The Contribution of Niobium Bearing Steels and Enhanced Sustainability

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Abstract

With the growing concern for the environmental impact of greenhouse gases and the rapid depletion of important resources, the use of Nb-bearing steels for advanced high strength steel applications can reduce raw material usage and the carbon footprint. The conservation and more efficient use of ironmaking and steelmaking raw materials is an urgent issue for steel producers globally. Recently-developed Nb-microalloyed steel applications provide a more effective product design and reduce CO_2 emissions and energy consumption per tonne of steel. A sustainability structural steel study presents the positive cost and reduced environmental impact of Nb-microalloyed steels. This analysis compares the CO_2 emission reduction and energy savings in the steelmaking process melted in both the Basic Oxygen Furnace (BOF) and the Electric Arc Furnace (EAF). Nb-microalloyed structural steels offer the opportunity to reduce the total weight of a given structure compared to non-microalloyed steel construction. The savings are associated with less material and lower construction costs. In addition, there is an environmental benefit in the reduction in emissions (kilograms of CO_2) and less energy consumption (GJ) due to the fact that less steel is melted. Plus, there are lighter sections and less material weight in the final end user design which reduces transportation and fabrication costs. A forecasted trend is presented which introduces an increased usage of microalloyed steel grades to replace traditional commodity-type non-alloyed higher carbon-manganese grades for environmental benefits and significant cost reduction.

Introduction

Environmental sustainability is one of the foremost considerations challenging steel companies around the world. The consumption of fossil fuels and their associated cost for coal, oil and natural gas will continue to be a primary cost driver in the ironmaking and steelmaking process. Certainly, the introduction of new clean steelmaking technologies will pave the way for some of the most environmentally clean steelmaking processes, but the learning and implementation curve will be steep and capital intensive.

A complementary initiative to this crucial clean steelmaking technological development and research activities involves a renewed product metallurgical focus on high strength low alloy (HSLA) product design, development and application. For example, the effort and focus of the automotive and steel producers over the past two decades have resulted in a remarkable reduction in steel weight, emissions and energy consumption by both producers and users. Within the automotive sector, the less weight-lower emissions approach has led the HSLA product development initiatives and implementation for several decades.

Within the pipeline sector, the required performance and cost considerations have driven development of HSLA steels to allow higher operating pressures and gas transmission rates through the development of lighter wall, higher strength steel pipelines. Although the introduction of HSLA into the structural sector is being done, the rate of product development and implementation is significantly slower. There is a compelling need to accelerate the adaptation of the HSLA technology within the structural market with the same intensity that was experienced within the automotive sector in North America and Europe.

A sub-segment of the structural market that involves long products has the potential to significantly further reduce the carbon footprint should more HSLA designed steels be introduced into these products.

Niobium HSLA Background

The benefit of Nb within a variety of HSLA applications for weight reduction purposes is well-established and documented within the automotive, pipeline and structural segments. Approximately 15 to 20 percent weight reductions have been experienced in some automotive, pipeline, offshore platform, heavy equipment, pressure vessel, construction and other structural applications [1, 2, and 3].

These applications translate into fewer raw materials, less emissions and less overall energy consumption. Consequently, the opportunity exists to further reduce the carbon footprint by a slight shift of additional usage from 5 to 10% more HSLA steels. This shift is possible today through the application of Nb-microalloyed structural plate, section and long product steels. Through the application of Nb-microalloyed structural steels, the opportunity exists today to reduce the total weight of a given structure, such as a bridge, compared to a non-microalloyed steel construction design. An example is later presented in this paper.

When one considers this cost effective microalloy approach, the cost savings associated with less material and lower construction costs will translate into lower overall project cost. The additional project cost that did not exist a decade ago in the structural and pipeline sector involves the cost of emissions. The reduction of the carbon footprint through the application of Nb-bearing steels can contribute to the beneficial reduction in CO_2 emissions and energy consumption from the fact that less steel is required to construct the structure.

Steel Producer Environmental vs. Processing Cost Challenges

Minimization of CO_2 emissions and energy usage is one of the primary cost drivers that affect a steel producer’s profitability, performance, competitiveness, and sustainability. Yet, environmental cost is often overlooked in the steelmaking cost calculation. These environmental operational dynamics are more prevalent than ever before in the world of steelmaking. The balance of producing more end-product through the consumption of fewer raw materials is the future of profitable steelmaking.

Activity-Based Cost Steelmaking

The primary cost drivers of steelmaking are typically related to raw materials including alloy cost, BOF/EAF operating cost, natural gas for reheating, hot mill conversion cost, electrical cost and cost of quality associated with cobbles and diverts. The cost of environmental carbon emissions is often not part of these operational cost analyses. Figure 1 illustrates the typical operational cost distribution for a low carbon HSLA structural composition.

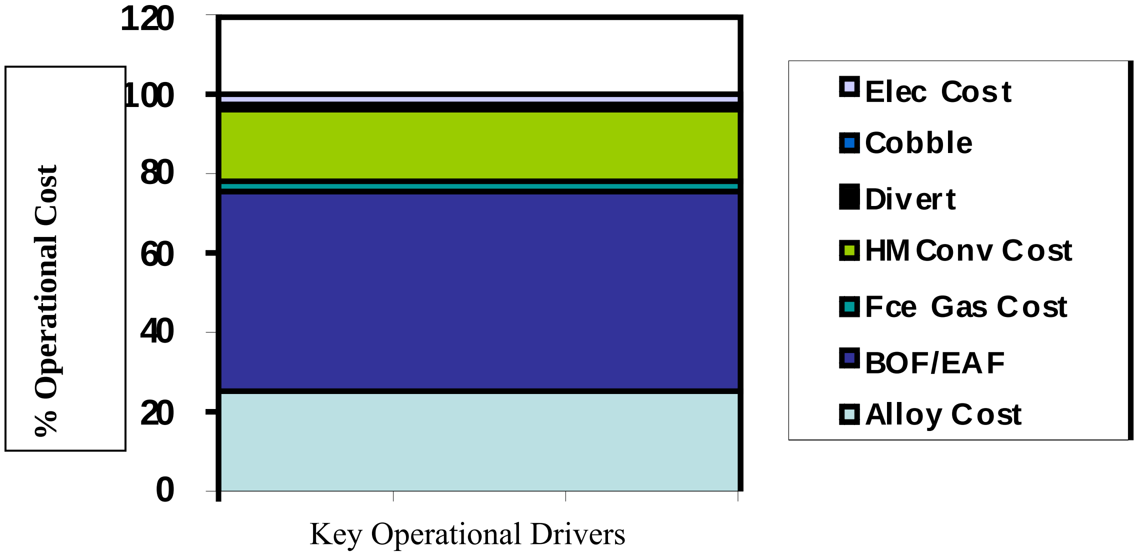

Figure 1. Low carbon HSLA Nb-Cu alloy 500MPA composition with intermediate cooling [4]

In the future steelmaking cost analysis (including a carbon emission cost such as a tax per tonne or a credit on the plus-side) will be included in the cost of carbon emissions. The result will be a re-distribution of costs which will reduce the alloy cost driver by as much as 3 to 5%.

Microalloy Additions Offset Carbon Emissions

The overall energy consumption and quantity of carbon emissions per unit of final product are actually reduced for microalloyed grades compared to non-microalloyed grades at thicker cross sections. With this realization, producers will want to re-examine their product mix and total activity-based operating cost systems to include the cost of carbon emissions.

The entire supply chain from the mine to the final end user will benefit from a switch to higher strength microalloyed steels at reduced weight for a given product. It is conservatively estimated that the efficient replacement of non-microalloyed steels by microalloyed steels offer the potential to reduce global CO_2 emissions and energy consumption by 3 to 6% based on current steelmaking technology [5].

Three trends and recommendations are defined to reduce emissions and energy usage immediately. These areas are: 1) hot roll steel to the low-side of the aim gauge such that thinner steel means more linear footage per hot rolled coil for the end user, 2) acceptance of microalloyed steels that replace traditional thicker C-Mn grades such as ASTM A36, S235 and other non-microalloyed bar and plate steels for commodity-type applications and 3) thorough understanding of the reheat furnace operation, efficiency, carbon emissions and effect on product quality [6].

C-Mn versus C-Mn-Nb Microalloyed Bridge Steel Sustainability Comparison

The application of Nb-microalloyed structural steels offer the opportunity to reduce the total weight of a given structure, such as a bridge, compared to a non-microalloy steel construction. Generally, one considers the cost savings associated with less material and lower construction costs associated with construction which translates into significant cost savings. The intangible benefit is the reduction in emissions and energy consumption from the fact that less steel is produced.

The following study illustrates the significant reduction in emissions (kilograms of CO_2) and energy consumption (gigajoules) comparing a bridge constructed from 10,000 tons of S235 steel versus a 9,000 ton S355 Nb-bearing HSLA steel bridge at 0.03%Nb. The 10% weight savings is a conservative estimate considering bridge design stiffness, specification requirements and design considerations. The results of the analysis are shown in Table I (CO_2 emission reduction) and Table II (GJ savings) compares steel plates and beams melted via the BOF versus the EAF route [7].

Table I. CO_2 Emission Savings - BOF versus EAF

Factor	BOF (kilograms CO_2 per tonne steel	Emission Reduction (x10^4 Kilograms CO_2	EAF (kilograms CO_2 per tonne steel	Emission Reduction (x10^4 Kilograms CO_2
Coke savings	51.1	5.11	0	-
Blast Furnace	1000	100.0	0	-
BOF	244.7	24.47	0	-
EAF	0	-	506.1	50.61
V Degas/Ladle Met	38.6	3.86	70.5	7.05
Cont Cast	19.8	1.98	19.5	1.95
Hot Rolling	188.5	18.85	141.1	14.11
Pickling	77.2	7.72	42.5	4.25
CO_2 Reduced Emissions	-	**161.99**	-	**77.97**
Reduced CO_2 Emissions 1,620 metric tons @ BOF & 780 metric tons @ EAF				

Table II. Energy Savings – BOF versus EAF

Factor	BOF (GJ per tonne of steel)	Energy Reduction ($x10^3$ GJ)	EAF (GJ per tonne of steel)	Energy Reduction ($x10^3$ GJ)
Coke savings	3.89	3.89	0	0
Blast Furnace	12.48	12.48	0	0
BOF	1.02	1.02	0	0
EAF	-	-	6.11	6.11
V Degas/Ladle Met	0.72	0.72	1.25	1.25
Cont Cast	0.34	0.34	0.34	0.34
Hot Rolling	2.67	2.67	4.10	4.10
Pickling	1.40	1.40	0.79	0.79
CO_2 Reduced Emissions	-	**22.52**	-	**12.59**
Reduced Energy Consumption 22,520GJ @ BOF & 12,590GJ @ EAF				

The integrated mills' opportunity to reduce carbon emissions and energy usage is nearly two times higher than the EAF operations. However, this analysis does not consider the carbon emissions generated from the generation of power for the electrodes to melt the 100% scrap charge or the production of direct reduced iron pellets for the EAF. With this in mind, it becomes apparent that the potential carbon savings are significant for both operational routes.

The bridge case study is just one example of the cost and environmental impact resulting from the simple substitution of S235 with S355. Upgrading some critical member sections of the bridge to S460 can result in an additional 3% reduction in emissions and energy consumption.

In 2007, the Intergovernmental Panel on Climate Change (IPCC) forecast significant increases in global temperature by more than 4 degrees Celsius unless global greenhouse gas emissions are reduced. The IPPC has advocated for substantial reductions in annual global greenhouse-gas emissions to at least 50% of present levels by 2050 in order to stabilize the world's climate [8]. The tightening of environmental controls and allowable emissions by regulators has a direct impact on steelmaking operational cost of production.

Structural Application Opportunities

Breakthrough ironmaking technology and various sustainable steelmaking technological development projects are under study throughout the world [9]. Breakthrough technology such as hydrogen-induced reduction processes, coal gasification and natural gas based fine ore processes are in development. Although these processes offer good opportunities to reduce emissions, the time for global commercial acceptance and operational implementation is slow. Therefore, in the short term, simultaneously an alternative approach is suggested through the application of proven Nb-microalloy technology incorporating current mill equipment and operational practices to reduce the carbon footprint today.

Since the carbon structural steel segment is by far the largest global segment in the world and represents well over 60% of total global crude steel production, application of Nb-bearing steels in this sector offers a high potential to reduce the carbon footprint.

Over 10 percent of the 669.9 million metric tonnes of structural plate and long products production in 2009 contained niobium. If one assumes an additional 5% replacement ratio of C-Mn steels with Nb-bearing steels within the sectors of wire rod, merchant bar, reinforcing bar, commodity plate, beams and sections, significant and astounding CO_2 emission reductions result in the billions of tonnes and energy savings in the trillions of GJ can be realized. The calculation is shown below considering BOF steelmaking production.

$$(669.9\text{mmt}) \times (0.05) \times 1620\text{mtCO}_2/\text{mt@BOF} =$$
$$54.27 \times 10^9 \text{ metric tonnes of CO}_2 \text{ eliminated}$$

$$(669.9\text{mmt}) \times (0.05) \times 22{,}520\text{GJ/mt@BOF} =$$
$$0.75 \times 10^{12} \text{ GJ of energy saved}$$

Niobium Low Carbon Low Alloy (LCLA) and MicroNiobium Alloy Approach®

Applications of value-added Nb-bearing steels can reduce the overall material and construction costs for many advanced high strength structural and civil engineering applications. Although there are different civil engineering designs and many diverse product applications in the structural market, the Nb metallurgy and production strategy to manufacture these steels often remain the same. Cross-application of similar niobium microalloy steel grade systems are specified for different end user requirements. Today's structural steel demands properties such as: 1) improved toughness at lower temperature, 2) higher yield strengths for lower cross sectional area of structure, 3) higher elongations, 4) improved weldability to reduce construction time, 5) improved elevated temperature properties, 6) improved fracture toughness, 8) seismic-resistance and 9) improved fatigue resistance.

Cross-application of Nb-bearing steels has resulted in a variety of large-scale structural designs with improved properties for diverse products for beams, bridges, storage tanks and wind tower supports. Currently, the MicroNiobium Alloy Approach for structural steel grades are being developed and implemented into commercial production at an accelerated pace in long products that require improved mechanical properties for more demanding applications such as automotive suspension components, microalloy forgings for power transmission, high carbon rail, bolts, wind tower supports and seismic rebar. There is an increasing end user demand to improve the seismic, fire resistance, toughness, yield-to tensile ratio consistency and/or weldability in construction steels.

Table III. Nb-Bearing Medium and High Carbon End User Steel Application via Micro-Niobium Alloy Approach® and TMCP Approach

Shapes	**Bar**	**Wire Rod**	**Structural Pipe & Tube**	**Rebar**
Power plants	**9259 Spring steels***	**1080 High carbon pre-stressed***	Structural scaffolding	**Seismic resistant***
Trailer support rails	Forging quality	Engineering	Construction	**Fire resistant***
Rails*	**1050 Automotive fasteners***	**Cold headed***	Irrigation and utilities	Bridges
High alloy tool steels*	Carburized gears & shafts	**High strength bolts***	Boiler tubing	Buildings
	Quench & Temper	Wire rope	Utility power plants	**Tunnels***

*** MicroNb Alloy Approach applications**

The global steel market technological advancement known as the Micro-Niobium Alloy Approach may ultimately be applied across all carbon levels to improve product homogeneity during the steelmaking and hot rolling process resulting in improved rollability, finer austenite grain size and less product variation. The concept involves the micro-addition of .005 to .020%Nb across all carbon grades. Product development results indicate that these micro-Nb alloy additions can significantly pin the austenite grain boundary and minimize the heterogeneous abnormal austenite grain growth that occurs in actual reheat furnace mill operations. This micro-approach offsets the austenite grain coarsening that can occur during normal reheat furnace or heat treat furnaces when temperature excursions cause overheating of the steel in normal operation [10]. Of course, in cases where the well accepted TMCP is in place, Nb levels will exceed this .005-.020%Nb range.

Reduced Emissions and Energy Consumption and Cost of Quality

The MicroNiobium Alloy Approach reduces emissions and energy consumption in higher carbon grades of steel. Fewer rejects and lower mmbtu per tonne result in the hot rolling operation of the mill. It is quite typical to overheat steel and/or inconsistently heat steel billets and slabs prior to hot rolling, which leads to rejects, higher energy consumption, more emissions and producing additional steel to remake the rejected portion of the customer order.

Overheating and inhomogeneous heating patterns result in preferential grain growth of the austenite in the reheat furnace. Homogeneous heating and soaking of slabs is vital in order to minimize temperature gradients (ΔT) between the surface and center of the slab and the ΔT from the front end to back end of the slab. Often during the rolling of C/Mn and microalloyed steels, variability of the ΔT from the front end to the tail end and/or high ΔT's from surface to center of the slab, billet or shape translate into variable mechanical properties within a coil, bar or plate regardless of the mode of rolling. In addition to less mechanical property variation, homogeneous heating translates into flatter and straighter hot rolled product (i.e. improved flatness and shape), more uniform and finer austenite grain size, solution of the microalloy carbon nitrides and improved rollability. Depending upon the reheat furnace efficiency and heating schedules, reheat temperatures for medium carbon and high carbon steels should generally range between 1125°C to 1230 °C range. Inefficient reheating is the reason some mills overheat Nb-bearing medium and high carbon slabs, billets and sections at 1230°C, whereas efficient heating can lower the soak temperature well below 1200°C. Generally, this data varies depending on the researcher and should be incorporated into the furnace model with caution. Actual operational experience indicates that over 75% Nb-solubility is achieved at temperatures as much as 25 to 50°C lower and the Nb is effective in pinning the prior austenite grain boundary. Based upon actual operational experience and performance, the following root causes promote the formation of coarse grain austenite in these medium and high carbon steels and increase energy consumption and emissions by as much as 5 to 10%: 1) excessive soak zone temperatures exceeding 1230°C; 2) improper furnace control cutback on operational delays, thereby overheating slabs, resulting in slab/billet sticking and lost production; 3) poor combustion fan efficiency (which directly correlates to surface quality) especially on high carbon sheet production exceeding 0.50%C); 4) same air-to-gas ratios for all steel grades (i.e. low, medium and high carbon steels) and 5) inefficient burner combustion at the orifice and maintenance considerations. Therefore, the role of the MicroNiobium Alloy Approach in the reheat furnace operation provides some processing flexibility, thereby reducing operational cost and cost of quality, in retarding the austenite grain growth due to several of the aforementioned operational and heating issues experienced in actual operating conditions.

Conclusions

Environmental mandates and legislation along with end user demands offer an opportunity for progressive steelmakers to reduce resource consumption and CO_2 emissions while improving cost and profitability through the increased production of Nb-based HSLA steels.

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