GERDAU OURO BRANCO INDUSTRIAL EXPERIENCE WITH ULTRA LOW NIOBIUM STRUCTURAL STEELS*

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Abstract

The partial replacement of manganese by niobium in structural low carbon steels has been extensively studied for several years and by different plants around the world, having shown good results in terms of cost, speeding up liquid steel refining processes and reducing carbon footprint. In the past, Gerdau Ouro Branco carried out successful trials with this new alloy design and adopted it for some steel grades. In this work, an analysis is made of the first results of the routine production of coils in the Steckel rolling mill using this alloy design, and a comparison is made with a conventional carbon-manganese steel.

Keywords: Ultra Low Niobium Steel; Structural Steel; Microstructural Evolution; Mechanical Properties.

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1 INTRODUCTION

The partial replacement of manganese by niobium in hot rolled low carbon structural steels, firstly proposed by Morozov [1], was extensively investigated in the last years [2-7], both in laboratory scale and industrial trials. It was successfully confirmed that 0.010% Nb can replace from 0.30 to 0.40% Mn in hot rolled structural steels. This approach has not impaired the mechanical properties in the final product and, additionally, reduced its microstructural banding and improved its inclusionary cleanness. The reduction of alloy content also decreased the footprint associated with ferroalloys and the carbon equivalent of the new steel, potentially increasing its weldability. The reduction in alloy content also implied in a smaller volume of ferroalloys to be added to the heat, which also provided several advantages from the point of view of liquid steel primary and secondary refining [8], resulting in additional economic and environmental advantages.

It is interesting to note that the ASTM 1011 standard specifies equivalent structural grades of hot strips, which can be produced with both plain CMn (Structural Steel, SS) and microalloyed steel (High Strength Low Alloy Steel, HSLAS) alloy designs, with it being up to the mill or the customer to decide which alloy design they wish to adopt.

Gerdau Ouro Branco [5] successfully tested the new alloy design in the production of hot coils meeting the mechanical properties requirements specified in the ASTM A36 standard. It was verified that an average addition of 0.010% Nb to a base alloy with an average chemical composition of 0.15% C and 0.45% Mn used in the Steckel rolling of hot coils with 3.0 mm gauge improved mechanical properties, promoting an increase of 101 and 36 MPa in yield and tensile strength respectively, which was attributed to a ferrite grain size refining from 7.7 to 5.5 μm due to the action of niobium. Similar improvements were got in heavier strips, including increase in energy absorbed in Charpy impact test results, which could not be measured in the case of the 3.0 mm hot coils due to its reduced gauge.

The good performance of the product during these trials encouraged Gerdau Ouro Branco to routinely produce hot coils of structural steel grades with higher strength using ultra-low additions of niobium instead of higher manganese content. The objective of this work was to verify whether the benefits achieved in preliminary trials were confirmed during the routine production of hot rolled coils on an industrial scale.

2 DEVELOPMENT

2.1 Experimental Procedure

The products selected for this analysis were two grades of hot coils rolled at the Steckel mill for use in building construction applications, designated by acronyms **SG300** and **SG350**. The first one is a plain carbon-manganese steel, while the other includes an ultra-low niobium addition. The specified chemical compositions for both steels can be seen in Table 1.

Table 1. Nominal chemical composition ranges of the steels studied in this work.

Alloy	C	Mn	Nb
SG300	0.14-0.18	0.80-1.00	-
SG350	0.14-0.18	0.80-1.00	0.006-0.016%

The specified mechanical properties for these steels can be seen in Table 2. According to the ASTM A1011 standard, the SG300 steel is very similar to the Grade 45 Type 2 structural plain carbon-manganese steel, whose specified mechanical properties ranges are 310-410 MPa for yield strength, 410 MPa minimum for tensile strength and 20% for elongation. For its turn, the SG350 steel is very similar to the Grade 50 Class 1 high strength low alloy steel, with a minimum content of 0.005% Nb, whose mechanical properties ranges are 340 MPa minimum for yield strength, 450 MPa minimum for tensile strength and 22% minimum for elongation.

Table 2. Nominal mechanical properties ranges for the SG300 and SG350 steels studied in this work.

Alloy	Yield Strength [MPa]	Tensile Strength [MPa]	Elongation [%]
SG300	≥ 300	≥400	≥ 20
SG350	≥ 350	≥450	≥ 20

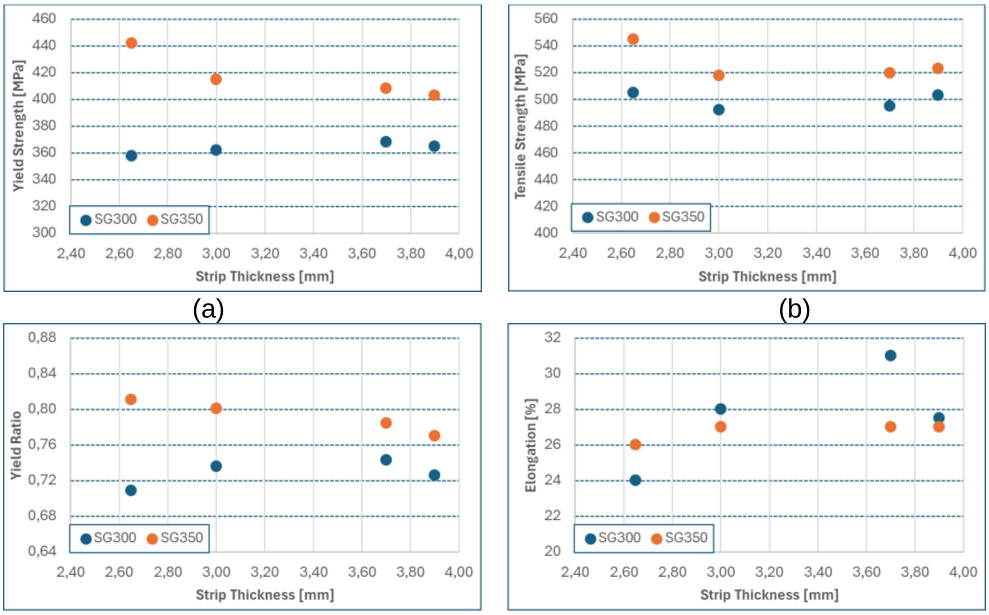
These steels were conventionally rolled at the Steckel Mill using the same process parameters, i.e., no TMCP was adopted. As niobium and carbon contents are low, the dissolution temperature of the niobium carbonitrides ranges between 1060°C and 1080°C according to Pickering [9], lower than the usual slab discharge temperature used in carbon-manganese steels. A holding step was included between roughing and finishing for all grades, with the intent to start the finish rolling in an adequate temperature to reach the specified final rolling temperature range, which is in the austenitic field. After rolling was completed, the strips were water cooled in the run-out table and coiled at the same aimed temperature. The hot band strips had nominal final thicknesses of 2.65, 3.00, 3.70 and 3.90 mm.

After coil cooling, samples were extracted from the tail of the strips in order to determine their mechanical properties through tensile tests. Specimens were machined in the transversal direction of the rolled strips. Data from a total of 254 hot coils were analyzed.

In addition, austenite conditioning and microstructural evolution that occurred during the rolling of a standard 3.0 mm hot coil were calculated using MicroSim software, which was developed by Centro de Estudios e Investigaciones Técnicas de Gipuzkoa – CEIT, Spain, under the sponsorship of the Companhia Brasileira de Metalurgia e Mineração – CBMM [10]. This was done to metallurgically explain the correlations between the final properties obtained in coils and the hot rolling parameters adopted for their production.

2.2 Results and Discussion

Mechanical properties specified for the SG300 and SG350 steels were satisfied for all coil thicknesses. Figure 1 shows the mechanical properties got in the hot coils of these steels in function of their final thicknesses. It can be seen in Figure 1a that the values of yield strength for the SG350 steel showed some decrease as coil thickness increased, while the corresponding values for SG300 were almost constant. Although the difference in coil thickness values was not so great, in principle, this could be attributed to a reduction in the grain refining effect as the thickness of the hot coil increases - that is, as the total reduction in thickness between slab and strip decreases. Grain refining effect is a more important hardening mechanism for niobium steels (through the so-called Hall-Petch effect) than for plain carbon-manganese steels, whose hardening mechanisms include solid solution and a higher fraction of pearlite in the microstructure. This trend was also observed in the former study developed at Gerdau Ouro Branco [5].



(a) (b)

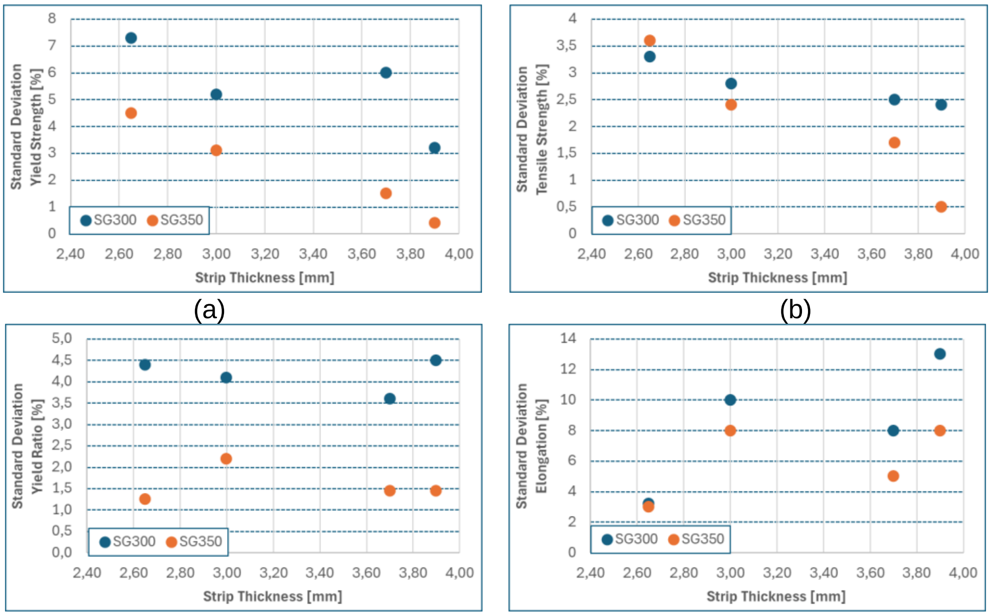
(c) (d)

Figure 1: Mechanical properties measured from the coils of SG300 and SG350 studied in this work in function of its thickness: (a) yield strength, (b) tensile strength, (c) yield ratio, (d) elongation.

This trend was not completely observed in the case of tensile strength, as one can see in Figure 1b: the difference in the values of this property between the steels SG300 and SG350 was almost constant. As expected, Figure 1c shows that yield ratio values were higher for the SG350 steel than for the SG300 steel. Once again, this fact can be associated with the finer grain size of the niobium microalloyed steel, a hardening mechanism that affects more yield strength than tensile strength, as found before [5]. It was expected that SG350 steel would present lower elongation values, as it has slightly higher mechanical strength, but Figure 1d shows that this did not always occur.

Figure 2 shows the percentage standard deviation associated with the average mechanical property values of hot coils of SG300 and SG350 steels shown in Figure 1. The global values of this statistical parameter increased in the following order: tensile strength, yield ratio, yield strength and elongation. It can be observed that, in almost all cases analyzed, yield strength (Figure 2a) and tensile strength (Figure 2b) limits showed a decreasing percentage standard deviation as the thickness of the hot coil increased within the range studied here. The other percentage standar deviation associated with yield ratio (Figure 2c) and elongation (Figure 2d) did not show a clear relationship with the thickness of the hot coil. SG350 steel presented the lowest percentage standard deviation value for all mechanical properties, apparently signaling that the rolling process of this steel has greater statistical capability than that of SG300 steel.

Figure 3 shows the evolution of some austenite microstructural parameters during Steckel rolling of the 3.0 mm coil, as calculated by MicroSim software [10]. They are: mean grain size, Dc_{10} parameter (which evaluates microstructure homogeneity, its value indicates that 10% of the grains are coarser than itself), accumulated strain (austenite strain hardening, a measure for dislocation density) and distribution of grain size immediately after rolling.



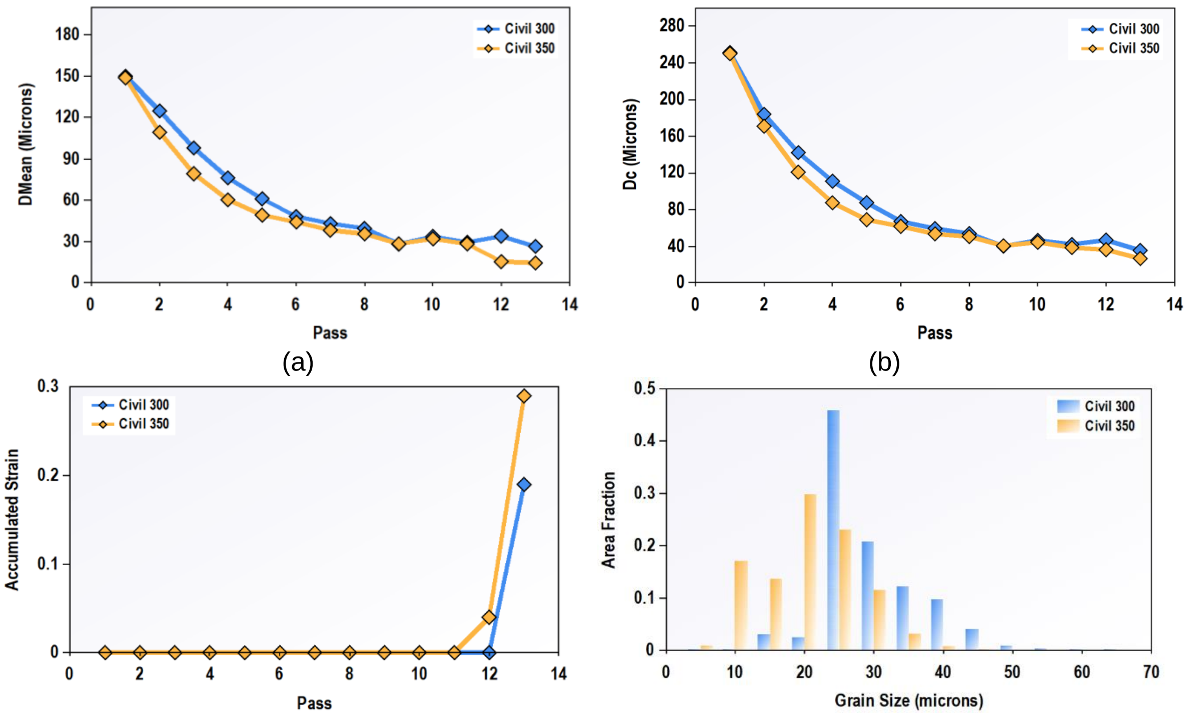
(a) (b)

(c) (d)

Figure 2: Percentual standard deviation of mechanical properties measured from the SG300 and SG350 steel strips studied in this work in function of its thickness: (a) yield strength, (b) tensile strength, (c) yield ratio, (d) elongation.

MicroSim predictions showed that there was no or very little precipitation of Nb(CN) at all during rolling of the strips; so, the effects of niobium over austenite recrystallization and grain growth occurred exclusively due to solute drag. It can be seen that the evolutions of these parameters between both steels, independently of strip thickness, were very similar, showing that the partial replacement of manganese by niobium did not significantly influence austenite conditioning. Both steels only showed a low austenite strain hardening after the last pass due to partial recrystallization, when rolling has already finished. As there was no precipitation of niobium during rolling, it can precipitate during the slow cooling of the hot coil, provided the coiling temperature is suitable for this.

Table 3 shows the mean values of some austenite microstructural parameters immediately after the end of Steckel rolling. These values confirmed the microstructural evolutions shown in Figure 3. As expected, mean austenite grain size was more refined for the SG350 steel, as also shown in Figure 3a. The final austenite grain size distribution, Figure 3(d), confirms this fact, as a higher fraction of austenite grains of the SG350 steel had size below 20 μm, while most of the austenite grains of the SG300 steel had size above 30 μm and a greater maximum grain size. The finer austenite grain size of the SG300 steel, plus its somewhat higher accumulated strain (i.e., strain hardening), indicates that ferrite nucleation will be intensified during transformation, assuring the formation of a fine final grain size. SG300 steel also showed a higher value of the Dc_{10} parameter, indicating that its austenite grain size distribution is less uniform than that of the microalloyed SG350 steel. This conclusion can be visually confirmed by the observation of Figure 3d. This could be a problem if minimum toughness requirements had to be met, but that is not the case here.



(a) (b)

(c) (d)

Figure 3: Evolution of mean grain sizes, Dc_{10} parameter, accumulated strain of austenite and final distribution of grain sizes during the Steckel rolling of the 3.0 mm strips of SG300 and SG350 steels studied in this work, as calculated by the MicroSim software.

Table 3. Final austenite microstructural features immediately after Steckel rolling, as calculated by the MicroSim software.

Alloy	**Mean Grain Size [µm]**	**Maximum Grain Size [µm]**	**Dc_{10} [µm]**	**Accumulated Strain**
SG300	26.4	64.8	35.3	0.19
SG350	14.4	44.8	26.4	0.29

3 CONCLUSION

The mechanical property results obtained in this analysis about the industrial rolling of hot coils of structural steels with ultra-low niobium content instead of the plain carbon-manganese alternative alloy design confirmed the findings previously obtained, not only in trials previously carried out at Gerdau Ouro Branco, but also in other steelworks all over the world. Besides that, there is evidence that the capability of the Steckel rolling process was improved due to the use of niobium steel. This additional confirmation of the good performance of structural steels with ultra-low niobium content is expected to definitively consolidate this alloy design and expand it to other applications.

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