1. Introduction

Structural steel is known worldwide as a solution for important challenges faced in the construction of buildings. To achieve higher economic efficiency, there is strong demand to build faster while lowering energy and raw material consumption. Due to this reality, structural steels are increasingly being applied in modern construction.

Among steel families, microalloyed steels are the solution for designing leaner structures. Advances in metallurgy involving microalloying and thermomechanical control processes over recent decades have led to steel grades with higher strength and improved overall attributes for structural applications that provide a superior answer to current challenges. Microalloyed structural steels are being employed in building construction, resulting in leaner...
structures and faster construction with lower raw material demands.

High strength microalloyed steels are steels whose properties have been modified by adding a small amount of an alloying element (usually less than 0.1%). Niobium is the solution when both increased strength and improved toughness are required. The economic benefits associated with using such small additions that confer significant improvements to mechanical properties have led to the growing popularity of microalloyed steels in the market.

This paper presents an actual case of 22% savings in total steel consumption with an optimized engineering solution for CBMM new sintering plant in Araxá, Minas Gerais, Brazil, using niobium steel technology for the structural beams and shapes.

1.1 Strengthening Mechanism of Niobium Microalloying

Niobium effectively controls the microstructure of steel and small amounts of this element can refine the grain size of rolled products. The effects of niobium as a microalloying element are schematically illustrated in Fig. 1\(^1\) for reheating temperatures up to 1,200°C.

1.2 Achieving Higher Strength

Fine grain size is an essential requirement for steels to obtain strength and toughness properties. Fig. 2\(^2\) shows the strong effect that grain size (d) has on mechanical yield strength (\(\sigma_y\)) in carbon-manganese steels.

Reducing grain size generates a robust increase in strength for all carbon contents considered. This is even stronger with niobium microalloying due to its effect of preventing recrystallization during controlled rolling. In addition, niobium precipitates as very fine particles, further contributing to increased strength.

1.3 High Strength and Increased Toughness Simultaneously

A study of ASTM 992 beam (S355) based on industrial heats led to the commercialization of low-carbon niobium-bearing beam in place of a vanadium-bearing beam\(^3\). The addition of niobium refines the grain and improves toughness.

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Fig. 1  Niobium precipitation at each stage of heating, rolling and cooling and its effect on refining ferrite grains and precipitation hardening\(^4\)

Fig. 2  Relationship between grain size and yield strength\(^5\)
High Strength Steel as a Solution for the Lean Design of Industrial Buildings

Near-net-shape cast structural beams containing niobium microalloy exhibit double the impact strength at room temperature compared to a vanadium microalloy system at similar carbon, sulfur, phosphorous, and nitrogen levels and cooling rates as illustrated in Fig. 3.

2. Objective

This paper presents the case of an industrial building at CBMM’s plant in Araxà, Brazil, as an example of lean design using microalloyed steels. The structure was made mostly with microalloyed ASTM A572 steel instead of the traditional carbon ASTM A36 steel. The objective is to show the advantages of using niobium microalloyed steel instead of carbon-manganese grades for lean structures.

3. Building Description

The sinter plant building, known as Sinter Plant II, is part of a project to increase production of CBMM’s plant to 150,000 tonnes annually. The structure was fabricated and built in 10 months in 2011 by CODEME, a leading Brazilian construction company specialized in steel structures.

Sinter Plant II houses a Dwight Lloyd type sintering machine that produces niobium oxide sinter. The equipment installed in the building includes raw material bins and machinery for size classification and crushing. The production process requires an intense daily flow of materials on vertical and horizontal levels. As a result of the process performed at Sinter Plant II, niobium oxide sinter is delivered internally in the correct composition and particle size to manufacture niobium final products.

A building 28.5 meters tall, 55 meters long and 15 meters wide was necessary to house the equipment for a production flow with vertical and horizontal processes.

3.1 Building Evolution

Sinter Plant II is a structural steel building composed of hot-rolled beams, plates and welded shapes made of ASTM A572 Grade 50 microalloyed steel, and hot-rolled shapes made of ASTM A36 carbon steel.

Fig. 4 shows some of the steps in the building’s construction. Sinter Plant II began operations in August 2011.

The steel shapes and types used to build Sinter Plant II are presented in Fig. 5. The gray tonality depicts different steel grades and different shapes. The amount of each steel shape and type used to build the entire structure is also listed.
4. Materials and Methods

4.1 Shapes and Grades

Table 1 shows the ASTM specifications for niobium microalloyed steels used in the project as compared to the less efficient carbon manganese steel, ASTM A36.

4.2 Metallurgic and Mechanical Tests

To demonstrate and compare the characteristics of niobium microalloyed steel and regular carbon manganese steel, hot-rolled samples of both steels were evaluated in different tests. The test results are as presented.

4.2.1 Stress-strain tests

A conclusive number of tests were performed for both steel types according to the ASTM A370 standard. Fig. 6 presents an example of the stress-strain curves and results for yield and tensile points.

The results show the superior properties of niobium microalloyed steels in terms of yield strength and tensile strength. Results show that both materials follow their specified ASTM standard. It is also interesting to compare the area under both graphs. The larger the area, the tougher the material and the higher its capacity to absorb energy before fracturing.

4.2.2 Impact tests

Charpy impact tests were performed according to ASTM A370 and ASTM E23 at room temperature (26°C) to evaluate the toughness of both steel types. Table 2 presents the results.

The better toughness results presented by niobium microalloyed steel (ASTM A572 Gr. 50) are consistent with the stress-strain curves and will be discussed in terms of microstructures below.

4.2.3 Microstructure analyses

In order to show the differences in steel microstructure, samples of ASTM A572 and A36 were analyzed. Fig. 7 presents the results of the micrographic analysis.

The lower grain size obtained in ASTM A572 Gr. 50 steel by niobium microalloying and proper thermomechanical process are the main reasons for the superior mechanical properties of this material, as presented above.

4.3 Building Design and Comparison between ASTM A572 and A36

To evaluate the benefits of using microalloyed steels, the same building has been re-designed using only ASTM A36. This paper evaluates the two different steel projects:

Project A: actual building with a high strength steel structure (niobium microalloyed steel, ASTM A572 Gr. 50).

Project B: hypothetical building with a regular carbon manganese steel structure (lower strength steel, ASTM A36).

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### Table 1  ASTM standard specifications

<table>
<thead>
<tr>
<th>Standard Designation</th>
<th>Application</th>
<th>Yield Strength (MPa)</th>
<th>Tensile Strength (MPa)</th>
<th>Elongation (%)</th>
<th>Chemical composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A 572 Gr. 50</td>
<td>Welded shapes</td>
<td>&gt; 345</td>
<td>&gt; 450</td>
<td>&gt; 21</td>
<td>C: &lt; 0.23, Mn: 0.45-1.35, Si: &lt; 0.40, P: &lt; 0.04, S: &lt; 0.05, Nb: 0.005-0.05</td>
</tr>
<tr>
<td>ASTM A 572 Gr. 50</td>
<td>Hot-rolled Shapes</td>
<td>&gt; 345</td>
<td>&gt; 450</td>
<td>&gt; 18</td>
<td>C: &lt; 0.23, Mn: 0.45-1.35, Si: &lt; 0.40, P: &lt; 0.04, S: &lt; 0.05, Nb: 0.005-0.05</td>
</tr>
<tr>
<td>ASTM A36</td>
<td>Welded shapes</td>
<td>&gt; 250</td>
<td>400-550</td>
<td>&gt; 20</td>
<td>C: &lt; 0.25, Mn: 0.8-1.20, Si: 0.15-0.40, P: &lt; 0.04, S: &lt; 0.05, Nb: —</td>
</tr>
<tr>
<td>ASTM A36</td>
<td>Hot-rolled Shapes</td>
<td>&gt; 250</td>
<td>400-550</td>
<td>&gt; 20</td>
<td>C: &lt; 0.26, Mn: —, Si: &lt; 0.4, P: &lt; 0.04, S: &lt; 0.05, Nb: —</td>
</tr>
</tbody>
</table>

---

### Table 2  Absorbed energy to fracture in Charpy test

<table>
<thead>
<tr>
<th>Samples</th>
<th>ASTM A572 Gr.50 Toughness (J)</th>
<th>ASTM A36 Toughness (J)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st test</td>
<td>179 ± 2</td>
<td>105 ± 2</td>
</tr>
<tr>
<td>2nd test</td>
<td>155 ± 2</td>
<td>111 ± 2</td>
</tr>
<tr>
<td>3rd test</td>
<td>169 ± 2</td>
<td>108 ± 2</td>
</tr>
<tr>
<td>Average result</td>
<td>168</td>
<td>108</td>
</tr>
</tbody>
</table>
4.4 Calculation Method

Calculation standards and all requirements in terms of applied load, internal building area, volume, span, height, length and width were kept exactly the same in both projects. It was considered that hot-rolled beams, plates and welded shapes of regular carbon manganese steel ASTM A36 would be applied in Project B.

The standard limits of yield strength, tensile strength, elongation and chemical composition for regular carbon manganese steel in both shapes of ASTM A36 presented in Table 1 were taken as the basis to calculate the building with a regular carbon manganese steel structure.

In Project B (hypothetical building), each element of the building was calculated with the ASTM A36 standard yield strength to support exactly the same load as in Project A (actual building).

A calculation example is shown in Fig. 8 and demonstrates how the new dimensions of each building’s elements were obtained considering the hypothetical use of ASTM A36.

Based on each element’s new dimensions and weight and their assembly, it was possible to show the differences between the two projects.

![Fig. 8 Calculation example](image)

Sample:
- Nb microalloyed steel ASTM A572 Gr. 50
- Hot-rolled - 12 mm thickness

Microstructure:
- Reagent Nital 2%
- Magnification of 200x
- Ferrite matrix with presence of oriented Pearlite

Grain size:
- ASTM n. 7.5, equivalent approximately to 26 μm of grain average diameter.

Sample:
- C Mn steel ASTM A36
- Hot-rolled - 12 mm thickness

Microstructure:
- Reagent Nital 2%
- Magnification of 200x
- Ferrite matrix with discrete presence of Pearlite

Grain size:
- ASTM n. 6, equivalent approximately to 45 μm of grain average diameter.

![Fig. 7 Micrographic analysis](image)

Where HSS is high-strength steel and LSS is low-strength steel.

Sample:
- Nb microalloyed steel ASTM A572 Gr. 50
- Hot-rolled - 12 mm thickness

Microstructure:
- Reagent Nital 2%
- Magnification of 200x
- Ferrite matrix with presence of oriented Pearlite

Grain size:
- ASTM n. 7.5, equivalent approximately to 26 μm of grain average diameter.

Sample:
- C Mn steel ASTM A36
- Hot-rolled - 12 mm thickness

Microstructure:
- Reagent Nital 2%
- Magnification of 200x
- Ferrite matrix with discrete presence of Pearlite

Grain size:
- ASTM n. 6, equivalent approximately to 45 μm of grain average diameter.

![Fig. 7 Micrographic analysis](image)

![Fig. 9 Comparison of the size of steel shapes made of regular carbon manganese steel versus high strength microalloyed steel](image)
5. Results

5.1. Dimensions

The hypothetical building (Project B) used regular carbon manganese steel. Due to reduced mechanical strength, the majority of the building’s elements, like beams and columns, had an increased size and transversal section area compared to the high strength steel building (Project A).

Fig. 9 shows in accurate scale a comparison of superimposed shapes from the high strength steel building and the regular carbon manganese steel building. The superimposed shapes are able to resist exactly the same applied load.

5.2. Weight

Table 3 shows the weight reduction in each type of structural element used in the existing building (Project A) compared to the carbon steel hypothetical building (Project B) while Table 4 shows a comparison of the total weight of elements applied in both projects.

By using high strength niobium microalloyed steel instead of regular carbon manganese steel to build Sinter Plant II, 22% less steel was used, representing an economy of 78.7 tonnes of steel.

6. Conclusions

This paper illustrates the benefits of using high strength niobium microalloyed steel instead of regular carbon manganese steel for the construction of an industrial building to house CBMM’S Sinter Plant II in Araxá, Brazil.

Metallurgical and mechanical tests demonstrated the significant improvements in steel properties reached by the lower grain size diameter achieved by niobium microalloying: yield strength increased by 39%; tensile strength increased by 23%; and toughness increased by 55%. The effect of niobium increasing strength and toughness simultaneously allowed a 22% savings in total steel consumption of this project.

<table>
<thead>
<tr>
<th>Shape</th>
<th>Linear weight (kg/m)</th>
<th>Project A</th>
<th>Wear</th>
<th>Step</th>
<th>Project B</th>
<th>Linear weight (kg/m)</th>
<th>Shape</th>
<th>Wear</th>
<th>Step</th>
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<td>155.0</td>
<td>Column</td>
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<td>38.5</td>
<td>Column</td>
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<td>800x350/350x350</td>
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<td>100x400/400x19.0</td>
<td>203.9</td>
<td>Column</td>
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<td>Column</td>
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<td>800x350/350x350</td>
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<td>Beam</td>
<td>8</td>
<td>W200x19.3</td>
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<td>Beam</td>
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</tbody>
</table>
| 600x300/300x16.0/16.0x8.00 | 111.0 | 800x250/250x19.00/19.00x8.00 | 122.4 | Beam for crane rolling

while Table 4 shows a comparison of the total weight of elements applied in both projects.
### Table 4  Steel consumption comparison - high strength steel versus regular carbon manganese steel

<table>
<thead>
<tr>
<th>Shape type</th>
<th>Project A</th>
<th>Project B</th>
<th>Difference (kg) B - A</th>
<th>Difference (%) Reduction in consumption adopting Project A</th>
</tr>
</thead>
<tbody>
<tr>
<td>H type - welded shapes</td>
<td>156.809</td>
<td>210.633</td>
<td>53.824</td>
<td>26</td>
</tr>
<tr>
<td>H type - hot-rolled beams</td>
<td>104.282</td>
<td>129.255</td>
<td>24.973</td>
<td>19</td>
</tr>
<tr>
<td>L type - hot-rolled beams</td>
<td>22.614</td>
<td>22.614</td>
<td>—</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>283.705</strong></td>
<td><strong>362.502</strong></td>
<td><strong>78.797</strong></td>
<td><strong>22</strong></td>
</tr>
</tbody>
</table>

### REFERENCES