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MicroNiobium-Low Manganese Steelmaking Approach at Gerdau Ouro Branco

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ABSTRACT

Recent steelmaking and hot rolling developments at Gerdau Ouro Branco evaluated the cost reduction, operational enhancements, and metallurgical property improvements through the application of MicroNiobium and reduced manganese additions for light, medium and heavy gauge structural steels. Industrial heats have been analyzed and successfully melted steel grades with as much as a 0.45% reduction in manganese content with a MicroNiobium replacement addition of .005 to .015% for structural hot coils meeting the mechanical property requirements in ASTM A36. The result promotes reduction in costs related to raw material alloying in the steelmaking process as well as cost reductions in steel refining. Beyond that, there was a reduction in internal manganese sulfide, lower centerline segregation, and less microstructural banding in the hot rolled slabs yielding a more homogeneous microstructure.

INTRODUCTION

The structural steel market is increasingly demanding higher strength steels, with yield strength increasing from 235 to 355 MPa, to reduce the weight of structures and, in turn, decreasing its footprint and construction costs. The more intuitive and cheaper way to achieve a such increase in mechanical strength is to use a higher content of carbon. However, its content is restricted to a maximum of 0.20% in many specifications, as carbon is deleterious to ductility, toughness, and weldability[1]. The next element of choice is manganese, as it provides an economical increase in mechanical strength due to various hardening mechanisms it promotes, such as solid solution, increase in pearlite fraction in the microstructure, and a discrete grain size refinement, since it reduces the temperature of the transformation of austenite into ferrite (Ar_3).

On the other hand, the use of manganese brings some inconveniences. When its content is above 0.8%, tapping temperature must increase in order to adequately melt a higher amount of ferromanganese, which brings several problems, such as greater wear in the refractory lining in the BOF/EAF furnace and in the ladle; a decrease of metallic yield; higher consumption of aluminum as deoxidizer; and increase in the contents of undesirable residuals like phosphorus, sulfur, hydrogen, and nitrogen amounts. Such problems can be minimized using a ladle furnace, but the operation of this reactor demands high amounts of electric energy, which significantly increase the process cost[2]. Manganese also tends to intensely segregate in the core of the slabs during its continuous casting, which can affect the performance of the finished product due to the massive formation of MnS inclusions in this location[3]. Other inconveniences are the increase in the degree of banding of the product microstructure and the reduction in weldability due to the higher value of carbon equivalent. The literature reports successful early experiences involving the reduction of manganese content in structural steels with the objective of minimizing costs and avoiding the aforementioned problems[4,5]. More recently, even the advantage of lower cost of manganese is diminishing due to an increase in its use, due to the increase of manganese contents in structural steels, as well as the advent of AHSS steels with very high content of manganese, and its use in batteries for electric cars[6].

The price hike of manganese encouraged the development of new structural steels where manganese is partially replaced by other alloy elements, which have lower and more stable prices over time, such as niobium, which, moreover, can be used at contents down to one hundred times lower than manganese. So, niobium, traditionally used in special applications and sophisticated steels, can also provide cost reduction benefits in commodity steels, without the need to modify the rolling processes or use controlled rolling.

The proposal for partial replacement of manganese by niobium in structural steels is not exactly new[7]. According to this reference, a 0.30-0.40% reduction in the manganese content could be compensated by an addition of 0.010% niobium while maintaining similar yield strengths. In turn, to keep the tensile strength constant, the corresponding reduction in manganese content could be from 0.10 to 0.20%. More recently this alloy design approach, here designed as ULNb steel, was studied with more detail for several hot rolled structural products produced in industrial scale[8-10], confirming the early findings described in[7]. It is important to note that such steels are hot rolled using the same process parameters of the conventional CMn steel – in other words, no Thermomechanically Controlled Processing (TMCP) is performed.

An additional advantage of this alloy design lies in the fact that the niobium content used to partially replace manganese is much lower than the correspondent content of this element, whose effect on hot strength of austenite is significant[11-13]. Therefore, the overall contribution of alloy elements to the solid solution hardening of austenite during rolling decreases. Furthermore, the niobium content in ULNb steels is too small to precipitate or even significantly delay austenite recrystallization during hot rolling. Consequently, the proposed alloy design have a slightly lower hot strength, which is reflected in lower hot rolling loads.

Another particularly important feature to be considered when processing ULNb steels is its lower carbon footprint as compared with conventional alloy designs with higher manganese contents[1,8]. The Global Warming Potential (GWP, for a time horizon of one hundred years) was calculated for CMn and ULNb structural steels. The ULNb steels allowed an average reduction of 34 kg of CO_2 equivalent per ton of product when compared with the CMn alloy design, a significant bonus considering the pressure being put on the steel industry to reduce its carbon footprint[8]. Considering that a typical passenger car emits about 4.6 tons of CO_2 per year (or 12.60 kg per day), the reduction in the CO_2 footprint due to the partial replacement of manganese by niobium compensates 2.7 days of car use for each rolled ton of steel[14].

DEVELOPMENT

Gerdau Ouro Branco trialed the Microniobium-Low Manganese (ULNb) alloy design in the production of hot band coils at the Steckel Mill, meeting the specifications of the ASTM A36 standard[15]. In order to check the ability of niobium to partially replace manganese, a study involving three steel grades was proposed: 1) low manganese (LowMn), 2) higher manganese (HiMn), and 3) low manganese with niobium (ULNb) . The nominal chemical composition ranges for these steels is shown in Table 1.

Table 1. Nominal Chemical Composition Ranges of the Steels Studied in This Work

Alloy	C [%]	Mn [%]	Nb [%]
LowMn	0.14-0.17	0.40-0.50	-
HiMn	0.14-0.17	0.70-0.90	-
ULNb	0.14-0.17	0.40-0.50	0.005-0.015

These steels were conventionally rolled at the Steckel Mill using 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 Irvine[16], lower than the usual slab discharge temperature used in CMn 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 aim temperature. Hot band coils with nominal final thickness of 3.0, 6.3, 8.0, 12.5 and 19.0 mm were rolled. LowMn and ULNb steels were tested for all coil thickness; HiMn steel was tested only for the 19.0 mm thick coil.

After coil cooling, samples were extracted from the tail of the strips in order to determine their microstructure and mechanical properties. Specimens were submitted to metallographical analysis using optical microscopy; ferritic mean grain size was measured according to the ASTM Standard E112[17]. Specimens were machined in the longitudinal direction of the rolled strips for tensile testing. Although ASTM A36 standard has no specifications for toughness, Charpy tests with a V-shaped notch machined in the longitudinal direction of the rolled strips were performed at -20°C. Toughness was measured to all thickness, minus the 3 mm due to thickness constrains according to ASTM A370.

In addition, austenite conditioning and microstructural evolutions that occurred during rolling were calculated for all cases 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[19].

Mechanical Properties and Microstructures

Figure 1 shows the microstructures of each hot band coil. The microstructures of the ULNb steels show a more acicular morphology than those of the CMn steels, which tended to present a polygonal ferrite structure with pearlite. Some banding appeared in the microstructure of CMn coils with thickness of 3.0 and 6.3 mm, but ULNb steels showed no banding at all.

Table 2 shows the ferritic grain size and mechanical properties measured in the samples from the coils studied, while Table 3 shows the differences in properties observed between ULNb and LowMn steels for each coil thickness. Ferritic grain sizes were consistently more refined for the ULNb steels than for the CMn steels, as expected due to the retarding action of niobium over recrystallization and grain growth. The values of mechanical properties specified by the ASTM A36 standard were satisfied in all cases but, in the case of the 19.0 mm strips, ULNb steel showed a performance more similar to the HiMn steel, despite the lower manganese content of the first alloy. The values of yield to tensile ratio were higher for the ULNb steels, probably due to their more refined ferritic grain size and lower pearlite fractions. These steels also showed higher values of Charpy energy impact at -20°C. Unfortunately, the scattering of the values in Table 3 do not allow a quantitative analysis, but it can be seen that the partial replacement of manganese by niobium lead to a consistent grain size refining, yield and tensile stress increase (although not as high in the latter case) and a slightly yield to tensile ratio increase. The effect on toughness was positive, but not so significant in some cases. Total elongation was somewhat impaired in some cases, but A36 requirements were fully satisfied with no risks of failing in all strips. All these points have also been observed in other literature[1,7-10].

Figure 2 shows the evolution of some austenite microstructural parameters during Steckel rolling of the strips as calculated by MicroSim software, as follows: mean grain size, Dc_{10} parameter (which evaluates microstructure homogeneity, at which 10% of the grains are larger than the Dc_{10}) and accumulated strain (austenite strain hardening, a measure for dislocation density). MicroSim predictions showed that there was no 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. The eventual differences observed in the microstructural evolutions of both steels were due to different temperature evolutions during Steckel rolling, which are almost unavoidable under industrial conditions.

Costs and Carbon Footprint

The results above demonstrated that the ULNb steel can perfectly replace the HiMn grade without loss in mechanical performance. But there are other advantages. The cost of ferroalloys for the ULNb steel is on average 46% lower than that observed for the HiMn steels and, as mentioned before, there are other operational advantages during liquid steel refining associated with the reduced manganese content of the ULNb steel. Besides that, the Global Warming Potential associated with these steels falls from 122 $kgCO_2$/metric ton for the HiMn steel to 52$kgCO_2$/metric ton for the ULNb steel, mainly because a smaller quantity of FeNb replaces FeMn during the steelmaking operations.

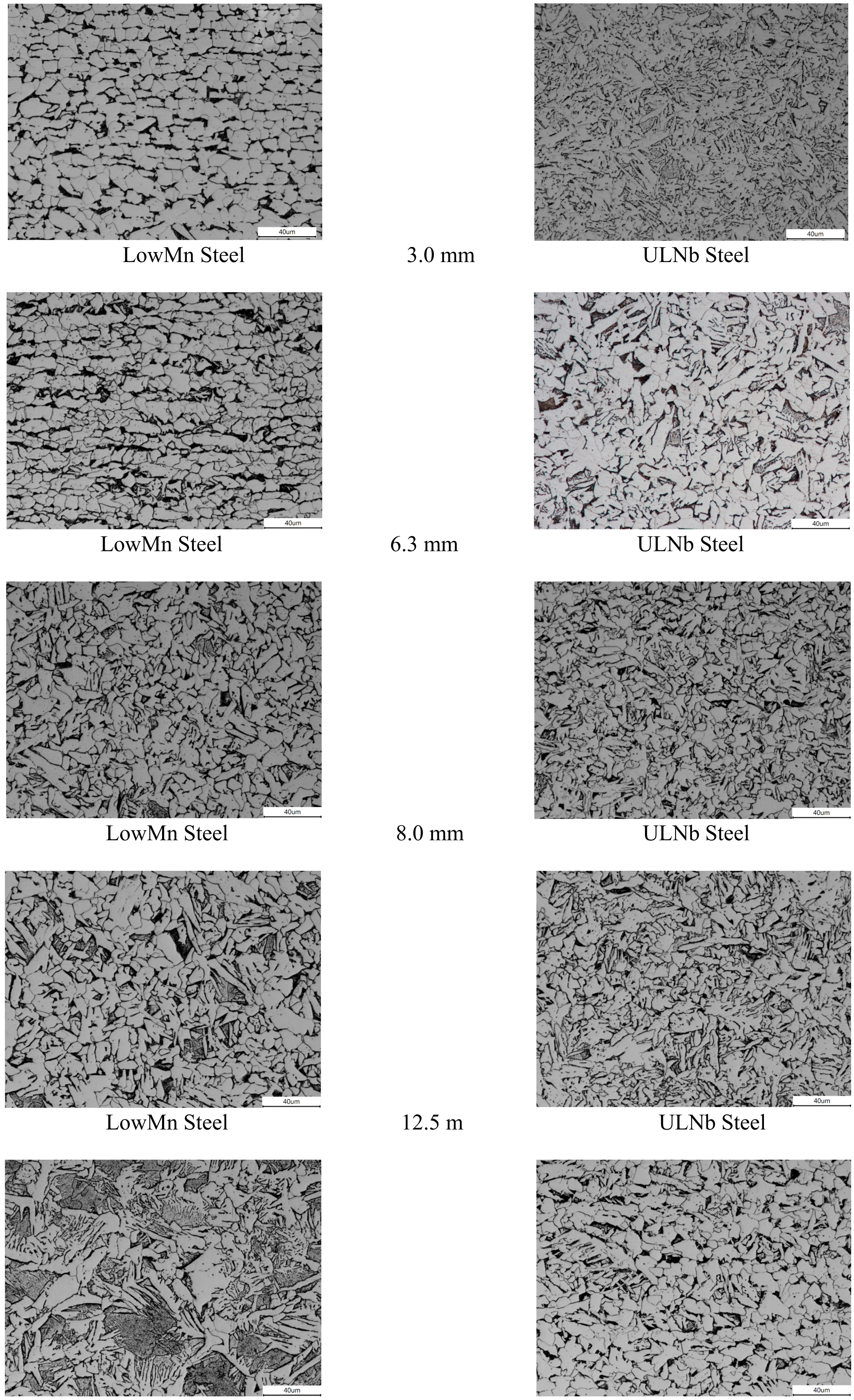

Figure 1. Microstructures of the hot rolled strips, longitudinal section. Nital etching, magnification 500 x.

Table 2. Ferrite Grain Size and Mechanical Properties Measured From the Strips Studied in This Work

Designation	GS [μm]	YS [MPa]	TS [MPa]	YR [%]	El [%]	CVN -20°C [J]
		> 250	400-550		≥ 23%	
LowMn	7.7	300	438	69	35	-
ULNb	5.5	401	474	85	26	-

3.0 mm

Designation	GS [μm]	YS [MPa]	TS [MPa]	YR [%]	El [%]	CVN -20°C [J]
		> 250	400-550		≥ 23%	
LowMn	7.4	326	460	71	42	149
ULNb	6.5	368	464	79	39	181

6.3 mm

Designation	GS [μm]	YS [MPa]	TS [MPa]	YR [%]	El [%]	CVN -20°C [J]
		> 250	400-550		≥ 23%	
LowMn	8.1	300	452	66	45	208
ULNb	5.6	360	470	77	46	212

8.0 mm

Designation	GS [μm]	YS [MPa]	TS [MPa]	YR [%]	El [%]	CVN -20°C [J]
		> 250	400-550		≥ 23%	
LowMn	7.7	307	455	67	45	135
ULNb	5.5	351	494	77	46	139

12.5 mm

Designation	GS [μm]	YS [MPa]	TS [MPa]	YR [%]	El [%]	CVN -20°C [J]
		> 250	**400-550**		**≥ 23%**	
LowMn	8.0	305	448	68	53	160
HiMn	7.5	339	460	74	53	168
ULNb	6.9	370	483	77	49	241

19.0 mm

GS: Grain Size; YS: Yield Strength; TS: Tensile Strength; YR: Yield Ratio; El: Elongation, CVN: Energy Absorbed during Charpy Test.

Table 3. Grain Size and Mechanical Property Differences Between the LowMn and the ULNb Steels for All Strip Thicknesses

Thickness [mm]	ΔGS [μm]	ΔYS [MPa]	ΔTS [MPa]	ΔYR [%]	ΔEl [%]	ΔCVN -20°C [J]
3.0	-2.2	101	36	16	-9	-
6.3	-0.9	42	4	8	-3	32
8.0	-2.5	60	18	11	1	4
12.5	-2.2	44	39	10	1	4
19.0	-1.1	65	35	9	-4	81

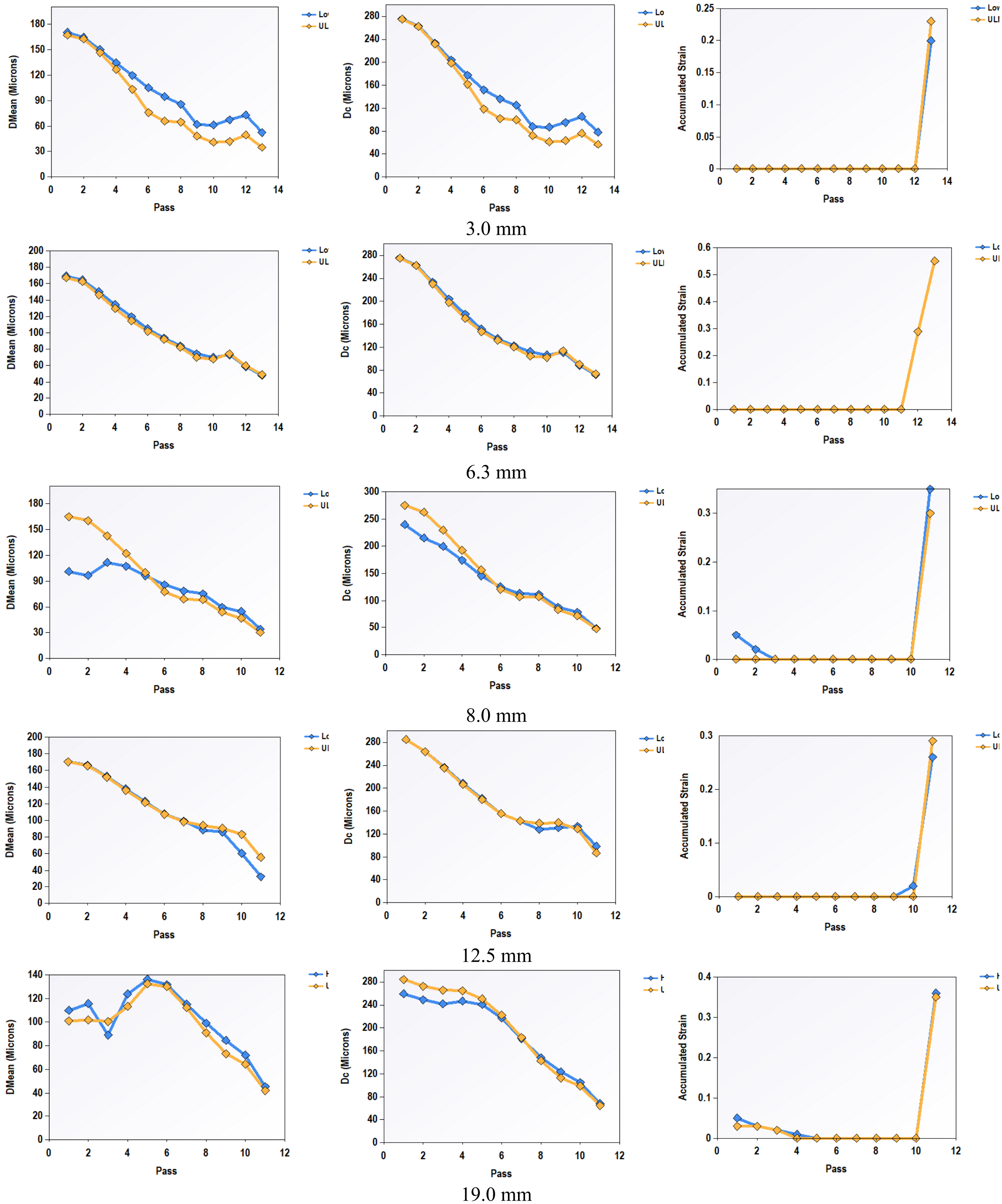

Figure 2. Evolution of mean grain sizes, Dc_{10} parameter and accumulated strain of austenite during the Steckel rolling of the strips studied in this work.

CONCLUSIONS

The search for clean energy, minimization of carbon footprint, and development of batteries is changing the traditional price relationships between ferroalloy prices. More than ever, it is necessary to "think outside the box" and seek competitiveness in creative solutions, which are not always evident at a first glance. This work shows one of these solutions, where an addition of 0.010% Nb can replace as much as 0.45% Mn in structural steels, keeping the same mechanical property aims at lower costs, with benefits in the steelmaking processes, no modifications in the rolling schedules, and lowering steel carbon footprint. New metallurgical tools, such as MicroSim, are allowing the optimization of thermomechanical treatments and, in turn, extracting the maximum effect from niobium and other alloying elements from steels. The optimization of alloy steel designs will progressively require deeper knowledge in metallurgy and the determination to experiment innovative approaches.

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REFERENCES

1. J. Patel. Ultra-Low Niobium (ULNb) Alloying Design Solution for Commodity Grade Structural Steels. Materials Today: Proceedings, 67, 2022, 523-530.
2. D.D.N. Guzela, P. Haddad, A.A. Gorni. Benefits for BOF/EAF Steel Plant Resulting from the Partial Substitution of Manganese by Small Additions of Niobium. CONAC 2023 – Steel Industry Congress and Exposition, AIST-Mexico, Monterrey, 2023, 13 p.
3. S.G. Jansto. MicroNiobium-Low Manganese Steelmaking Approach, Methodology and Process Metallurgy. 49° Seminário de Aciaria, Fundição e Metais Não-Ferrosos. Associação Brasileira de Metalurgia e Materiais, São Paulo, 2018, 11 p.
4. A.A. Gorni, J.S.S. Reis, C.N.P. da Silva, C.G. Cavalcanti. Otimização da Composição Química e do Processo de Laminação Controlada de Chapas Grossas Navais. 32° Seminário de Laminação – Processos e Produtos Laminados e Revestidos, Associação Brasileira de Metais, Curitiba, 1995, 373-392.
5. L.P. Carvalho, M.P. Silva, C.R.G. Carvalho, J.A. Tiburcio, C.F. de Souza. Redução do Custo de Produção de Laminados a Quente na Especificação LNE 38 ou LNE 380 Através da Alteração de Rota de Produção de Refino na Aciaria. 51° Seminário de Laminação – Processos e Produtos Laminados e Revestidos, Associação Brasileira de Metalurgia e Materiais, Foz do Iguaçu, 2014, 5 p.
6. K. Fowkes. What is Manganese? London: Alloy Consult; 2015.
7. Yu. D. Morozov, Yu.D., A.M. Stepashin; S.V. Aleksandrov. Effect of Manganese and Niobium and Rolling Conditions on the Properties of Low-Alloy Steel. Metallurgist, 46(5-6), 2002, 152-156.
8. J. Patel, C. Sobue, J. Souto, J. Tan. Structural Steel Products Manufacturing Strategy for ASEAN Steel Industry Post COVID-19. SEAISI 50th Anniversary e-Conference & Exhibition. 2021.
9. D.G. Stalheim, R. Barbosa, J. Rodriguez-Ibabe, M. Rebellato, D. Jarreta. A New Cost Effective Metallurgical Design Strategy to Develop Optimized Strength and Ductility Properties in Structural Steels. In: 2018 SEAISI Conference & Exhibition. Singapore, 2018, 13 p.
10. A.A. Gorni, M.A. Rebellato, L.M. Silvestre. Partial Replacement of Manganese by Niobium in Low Carbon Structural Steels. 57° Seminário de Laminação e Conformação de Metais, Associação Brasileira de Metais, São Paulo, 2022, 15 p.
11. S.F. Medina, C.A. Hernandez. General Expression of the Zener-Hollomon Parameter as a Function of the Chemical Composition of Low Alloy and Microalloyed Steels. Acta Materialia, 44(1), 1996, 137-148.
12. R. Colas. A Model for the Hot Deformation of Low-Carbon Steel. Journal of Materials Processing Technology, 62, 1996, 180-184.
13. P. Kawulok, P. Opela, I. Schindler, R. Kawulok, S. Rusz, M. Sauer, K. Konecna. Hot Deformation Behavior of Non-Alloyed Carbon Steels. Materials, 15:595, 2022, 26 p.
14. EPA. Greenhouse Gas Emissions from a Typical Passenger Vehicle (https://www.epa.gov/greenvehicles/greenhouse-gas-emissions-typical-passenger-vehicle), accessed August 16, 2022.

15. ASTM A36. Standard Specification for Carbon Structural Steel. West Conshohocken, 2019, 3 p.
16. K.J. Irvine, F.B. Pickering, T. Gladman. Grain Refined C-Mn Steels. Journal of the Iron and Steel Institute, 205, February 1967, 161-182.
17. ASTM E112. Standard Test Methods for Determining Average Grain Size. West Conshohocken, 2021, 28 p.
18. ASTM A370. Standard Test Methods and Definitions for Mechanical Testing of Steel Products. West Conshohocken, 2021, 47 p.
19. P. Uranga, J. Rodriguez-Ibabe, D. Stalheim, R. Barbosa, M.A. Rebellato. Application of Practical Modeling of Microalloyed Steels for Improved Metallurgy, Productivity and Cost Reduction in Hot Strip Mill Applications. In: Proceedings of the Iron & Steel Technology Conference - AISTech 2016, 2016; Pittsburgh. Warrendale: AIST; 2016. p. 1769-1778.