# Application of Niobium Low Carbon Low Alloy Structural Steel Approach

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## Abstract

Niobium Bearing Low Carbon Low Alloy (LCLA) value-added S355 structural steels reduces the overall material and construction costs for many high strength construction steel and heavy equipment applications. The recent development of the Nb-LCLA Approach is a value-added low cost approach for many structural steel applications including windtower supports, beams and other structural plate applications. Case examples are presented from Brazil, China and the USA. These Nb-bearing steels at lower carbon content compared to the traditional higher carbon normalize heat treated grades are more cost effective and reduce structural fabrication time through improved weldability as well.

## Introduction

The unique metallurgical attributes that niobium provides in structural steels create the opportunity to successfully meet stringent mechanical, corrosion and elevated temperature demands. Nb-based structural steels were in limited production during the 1980's. Different from the automotive or pipeline segment where carbon levels are typically less than 0.10%, many of the plate structural products still exceed 0.10%C approaching allowable specification maximum carbon levels of 0.22%. Also, a large volume of structural steels are produced in the peritectic regions. Some mills choose the higher carbon level approach to achieve strength, but sacrifice toughness, weldability and end user product performance at an increased cost. Mills which have not adopted the low carbon-Nb approach are missing out on the inherent advantages Nb provides in yield strength, ductility, toughness and weldability at a lower overall operational cost. Several case applications are presented which exhibit the quality and production advantages of producing Nb-LCLA structural steels at less than 0.10%C. Specific case application examples involve medium and heavy section structural beams for high rise structures such as the Freedom Tower in New York City, windtower structural supports with improved fatigue and fracture toughness and a plate steel ball mill replacing higher carbon plate and forged rings for the heavy equipment ball mill installed at CBMM's Araxa metallurgical industrial plant in Brazil.

## Background

Over 50% of the structural plate and beam sections are intermediate carbon levels from 0.15 to 0.22%. There is a gradual shift at some mills seeking participation in the value-added structural plate and beam segment to produce Nb-bearing structural grades at less than 0.10%C to make lower carbon base alloys for both plate and some long product applications. The benefits are not only improved mechanical properties and functional performance, but also the opportunity to reduce overall steelmaking cost per tonne through improved productivity, reduced diverts and improved product quality [1]. With increasing raw material and energy costs, the effects of processing parameters such as reheating temperature and cooling rate after hot rolling to achieve improved mechanical properties can result in significant savings. A lower total cost of production may be achieved through a low carbon-low alloy (LCLA) chemistry with selective accelerated cooling and better control of reheat furnace temperatures.

## Structural Plates and Beams

Successful commercialization has resulted in the production of Nb-bearing beams replacing V-bearing beams with significant toughness improvements in beams and plates produced to such specifications as ASTM992, ASTM572, ASTM588, ASTM710, Q345e, and S355 to name a few. The incorporation of Nb technology has significantly improved toughness properties through grain refinement and strategic cooling practices during rolling. The LCLA chemistry is less than 0.10%C, 0.025-0.035%Nb, less than 0.010%S, less than 0.015%P, less than 1.40%Mn and residuals less than 0.70% (i.e. Cr+Ni+Cu+Mo). The Nb addition refines the grain by 2 ASTM sizes, lowers the carbon equivalent by 0.07% and significantly improves the toughness improves the toughness compared to V-bearing low C steels as shown below.

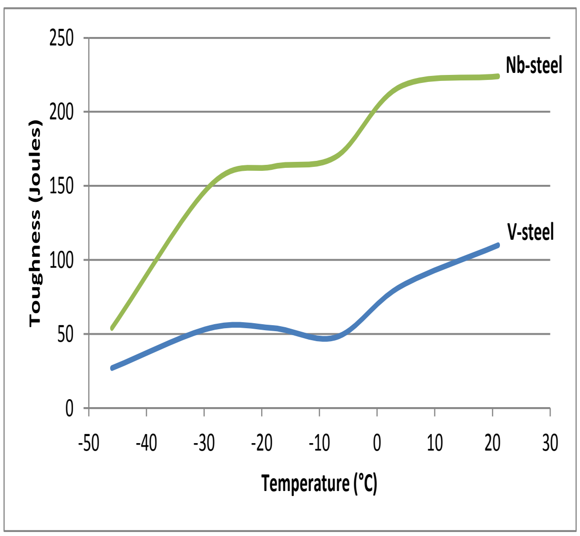


Figure 1. (a)Charpy V-notch impact strength comparison – Nb vs. V at Mill #1 [2]

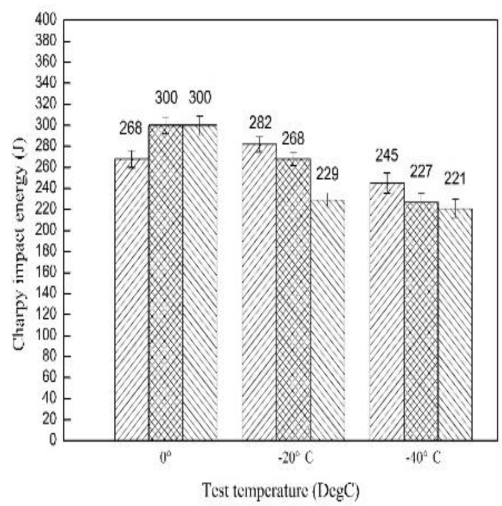


Figure 1. (b) Charpy V-notch impact strength toughness Nb steel at Mill #2

Results in different mills in different geographic regions have been congruent. For example, near net shape cast structural beams containing only a single Nb microalloy exhibit double to triple the Charpy impact strength energy at room temperature compared to a V-only microalloy system at similar sulfur, phosphorous and nitrogen levels and cooling rates as illustrated in Figure 1. At mill #2 in China, they incorporated an even higher cooling rate and Charpy values further increased.

A second part of the study investigated a comparison of different cooling rates. Micrographic analysis revealed that the primary microstructural constituents at a low cooling rate were polygonal ferrite and pearlite. At intermediate and high cooling rates, the microstructure consisted of lath-type/bainitic ferrite and degenerated pearlite together with conventional ferrite-pearlite. With an increase in cooling rate, there was an increased tendency towards formation of lath ferrite/bainitic ferrite with a consequential decrease in the conventional ferrite-pearlite microstructure. Figure 2 illustrates the influence of Nb on the transformation to the formation of degenerated pearlite (approaching a bainitic-type microstructure) which contributes to the improved toughness. No degenerated pearlite was observed in the V-bearing steel grade.

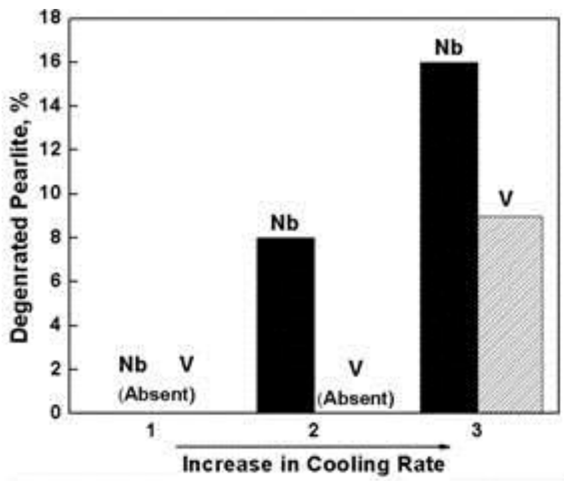


Figure 2. Percent degenenerated pearlite versus cooling rate – Nb and V comparison [3]

## Construction Plates for Windtowers

The windtower end users require better power generation efficiency which requires construction of towers to higher elevations. Fatigue and fracture toughness limitations of traditional steel higher carbon structural supports moved designers to consider carbon fiber composites. As a result of this threat of carbon fiber composite substitution for the HSLA S355 structural steel supports, a new steel material design was required to halt the threat. With the proven success of the beam applications, the Nb-Low Carbon Low Alloy (Nb-LCLA) as hot rolled plate product provided a viable, cost effective solution. Table 1 compares the mechanical properties of low C versus medium C Nb containing windtower plate for 20mm plate thickness.

Table I. Mechanical Property Comparison [4]

| Steel | Orientation | Yield Strength (MPa) | Tensile Strength (MPa) | Elongation in 200mm (%) | CVN @ -15.5°C (Joules) |
|---|---|---|---|---|---|
| Low C-Nb | L | 436 | 514 | 29.7 | 384[1] |
| | T | 450 | 521 | 28.1 | 371[1] |
| Med C-Nb | L | 439 | 561 | 21.9 | 103 |
| | T | 442 | 569 | 23.3 | 42 |
| Med C-Nb Norm | L | 384 | 528 | 28.3 | 243 |
| | T | 391 | 530 | 27.6 | 132 |
| ASTM A572-50<br>ASTM A709-50 | | 345min | 448min | 18min | 34min LCVN @ -12.2°C[2] |

| | | | | | |
|---|---|---|---|---|---|
| EN10025-2 S355K2³ | | 345min | 469-627 | 20min | 41min LCVN @ -20°C |

[1] Full-Size Equivalent; [2] ASTM A709 requirement for Zone 3 fracture critical tension components; [3] 16 < t ≤ 40 mm

<u>Low Carbon Nb- versus V-Bearing Impact Strength Comparison</u>

Figure 3 below illustrates the significant difference in upper shelf CVN energy performance for the Nb LCLA compared to the low carbon V structural plate.

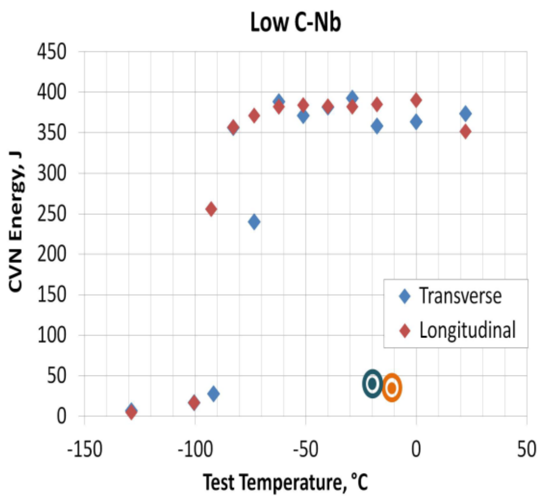


Figure 3. (a) Low C-Nb transverse and longitudinal Impact toughness

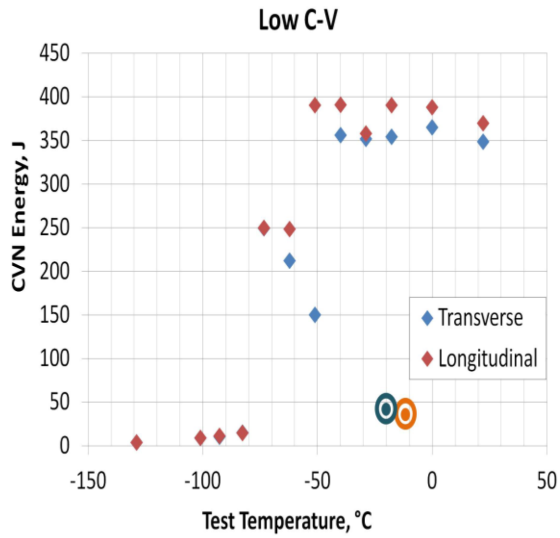


Figure 3. (b) Low C-V transverse and longitudinal impact toughness

## Araxa Ball Mill

The mill is a 4,900 mm diameter ball mill with a welded two-piece shell, welded forged flanges and cast covers (Figure 4) [5]. The traditional project called for cast flanges that were to be heat treated to attain final properties. With niobium microalloyed forged flanges, controlled hot mechanical working and cooling guarantee the microstructure and mechanical properties without heat treatment.

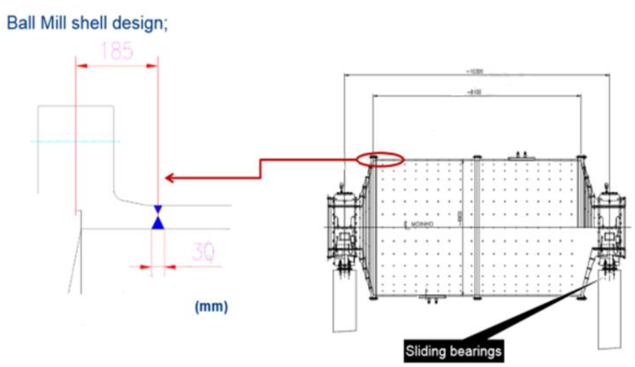


Figure 4. (a) Ball mill design illustrating (b) Image of ball mill.

The original project considered ASTM A36 carbon steel for the shell and flanges, but instead a low carbon niobium microalloyed steel was used for the light design project (Table II). A low carbon steel was chosen in order to improve weldability. The Ceq dropped from 0.46 to 0.36

using this concept. Since Nb is a very effective grain refiner, niobium compensates for the reduction in carbon, improving mechanical strength and weldability compared to A36.

Table II. Chemical composition of the Nb LCLA Ball Mill

| | C | Mn | P | S | Si | Nb | Ti | N | Ceq |
|---|---|---|---|---|---|---|---|---|---|
| Shell & flanges | 0.06-0.10 | 1.2-1.4 | <0.015 | <0.005 | 0.15-0.25 | 0.03-0.04 | 0.09-0.016 | <80 ppm | 0.36 |

Weldability of large and thick-walled structures is a major obstacle for manufacturers for a variety of reasons. The most critical challenge is the wide HAZ, distortion due to high pre- and post-heating temperatures, risk of cold cracking and tight surveillance in maintaining preheating and interpass temperatures. Due to these issues, an alloy design in Zone I of the Graville diagram significantly minimizes these issues. The solution of using niobium microalloyed steels shifted the composition to a very safe zone concerning weldability (Figure 5) [5].

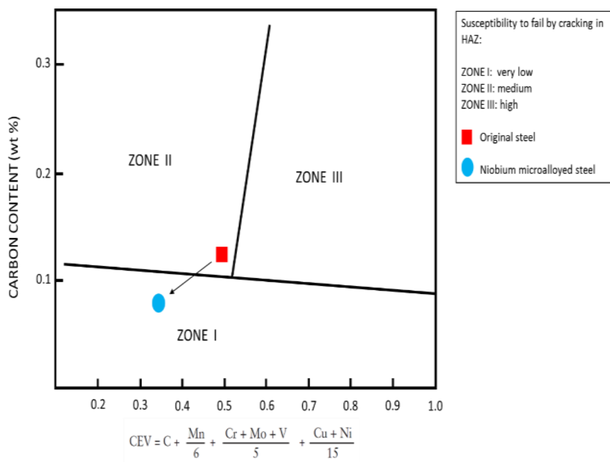


Figure 5. Graville diagram

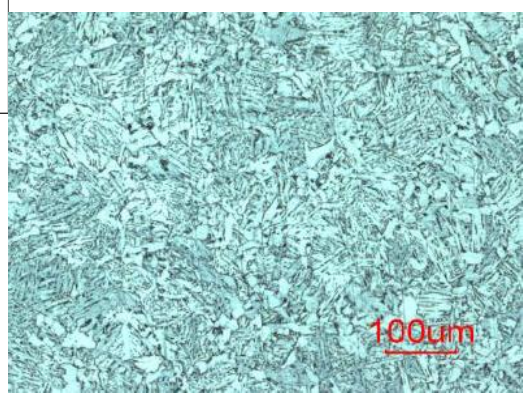


Figure 6. Microstructure of flange surface: ferrite and bainite

The improved weldability and F/B microstructure of the niobium microalloyed steel shell and flanges were fine and homogeneous (see the forged flange in Figure 6). The Nb-LCLA steel has higher tensile test properties and lower transition temperature on Charpy V tests compared to the A36 grade for the shell and flange. (Tables III and IV) [5].

Table III. Mechanical properties of ASTM A36 and low C- Nb microalloyed steel ball mill shell

| Grade | YS (MPa) | TS (MPa) | El (%) | Charpy TT (ºC) |
|---|---|---|---|---|
| A36 shell | 250 | 400 | 20 | -10 |
| Niobium microalloyed shell | 400 | 510 | 29 | -40 |

Table IV. Mechanical properties of ASTM A36 and low C- Nb microalloyed steel flanges

| Grade | YS (MPa) | TS (MPa) | El (%) | Reduction of area (%) | Charpy room temp. (MPa) |
|---|---|---|---|---|---|
| A36 flanges | 235 | 375 | 18 | 28 | 33 |
| Nb-microalloyed flanges | 420 | 530 | 25 | 80 | 279 |

The high values of energy absorption impact tests for the higher values of tensile and yield strength reflect the effect of small additions of niobium on improving strength and toughness characteristics simultaneously. Table V summarizes 7% savings in realized overall cost savings in the heavy equipment ball mill application for this “first-of-its-kind” prototype mill..

Table V. Cost benefit analysis between ASTM A36 and niobium microalloyed steel processes.

| **ASTM A36 Process** | **US$** | **Niobium Microalloyed Process** | **US$** |
|---|---|---|---|
| Melting & casting (1 ingot) | 7,500 | Melting & casting (1 ingot) | 8,000 |
| Ingot preparation/cutting | 200 | Ingot preparation/cutting | 200 |
| Heat & upset forge | 8,500 | Heat & upset forge | 8,500 |
| Ring roll single stage | 8,000 | Ring roll single stage | 11,500 |
| Heat treatment | 6,500 | | |
| NDT test | 400 | NDT test | 400 |
| Machine | 5,000 | Machine | 5,000 |
| **Total** | **36,100** | **Total** | **33,600** |

Another benefit of the microalloyed design is that the heat treatment step after hot mechanical working is eliminated because the exceptional properties are the result of the Nb-thermomechanical process and controlled cooling. The elimination of this step in the process offsets the slightly higher steelmaking and ring rolling production steps.

## Nb-Low Carbon Weathering Bridge Steel

A high-performance Q370qE-HPS bridge steel with low carbon content (≤0.10wt%), Nb microalloying (0.025-0.050wt%) and low carbon equivalent (CEV) (≤0.38%) has been produced using TMCP procedure. The results show that the microstructure consists of fine-grained quasi-polygonal ferrite (QPF), less pearlite and a large number of fine dispersed Nb-rich precipitates. As shown in Fig. 6, the *E*KV2 (-40°C) of Q370qE-HPS steel plate increases significantly with the decreasing *dα* or P%, and the effects can be described quantitatively by Boltzmann model.

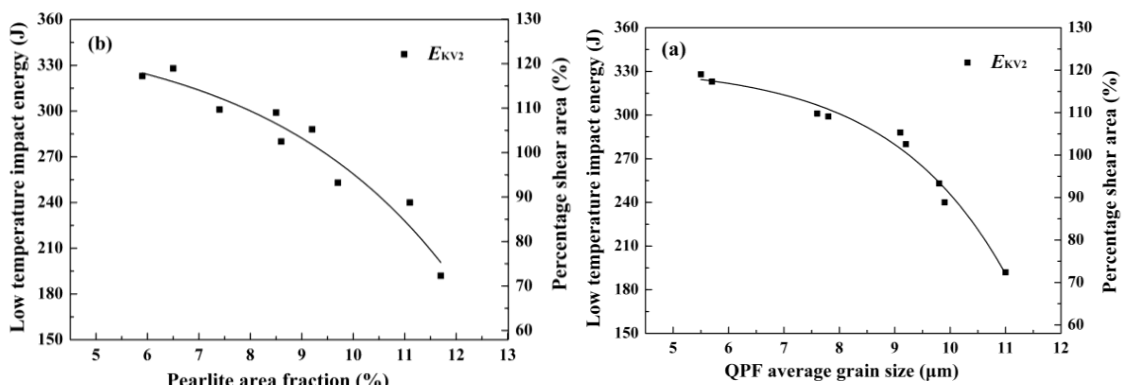


Figure 6. Effects of (a) pearlite area fraction (b) QPF grain size on *E*KV2 (-40°C)

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