also demonstrated.

Steelmaking and Casting

Corus Plate Mills carried out a series of rollings of High Nb steel between late 2004 and early 2006. Steels of this generic type are not new, and have been used on linepipe projects before, e.g. the Cantarell offshore oilfield project [1], and are known to have good strength and toughness characteristics.

A number of casts of High Nb steel were made at Corus Scunthorpe Works. This is an integrated steelworks starting with coal and iron ore as the raw materials. Steelmaking is by the BOS process with ladle arc and vacuum degassing secondary steelmaking facilities. The casts were all twin strand cast to 230mm thick slab. Most of the production was machine scarfed, however to investigate slab surface quality a number of slabs underwent a hand flame dressing process.

Conventional Nb microalloying for pipeplate or structural steels uses a Nb content of around 0.02–0.04% Nb. This 'High Nb' steel was characterised by a Nb content of ~0.09%. The following principles were applied in determining the base alloy composition: C content kept low (~0.05%); Ti treatment (~0.015%) used to control austenite grain size during slab reheating; Cr (0.25%), Ni (0.15%) and Cu (0.25%) added for strength and toughness; P kept low to minimise segregation effects; and S was varied, with a maximum of 0.006% and a minimum of 0.001%. CEV's were ~0.38 and Pcm was ~0.16. See Table 1 for the cast analyses.

Table 1 – Typical ladle analyses of selected High Nb steel casts

	81913	**67126**	**67665**
Date cast	16.11.2004	28.12.2005	11.01.2006
C	0.054	0.042	0.047
Si	0.16	0.18	0.19
Mn	1.61	1.51	1.49
P	0.013	0.008	0.009
S	0.005	0.006	0.001
Cr	0.25	0.25	0.25
Ni	0.16	0.16	0.15
Al	0.037	0.025	0.036
N	0.0059	0.0063	0.005
Cu	0.25	0.26	0.25
Nb	0.093	0.093	0.096
Ti	0.015	0.012	0.012
H (ppm)	2.0	2.6	1.0

All wt% except where stated.

Surface Quality

Slab quality was assessed prior to rolling by visual examination of the flame dressed surfaces and also in the machine scarfed condition. There were no indications of any surface defects. On the one hand the microalloy content of this steel is relatively high, and on the other the C content is low and away from the peritectic region.

During each plate rolling and subsequently during pipe forming operations, the surface quality of the material was assessed. A small region of transverse cracking was found on one plate which was removed by finishing. Other than this no cracking or other metallurgical defects were found. This was the case whether the plates were machine scarfed or not. It was concluded that the surface quality of this High Nb steel was very good and that the beneficial effects of the low C content offset any negative effects of a high microalloy content.

Plate rolling and review of properties

Corus has two Plate Mills, both in the United Kingdom, at Scunthorpe (Scunthorpe Plate Mill, SPM) and at Motherwell (Dalzell Plate Mill, DPM). Both mills are conventional plate mills and carry out a wide range of rolling schedules, from as-rolled to heavy TM schedules, on a product mix from around 6mm up to 150mm thick. Neither mill has accelerated cooling facilities.

A series of rollings was carried out using different schedules. The main objective of the work was to establish if the plate requirements for X65 pipeplate at 25.4mm thick with a –22°C Battelle could be achieved using High Nb steel. After this a number of rollings at around 20mm were conducted, varying different aspects of the rolling schedules and using different casts. For the HIPERC [2] project, a small number of other plates at gauges from 15 to 50mm were also rolled.

The sections below outline the main findings.

25.4mm X65 rollings

The first plates of High Nb steel were rolled at SPM and DPM to 25.4mm pipeplate from cast 81913. 21 plates were rolled in total. This rolling was a first attempt to see what the mechanical properties of the plates would be like.

The rolling schedule used was a 3:1 reduction ratio from the hold and an end hold temperature (EHT) of 800°C. The mechanical property and microstructural data are summarised below in Table 2 and Figures 1-3.

Table 2 – Tensile and impact data for 25.4mm High Nb steel from cast 81913

	Scunthorpe Plate Mill		**Dalzell Plate Mill**		**'X65' Requirements in plate**
	Min	Max	Min	Max	Min
$Rt_{0.5}$ (MPa)	476	540	495	518	460
UTS (MPa)	527	610	553	591	531
Impacts –40°C (Ave J) Quarter depth, transverse	168	382	164	278	40

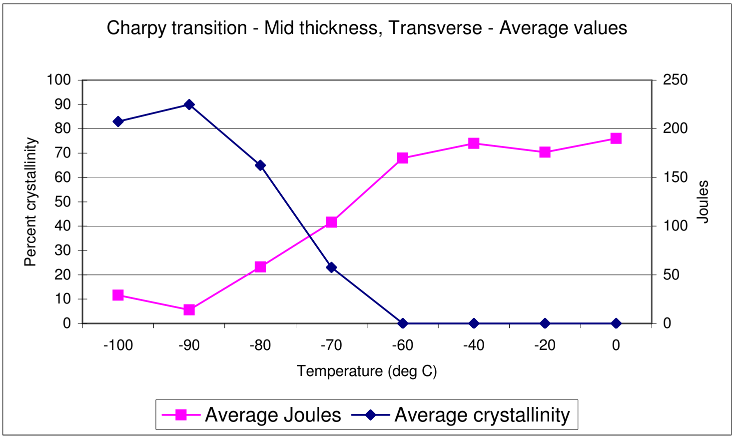

Figure 1 – Typical Charpy impact transition plot for 25.4mm High Nb plate

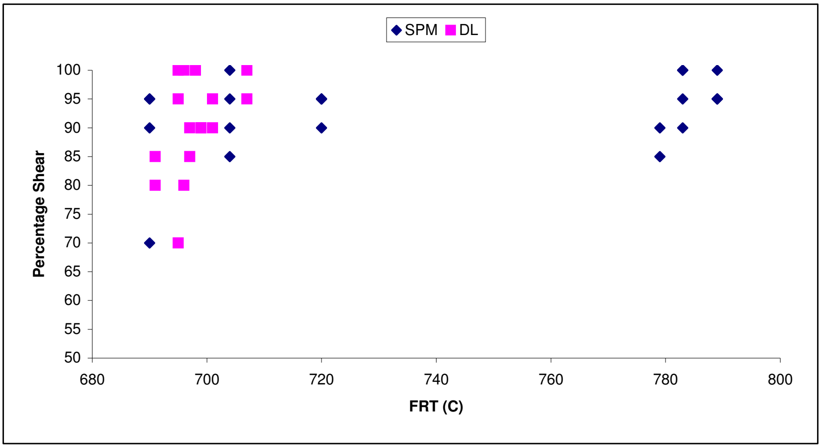

Figure 2 – Battelle % shear data at –22°C for 25.4mm plates

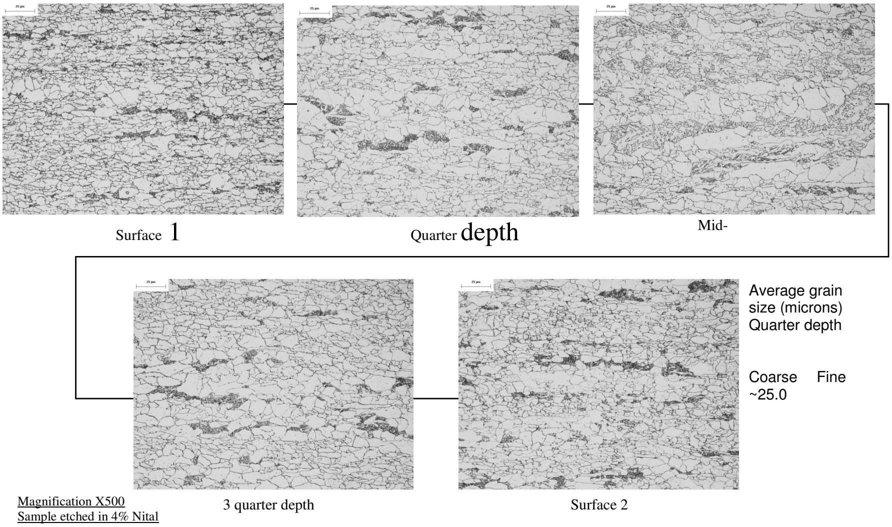

Figure 3 – Typical microstructure of a DPM 25.4mm plate

It can be seen from Table 1 that the strengths were generally adequate although there was one plate which failed to make the minimum UTS required. Impacts were good, with a 50% FATT of around –75°C at mid-thickness in the transverse orientation, and better at quarter depth. The Battelle performance at –22°C did not achieve the requirements of a minimum of 85% shear. The points at the right hand side of Figure 2 were rolled with a higher EHT and Finish Roll Temperature (FRT).

The microstructure was predominantly fine ferrite but throughout the thickness of the rolled plate there were islands of coarse ferrite with grain size around 25 microns. There was evidence of some modest segregation and associated transformation products at the centreline of most of the plates.

A range of other tests were carried out. In summary this showed no HIC resistance, attributed to the S content and segregation being inappropriate; CTOD values in excess of 0.25mm were achieved to –40°C; and weld HAZ Charpy values in SAW pipe were generally OK although there were some low values associated with centreline locations.

As this was the first rolling, its aim was partly to see how this steel performed and assess what mechanical properties were obtained. It was recognised that a 3:1 reduction ratio would probably not be enough to obtain good Battelles. A further rolling to a similar schedule but with a 4:1 reduction ratio was carried out; however the Battelle results were broadly similar to before and not good enough.

In summary, the 25.4mm plate rollings showed that good strength and impact toughness could be achieved, but not the Battelles at –22°C.

20mm rollings – for X65 / X70

Slab was rolled to 20.9mm plate at SPM. The schedule was a 4:1 reduction ratio from the hold, with an EHT of 800°C. This gauge and width was selected to be a direct comparison to plate supplied for the Balgzand to Bacton Link (BBL – gas interconnector between the Netherlands and the UK) pipeline contract which had high strength and toughness requirements. The cast used was 81913 with 0.005% S. Table 3 shows the results of the comparison.

Table 3 – Mechanical property comparison for 20.9mm High Nb steel from cast 81913

	Results range	**BBL requirement**
$Rt_{0.5}$ (MPa)	522-533	470 – 590
UTS (MPa)	585-592	560 – 670
Yield / UTS ratio	89-90	92 max
Elongation (%) on 200mm	18-20	17 min
Impacts –40°C (% shear) **Quarter depth, transverse**	90	85 min average 75 min individual
Impacts –40°C (Ave J) **Quarter depth, transverse**	168-210	100 min average 75 min individual
BDWTT (% shear) –22°C	100 100	85 min average 75 min individual
BDWTT Energy –22°C (kJ)	8.868-16.332	Not specified.

This shows that the High Nb material met all the plate requirements of the BBL contract material which were in excess of X65 strength.

The Charpy impact uppershelf energy was around 175 joules, and at the mid-thickness position the 50% FATT (Fracture Appearance Transition Temperature) was below –100°C. Given the cast contained 0.005% S this was felt to be a good level of toughness.

Material was taken to carry out a limited Battelle transition curve, shown in figure 4.

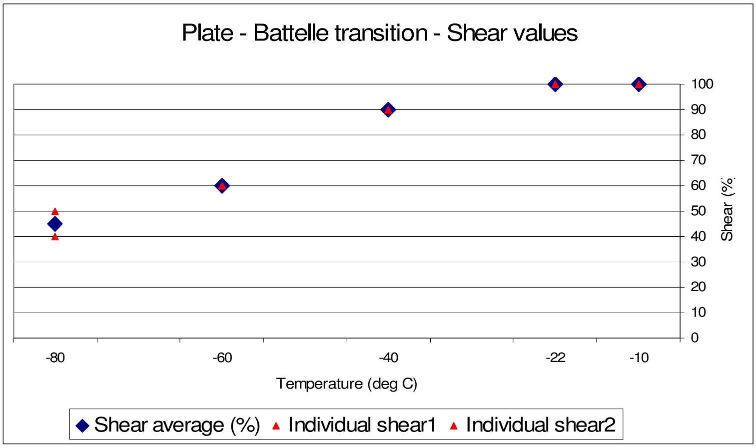

Figure 4 – Battelle transition for 20.9mm High Nb plate

This plate was fully upper shelf at –22°C and maintained a reasonable level of Battelle toughness to lower temperatures. It is recognised that level of energy absorption will not be as good at 0.005% S as it would have been if casts with lower S had been used.

Microstructural assessment showed a very similar mixed grain size ferrite pearlite microstructure to that seen previously in the 25.4mm plates, except that the grain size was further refined. At the quarter depth position, the large sized grains were around 20 microns in size, whilst the majority of the microstructure was very fine with the finer grains typically around 1.7 microns.

20mm rollings – Battelles with varying End Hold Temperatures

A large number of plates were rolled to 20.6mm plate to a lower strength requirement than X65. As a result of this there was the opportunity to try some significant variation in the schedules, especially the End Hold Temperature (EHT). In particular the higher temperature processing was being explored as this was part of the original concept of the High Nb steel design.

Pairs of slabs (in most cases) were selected from cast 67126 (0.042% C and 0.006% S) and rolled to schedules with a 3:1 reduction ratio from the hold, and where the EHT was changed in 50°C increments, upwards from 750°C: i.e. 750°C, 800°C, 850°C, 900°C, 950°C. The duration of the hold period is heavily influenced by the EHT, and at 950°C, the hold was of minimal duration.

This set of parameters combines the highest S of all the casts, a reduction ratio of 3:1 and EHT's up to 950°C, which it was felt should test where the limits of impact and Battelle capability lay.

Figure 5 shows a plot of the Charpy 50% FATT (transverse, mid-thickness) and the Battelle upper shelf point against rolling schedule.

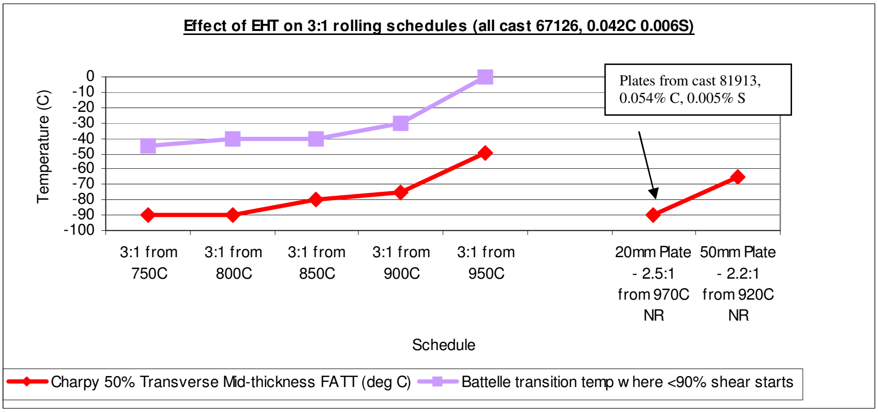

Figure 5 – Battelle and Charpy transition data for 20.6mm High Nb plate

This figure shows the Charpy transition temperature at –50°C on the 950°C EHT plates, and down to –90°C on the 750 and 800°C plates. These latter plates showed transition data similar to other High Nb plates rolled at Corus. The Battelle transition point was taken as the point at which the % shear starts to drop below 90%. This was because the work was interested in determining the temperature range of upper shelf behaviour. All the plates except those rolled from 950°C EHT were upper shelf down to –30°C or lower. Both the Charpy and the Battelle behaviour starts to change more rapidly above an EHT of 900°C.

All these plates had a strength level in excess of X56.

The two data points on the right of Figure 5 show two plates rolled on a Normalised Rolled schedule to 20mm and 50mm thick (from cast 81913, 0.005%S). It can be seen that these also exhibit good Charpy impact transition temperatures. The 50mm plate has a mid-thickness transverse FATT of –65°C.

The good levels of Battelle and Charpy toughness at fairly high rolling temperatures is probably attributable to the fact that with a Nb content of 0.093%, the T_{nr} temperatue will be high. Whilst a T_{nr} temperature was not experimentally determined, it is possibly at a temperature roughly equal to that during the last few passes of the roughing phase. The implication is that recrystallisation begins to be suppressed before the hold is taken for all schedules used in this work.

20mm rollings – Effect of slab reheat temperature

During rolling of a portion of the High Nb material, the effect of a range of reheating temperatures from 1170°C to 1200°C was investigated. To see the reheating effect, only one rolling schedule has been selected (many variations were being used as noted above). A number of plates rolling on a 5:1 reduction ratio from 800°C EHT were affected by the low reheating temperatures and these are shown in Figure 6 below.

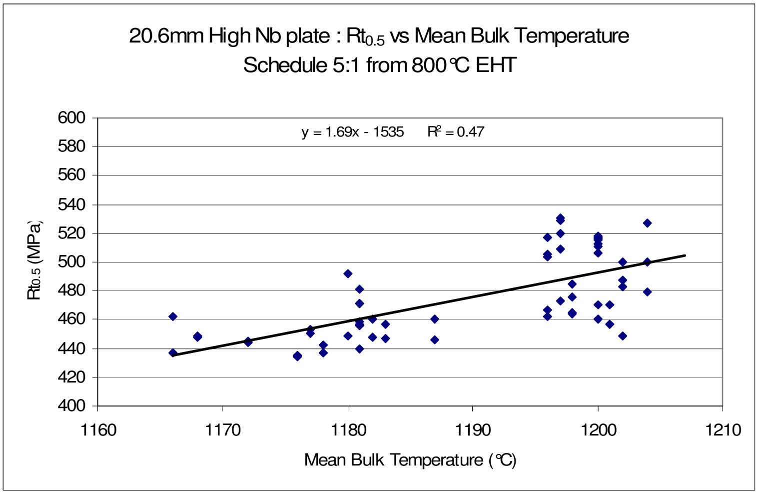

Figure 6 – Effect of reheating temperature on yield strength for 20.6mm High Nb plate

Whilst imperfect there is clearly a trend toward higher strength with higher reheat temperatures. This is not surprising when the temperature required to dissolve the Nb into the austenite is considered. There are different formulae of determining this temperature.

Using an equation for the solubility product of NbCN:

$$\mathrm{Log}_{10}\left[\mathrm{Nb} \times \mathrm{C} + \frac{12}{14}\mathrm{N}\right] = \frac{-6770}{T} + 2.26 \qquad \text{.....(1)}$$

with values of 0.05% C, 0.09% Nb and 0.005% N, gives a solution temperature of 1210°C.

This suggests that a proportion of the Nb in the steel is not contributing to strengthening, and this proportion increases as the reheat temperature falls further below the solution temperature. It may be expected that this would affect the yield more than the UTS, and this was seen to be the case.

Other rollings

This work was mainly looking at the suitability of High Nb steels for pipe plate applications. It was not intended that the steel be rolled into structural steel grades. This was because the structural steel standard EN10025:2004 implies that Nb levels should be below 0.06%. However the properties developed on the various Normalised Rolled (NR) and Thermomechanical (TM) schedules during this work are attractive for structural steel grades. In some cases the rolling schedules required to achieve a given product would be less arduous using High Nb steel than conventional steel grades compatible with the standard as it currently stands.

Conclusions

Corus successfully rolled High Nb steel to a wide variety of schedules and gauges. The original objective of achieving X65 at 25.4mm thick with Battelles at –22°C was not achieved. However at 20mm thick, excellent Battelles to better than –22°C were achieved coupled with good strength in excess of X65. Work varying the End Hold Temperatures (EHT) over a wide temperature range showed that good Battelles and Charpy toughness could be maintained with EHT's up to 900°C. The importance of having a reheat temperature that gets the high levels of Nb into solution was demonstrated on a number of plates. Whilst this work has mainly been about pipe plate steels, the High Nb steel concept develops mechanical properties that would be attractive in structural steels.

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