Strategic Importance Of Thin-Slab-Casting Technology

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ABSTRACT

Thin-slab technology (CSP} provides two strategic objectives. It allows steelmakers to increase the share of flat products efficiently and economically. It also allows the substitution of high-strength microalloyed steel for commodity carbon steel, contributing to weight reduction and decreasing the demand for steel. The results, beneficial both to steel producers and users, lead to wealth formation.

Key words: Thin-slab technology, microalloys, energy, steel competitiveness, economics of substitution.

STEEL-INDUSTRY OBJECTIVES

Among the strategic objectives for the steel industry in China, two are particularly important. The first is to assure an adequate supply of steel to support the national economic growth of 7% per year. The second is to increase the percentage of flat products produced (including pipes) to between 60 and 70%, typical for developed industrialized countries. Through greater use of microalloyed (MA) steels and the new thin-slab-processing technology, these goals may be achieved.

It is estimated that by 2005, steel consumption in China will surpass 200 million tons. To maintain this economic growth, essential to prevent unemployment, steel supplies must increase by 3 to 5% annually. Increasing steelmaking capacity by 5.4 to 9.0 million tons per year requires a large amount of capital; increases the demand for energy, especially for the blast furnace-basic oxygen furnace (BF-BOF) route; and impairs ecology by increasing CO_2 pollution[1].

THE CONCEPT OF SUBSTITUTION

A desirable scenario is one that satisfies engineering needs with less steel of better quality and higher strength. To make such a substitution both technically and economically attractive, two conditions must be fulfilled. The steel producer must be assured that his profits will not decrease in spite of selling less steel. In addition, the consumer should be offered a stronger and a lighter product at a lower material cost[2].

These benefits can often be obtained when microalloyed (MA) steels replace carbon-manganese (C-Mn) steel[3]. To be competitive both technically and economically, MA steels must meet three requirements: attractive mechanical properties, potential for weight reduction, and low cost. Because of low-carbon content and fine grain structure, microalloyed steels have excellent engineering properties, such as fabricability, weldability, and toughness. They are two to three times stronger than hot-rolled C-Mn steels, and depending on type of loading, may reduce weight by 25 to 50%.

The high yield strength of MA steels (350 to 600 MPa) is the result of an interaction between the microalloying elements (usually niobium or vanadium, singly or in combination) and plastic deformation during hot rolling and subsequent accelerated cooling. The resulting microstructure is characterized by fine ferritic grains and precipitation of microalloying compounds (carbonitrides, nitrides, or carbides). These two strengthening mechanisms may account for up to 70% of yield strength. The microalloying elements responsible for these two mechanisms are added in small amounts (less than 1 kg per ton of steel or 0.1%). This explains the unique cost-effectiveness of MA steels.

The technical and economic viability of this substitution has been demonstrated recently by the internationally sponsored project on Ultra Light Steel Auto Body (ULSAB). By replacing "cheap" C-Mn steel sheets with high-strength, low-alloy (HSLA) steel, the three objectives of the project have been achieved. They are: (a) produce a stronger and safer auto body, compared to best currently produced models, (b) reduce the weight and (c) lower the overall cost.

These results were obtained in a full-scale demonstration project. As a result, HSLA steels (cold-rolled or hot-rolled sheets, predominantly 350 MPa in yield strength) have become the material of choice in the cost-conscious automotive industry[3]. Needless to say, similar opportunities exist in many other industries, such as construction, machine building, and transportation, to name a few.

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ECONOMICS OF SUBSTITUTION

The following simplified calculation illustrates the benefits of substitution for both the steel producer and the steel user. The selling price of carbon-manganese steel, assumed to be $345 per ton, is based on a production cost of $300 and a $45 or 15% profit. The microalloyed steel sells for $420 per ton, based on the same production cost, $30 for the cost of the microalloys, and a $90 or 30% profit. Since microalloyed steel can be twice as strong as carbon-manganese steel, users can reduce steel usage by about 30% and save 15% in costs, as shown in Example 1 in the Annex. The effect of this saving on the steel producer and the steel user is shown below:

LOWER COSTS FOR USERS
(Dollars per Ton of Steel)

Carbon Steel (1 Ton x $345)	$345
Microalloyed Steel (0.7 Ton x $420)	294
Cost Savings	**$ 51**

At the same time, the producer increases his profit by 40%, as shown below:

HIGHER PROFITS FOR STEELMAKERS
(Dollars per Ton of Steel)

	Carbon Steel (1 Ton)	Microalloyed Steel (0.7 Ton)
Selling Price	$345	$294
Microalloying Cost	-0	-21
Other Production Costs	-300	-210
Steelmaker's Profit	**$ 45**	**$ 63**

This "win-win" situation is financed by savings resulting from producing less steel. The economic success of substitution is due to the use of microalloying. This technology therefore contributes to the formation of wealth[4].

In China, this concept of substitution is being practiced on a large scale. Concrete-reinforcing bars represent a large-tonnage item, with production exceeding 20 million tons. At present, China is upgrading rebar from low-strength C-Mn Grade 2 to high-strength Grade 3 (470 MPa yield strength). Microalloying with vanadium and enhanced nitrogen has made these higher strength rebars possible[5].

Work is also in progress on developing an atmospheric corrosion-resistant ("weathering"), high-strength steel to be used in rolling stock on railroads. By reducing the weight of railroad cars, the pay load will be substantially increased**.**

In the United States, carbon steel used in bridge construction is being replaced by HSLA steel (470 MPa yield strength), contributing to both weight and cost reduction.

COST-REDUCING TECHNICAL INNOVATIONS

The cost of microalloyed steel has been further reduced by two innovations in steelmaking technology. During the last decade, the use of electric-arc furnaces (EAF) grew steeply, accounting for almost 40% of worldwide steel production. The reason for this technology expansion is the low capital cost and reduced energy consumption of new facilities compared to traditional blast furnaces and basic-oxygen furnaces, the availability of scrap or scrap substitutes, and the high flexibility of these operations. Today, virtually all long products are made by EAF technology.[6]

Secondly, thin-slab-casting technology drastically changed the economics of producing coiled flat products. The capability of producing a marketable hot-rolled strip, in line without interruption directly from liquid steel, represents a revolutionary cost-reducing step. The importance of thin-slab technology on the economics of steelmaking is similar to two previous developments:

• Replacement of the open-hearth furnace by a converter, which reduced the time for making a 200-ton heat from 6 or 8 hours to about 40 minutes.

• The introduction of continuous casting instead of traditional ingots. This development increased the yield of fully-killed steels by 15% and made semi-killed steels obsolete.

To highlight the significance of thin-slab technology, one may refer to this development as the third revolution in steel making.[7]

METALLURGICAL FEATURES OF THIN-SLAB TECHNOLOGY

In the course of processing steel from the tundish to the coiler, there are several steps of metallurgical significance:[8]

• Rapid solidification of the thin slab (50 to 70 mm compared to conventional thicknesses of 200-250 mm) refines the dendritic structure and contributes to greater homogeneity.

• Non-metallic inclusions are small and globular, retain their shape during hot-rolling and contribute to isotropic properties (toughness, bendability).

• All added microalloying elements remain in solution. Because of the high temperature of the concast slab prior to hot rolling, premature precipitation is avoided.

• To minimize the difficulties of concasting in the peritectic region, the carbon content of many microalloyed steels is restricted to between 0.05% and 0.06%. This restriction benefits toughness and weldability.

• The high temperature of the slab during bending and unbending minimizes the tendency to form transverse cracks.

• The temperature in the equilibrating furnace depends on the microalloying element and is designed to keep the microalloy in solution.

• Direct charging is the main factor that reduces energy consumption during hot rolling.

• In rolling thin slabs, the deformation in the initial passes often exceeds 50%. Heavy deformation at high temperatures is essential to refine coarse (over 1000 μm) austenitic grains by recrystallization.

• The refinement and uniformity of austenitic grains is a prerequisite for a fine ferritic structure down to 4 to 5 μm.

• Accelerated cooling on the run-out table and undercooling of the austenite further refines the ferrite.

The majority of microalloyed steel has a ferritic matrix and uses either niobium (Nb) or vanadium (V) as microalloying additions. These two elements, V and Nb, are not interchangeable and may have different effects on properties and economics.

DIFFERENCES BETWEEN VANADIUM AND NIOBIUM

The important differences between microalloying with Nb and V are as follows:[9]

• The solubility of Nb (C,N) is much lower than of VN so that they tend to precipitate from austenite at a higher temperature.

• The propensity for transverse cracking is much stronger for Nb steels than for V steels. A higher temperature (by about 100°C) must be maintained during slab bending of Nb steels than for V steels.

• Because of the high solubility of VN, a temperature of 1150°C is adequate to dissolve this compound in austenite. For Nb, this temperature is 1200°C, or higher, depending on the nitrogen content of steel.

• VC does not precipitate in austenite and VN may precipitate only in a narrow temperature range below 900°C, provided the supersaturation of V and N is high. For Nb, the precipitate formed in austenite is Nb (C,N), its solubility decreasing with an increase in the nitrogen content in steel. Nitrogen causes an undesirable premature precipitation of Nb in austenite.

• During hot-rolling, V steels refine the grain size of austenite by repeated recrystallization. The hot-rolling start temperature is low (1150°C) and the finishing temperature is high (950-1000°C). In Nb steels, the hot-rolling start temperature is high (1200°C) and the finishing temperature is low (850°C). It is in the temperature region in which austenite does not recrystallize and is flattened (pancaked) by the deformation.

• Because of the high solubility of VN in austenite, almost all the vanadium present in steel is available for the precipitation strengthening of ferrite. Vanadium has a much higher affinity for N than for C. By increasing the N content in steel, the nucleation of VN is enhanced. This increases the dispersion of fine VN (or V (C,N)) particles, reducing the interparticle distance and causing more efficient strengthening by precipitation. Because of this mechanism, N additions allow a reduction of the V addition by 20 to 40%. Nb has a limited capacity for precipitation as NbC in ferrite, so that its role is mainly grain refinement.

ADVANTAGES OF VANADIUM STEELS

Because of the above differences between V and Nb, vanadium steels offer the following technical and economic advantages compared to Nb:[10]

• Vanadium uses two strengthening mechanisms: grain refinement and precipitation hardening.

• Transverse cracking during concasting can be readily prevented by maintaining the bending temperature at about 950°C. For Nb steels, this temperature is about 100°C higher.

• For directly-charged slabs, the coarse as-cast structure can be readily refined by heavy deformation since vanadium does not retard recrystallization.

• Hot rolling is energy-efficient because of low-start and high-finishing temperatures.

• As a nitrogen-binding element, only vanadium has the capacity of (a) neutralizing the negative effect of N in solution by making steel non-aging, and (b) using N as a valuable, cost-effective alloy capable of optimizing the precipitation reaction.

THE DUAL ROLE OF THIN-SLAB CASTING

In China the rapid expansion of thin-slab-casting technology is motivated primarily by the need to increase the share of flat-rolled products. The rising standard of living is accompanied by the growth of appliance and automobile industries, the main consumers of hot- and cold-rolled sheet. At present, the share of flat products in China, including plates and tubular products, amounts to about 30% of the overall product mix. An enormous capital expense is needed to come closer to the benchmark of 70%, typical of highly industrialized countries.

Thin-slab technology provides a most economical way to increase the share of hot bands. The capital investment, energy consumption and flexibility of operations are very favorable, compared to traditional hot-strip-mill processing. These advantages are reflected in the competitive cost of hot-rolled coils. Predictions have been made[6] that mini-mills using EAF and CSP facilities will continue to increase their market share at the expense of high-cost integrated producers.

The second area of growth using thin-slab technology involves high-strength microalloyed steels. CSP is capable of producing strip, 1.2 to 14-15 mm thick in yield strengths ranging from 350 to 600 MPa, offering a low-cost increase in strength.

This is most evident when processing vanadium steels made by EAF steelmaking. The high-nitrogen content of EAF steels (70 to 100 ppm) is an asset for steels microalloyed with vanadium. The precipitation of VN or V (C,N) contributes to both of the main strengthening mechanisms -- grain refinement and precipitation hardening. During continuous casting, edge cracking can be readily avoided, since the temperature at which a drop in ductility commences is about 100^{o} C lower than that in Nb steels. Because of the high solubility of VN in austenite, the slab temperature in the tunnel furnace is relatively low -- 1150^{o}C. Since grain refining takes place through repeated recrystallization, the finishing temperature may be as high as 950-1000^{o}C. These hot-rolling parameters account for low energy requirements both for heating and rolling. Since virtually all vanadium is available for precipitation in ferrite, an increase in strength up to 200 MPa can be obtained. The potential embrittlement due to precipitation is effectively prevented by grain refinement down to 4 to 5 micrometers, thanks to fine grains of austenite and to the lowering of the transformation temperature by accelerated cooling.

The resulting high-strength vanadium steel is an excellent substitute for low-strength carbon steel. Promising applications may include: spirally welded pipe, shipping containers, railroad cars, stampings for machinery, etc. Roll forming of structural shapes offers the means for controlling rigidity by adjusting the geometry of the final product.

The technical and economic advantages resulting from substitution, however, do not guarantee an immediate market acceptance. The experience of the past forty years indicates that the acceptance of microalloyed steels is sluggish and universally used only in a few specific products, like line pipe. It is evident that to realize substitution, new methods of promotion are needed to gain acceptance by customers.

PATH FROM ATTRACTIVE CONCEPT TO COMMERCIAL REALITY

To gain the acceptance of substitution, the methodology used in presenting the advantages of the Ultra Light Steel Auto Body (ULSAB) is instructive and should be duplicated. In addition, the promotion of this substitution should be spearheaded by an alliance of potential beneficiaries. This group includes steel producers, steel users, and suppliers of microalloying elements. Support may also be secured from institutions concerned with energy conservation and organizations involved in protecting the environment.

Several fully documented demonstration projects, illustrating the technical and economic benefits of substitution, should be broadly publicized. Care should be exercised in meeting all the applicable standards and specifications. If necessary, steps should be taken to amend the existing standards. By working closely with the appropriate technical societies and organizations, the engineering manuals should be adjusted to incorporate the specifics of the new material.

The process of changing the habits of consumers and steel users is difficult and time consuming. To overcome these obstacles, a long term strategic plan must be formulated and implemented by all participants of the alliance.

In a recent speech, Chairman of the Board of a major Chinese steel company labeled the development and perfection of microalloyed steels as the most significant metallurgical achievement of the past century.[12] The new century offers the opportunity to derive full benefits from this unique development. The fact that through substitution of microalloyed steel for commodity steel, the profits for the producer are increased and the cost for the consumer reduced, is interpreted as means to wealth creation. The unique "win-win" situation is financed by savings generated by steel tonnage which was not produced. This is made possible through the "miracle" of microalloying, leading to weight reduction without an undue increase in cost.

PROGNOSTICATION

The economic situation in China provides fertile soil for the rapid growth of thin-slab technology. The expansion of flat products will proceed at the lowest possible cost to a level dictated by rising living standards. At the same time, the application of thin-slab technology to produce microalloyed steels, which offer units of strength at the lowest cost, will make the realization of substitution possible. The engineering demands of an expanding economy will be satisfied by less steel of better quality. Through the "miracle" of microalloying, this economic growth will be accompanied by wealth generation.

ANNEXES

1. EFFECT OF YIELD STRENGTH ON WEIGHT REDUCTION

By substituting a stronger microalloyed steel (YS_{MA}) for commodity carbon steel (YS_C), the approximate weight reduction (W_{RED}) is given by the following formula:[11]

$$W_{RED} = 1 - (YS_C : YS_{MA})^{1/2}$$

For example, by applying microalloyed steel that is twice as strong as carbon steel, the approximate weight reduction is:

$$W_{RED} = 1 - 0.5^{1/2} = 1 - 0.7 = 0.3 \text{ or } 30\%$$

2. ENERGY CONSUMPTION FOR PRODUCING AND PROCESSING STEEL[1]

Million Btu per Ton of Steel

a. **Steelmaking**	
Blast Furnace and Converter	3.0
Electric-Arc Furnace	5.2 to 5.6
b. **Casting**	
Ingots	2.8
Continuous Casting	0.3
c. **Slab Heating**	
Cold Charge	1.4 to 1.8
CSP Tunnel Furnace	0.5 to 0.8
d. **Hot Rolling**	0.6 to 1.2

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