NEW STRUCTURAL ULTRA LOW MANGANESE STEEL PLUS NIOBIUM: THE APERAM EXPERIENCE*

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Abstract

This paper describes a cooperative project developed by Aperam South America (ASA) and Companhia Brasileira de Metalurgia e Mineração (CBMM) with the aim of completely replacing manganese with small concentrations of niobium in structural low carbon steels, like SAE/AISI 1012. The results got in the final product after Steckel rolling and delivery to partner customers showed the following advantages: potential cost reduction and improvement in microstructural refinement, homogeneity, and inclusionary cleanness, while keeping the same level of mechanical properties. This project allows ASA to include in its product mix an alloy that innovates the design for structural steels. Besides that, this alloy broke ground for the replication of this concept in other structural steels.

Keywords: Low carbon structural steel; Alloy design; Manganese; Niobium.

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1 INTRODUCTION

The partial replacement of manganese by niobium in low-carbon structural steels was first proposed about twenty years ago [1] and has been successfully implemented in several mills in the last years [2-4]. This new approach allows that the mechanical properties of the final product are kept but having a microstructure with lower degree of segregation and banding, as well good potential for cost reduction and, most likely, decrease of the carbon footprint when compared to conventional alloys.

The development of technological, ambitious and, above all, innovative products is part of the essence of Aperam South America (ASA) which, faithful to its guideline that advocates the ambitious development of innovative products, broke the limits of this new concept, proposing to Companhia Brasileira de Metalurgia e Mineração (CBMM) an even more challenging level of substitution of manganese for niobium, as will be described below.

2 DEVELOPMENT

The Division of Metallurgy of ASA, in collaboration with the technical and commercial teams of CBMM and its consultants, decided to test the new alloy design approach for the production of SAE 1012/ASTM A36 hot coils, adopting the two chemical compositions shown in Table I: the CMn conventional steel, normally adopted for this product, and the so called ULNb steel, where manganese amount was reduced to residual values and completely replaced by niobium.

TABLE 1: Chemical compositions of both steels studied in this work.

Steel	C [%]	Mn [%]	Nb [%]
CMn	0.10 –0.15	0.30 – 0.60	-
ULNb	0.10 – 0.15	0.08 – 0.20	0.008 - 0.015

Slabs of both steels were processed at the Steckel Mill line, as shown in Figure 1, during a campaign for standard structural CMn steel, with no process changes or specific adjustments being made to processing the new ULNb steel. Discharging temperature from the reheating furnace was above 1080°C, the niobium dissolution temperature calculated according to Irvine [5] using the real carbon, nitrogen, and niobium nominal contents of the ULNb steel. It should be noted that this temperature was lower than the usual slab discharge temperature used in CMn steels. The coils rolled had similar thickness and width (2.8mm to 3.0mm x 1200mm) and were coiled at a temperature below 750°C. The mechanical properties aimed for the hot coils of both steels were similar to those specified by the ASTM A36 standard [6].

After coil cooling, samples were extracted from its tail according to the NBR 11888 Brazilian standard [7]. A detailed characterization of non-metallic inclusions in the ULNb steel was carried out at the Research Center of ASA, using SEM and EDS, while optical metallography and EBSD characterization of the ferritic-pearlitic microstructure of both steels were performed at the Centro de Estudios e Investigaciones Técnicas – CEIT, in San Sebastian, Spain.

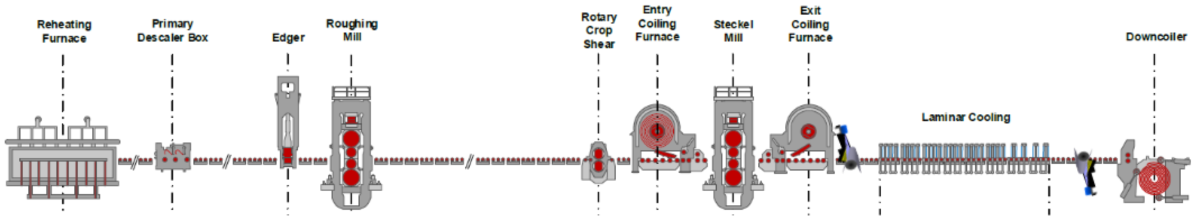


Figure 1: Schematic diagram of the hot rolling mill at the APERAM plant, Timóteo MG, Brazil.

2.1 Inclusionary Cleanness Analysis

The size of the inclusions in the ULNb steel is very small, ranging from 2 to 5 micrometers, and no MnS inclusions were found, as shown in the SEM micrographs that can be seen in Figure 2. All micrographs were taken without chemical etching.

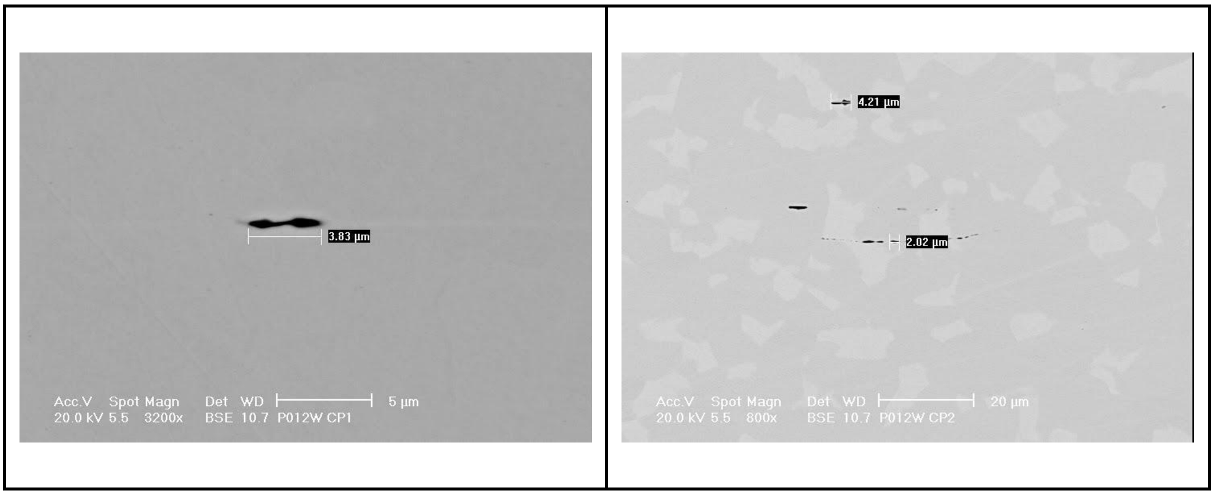
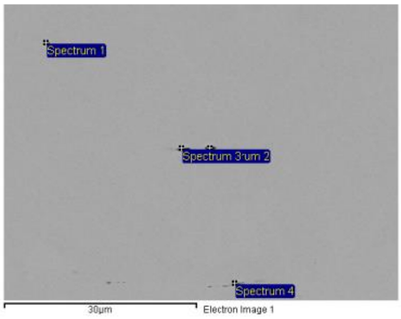


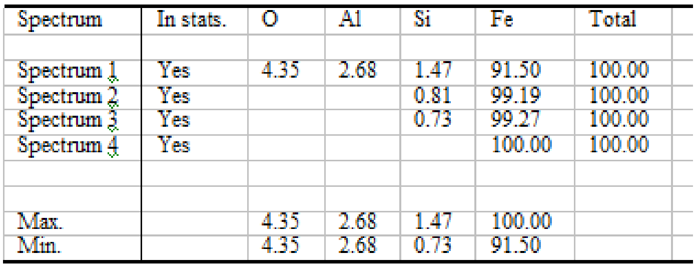
Figure 2: SEM micrographs of the ULNb steel showing the non-metallic inclusions present in the microstructure.

The results of extensive EDS analyses performed in the ULNb steel samples are presented in Figure 3. It can be seen that almost no sulfur and manganese were detected in the inclusions. This fact was already expected due to the extra low amounts of manganese and sulfur of the ULNb steels. This was due, respectively, to the alloy design approach and to the fact that the steel is “green”, that is, only charcoal, intrinsically with low sulfur, is used in the ASA blast furnaces instead of coke.

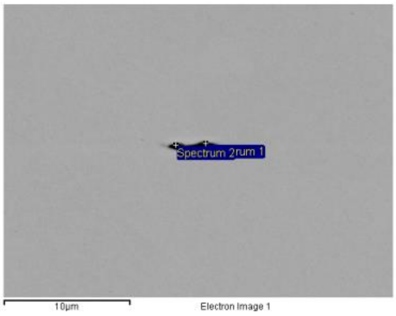
2.2 Metallographic Analysis

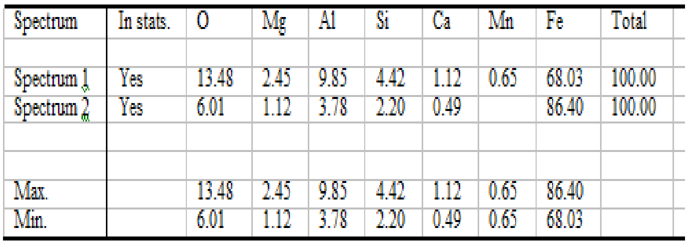
Figure 4 shows optical micrographs of the samples of CMn and ULNb steels, at ¼ and ½ thickness. The analysis of such microstructures suggests that, in the case of CMn steel, they are composed of polygonal ferrite, non-polygonal ferrite, pearlitic and bainitic regions while, for the ULNb steel, they are mostly ferritic with pearlite as a secondary constituent. In addition, a considerably coarser microstructure was observed in the CMn steel, while a clear microstructural refinement was noted in the microstructures of ULNb steel.



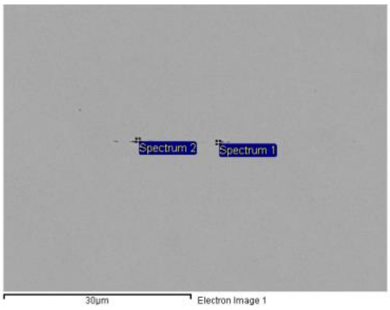


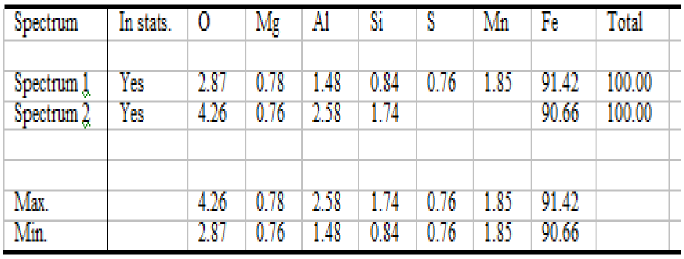
Spectrum	In stats.	O	Al	Si	Fe	Total
Spectrum 1	Yes	4.35	2.68	1.47	91.50	100.00
Spectrum 2	Yes			0.81	99.19	100.00
Spectrum 3	Yes			0.73	99.27	100.00
Spectrum 4	Yes				100.00	100.00
Max.		4.35	2.68	1.47	100.00	
Min.		4.35	2.68	0.73	91.50	



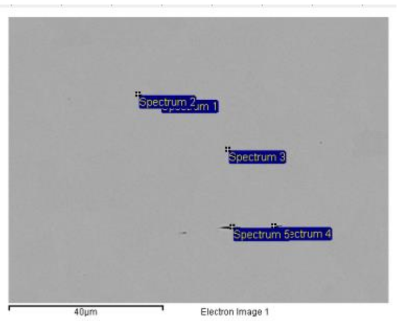


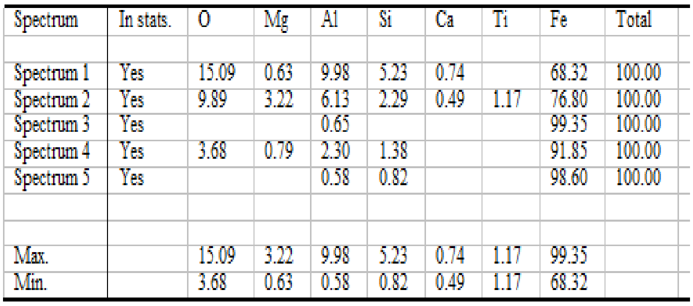
Spectrum	In stats.	O	Mg	Al	Si	Ca	Mn	Fe	Total
Spectrum 1	Yes	13.48	2.45	9.85	4.42	1.12	0.65	68.03	100.00
Spectrum 2	Yes	6.01	1.12	3.78	2.20	0.49		86.40	100.00
Max.		13.48	2.45	9.85	4.42	1.12	0.65	86.40	
Min.		6.01	1.12	3.78	2.20	0.49	0.65	68.03	





Spectrum	In stats.	O	Mg	Al	Si	S	Mn	Fe	Total
Spectrum 1	Yes	2.87	0.78	1.48	0.84	0.76	1.85	91.42	100.00
Spectrum 2	Yes	4.26	0.76	2.58	1.74			90.66	100.00
Max.		4.26	0.78	2.58	1.74	0.76	1.85	91.42	
Min.		2.87	0.76	1.48	0.84	0.76	1.85	90.66	





Spectrum	In stats.	O	Mg	Al	Si	Ca	Ti	Fe	Total
Spectrum 1	Yes	15.09	0.63	9.98	5.23	0.74		68.32	100.00
Spectrum 2	Yes	9.89	3.22	6.13	2.29	0.49	1.17	76.80	100.00
Spectrum 3	Yes			0.65				99.35	100.00
Spectrum 4	Yes	3.68	0.79	2.30	1.38			91.85	100.00
Spectrum 5	Yes			0.58	0.82			98.60	100.00
Max.		15.09	3.22	9.98	5.23	0.74	1.17	99.35	
Min.		3.68	0.63	0.58	0.82	0.49	1.17	68.32	

Figure 3: Images and chemical micro-analysis of non-metallic inclusions got through EDS analysis in the samples of ULNb steel.

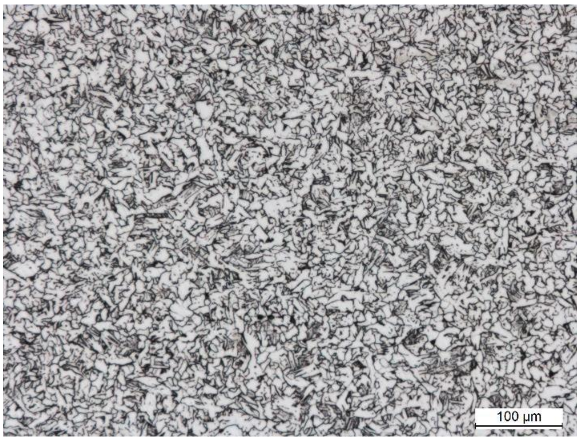
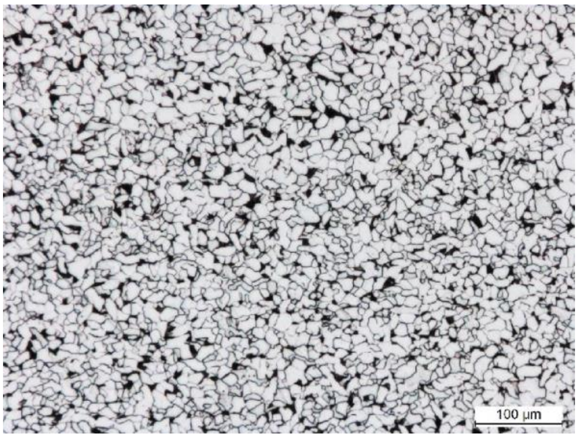
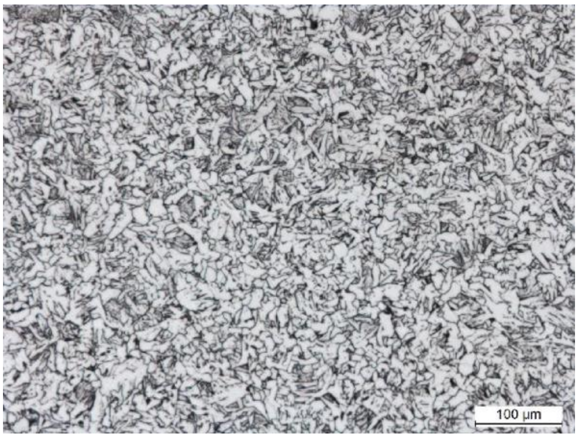
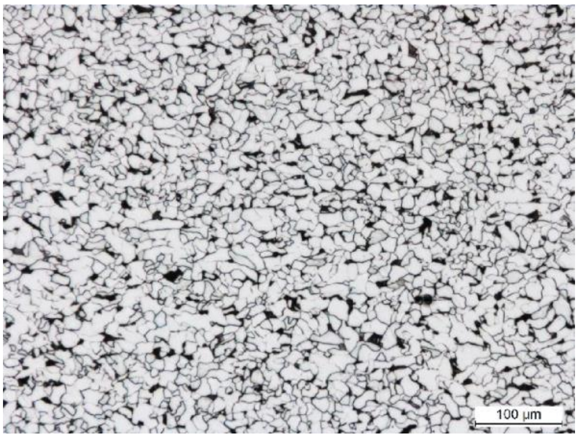
CMn Steel (Conventional)	ULNb Steel
 ¼ Thickness	 ¼ Thickness
 ¼ Thickness	 ¼ Thickness

Figure 4: Comparison between the ferritic-pearlitic microstructures got in the samples of CMn (conventional) and ULNb steels. Magnification: 100 x.

2.3 EBSD Analysis

Electron Backscattering Diffraction (EBSD) scans were performed at the quarter-thickness position of the rolled strips. The main objective was to quantify microstructural parameters, such as crystallographic unit size distributions and the mean value of kernel average disorientation, which is related to dislocation density. Figure 5 shows the distribution of crystallographic units and the average grain size. The CMn steel showed an average grain size of 7.2 µm and a degree of kernel average disorientation of 0.75°. On the other hand, the average grain size of ULNb steel was 5.7 µm, with a degree of kernel disorientation of 0.70°. Both values of grain size were measured considering a misorientation degree of 4°, which corresponds to the unit size that controls tensile properties. The higher value of kernel average disorientation of the CMn steel confirms the formation of a more bainitic microstructure with slightly higher dislocation density. It was also found that grain size distribution of the ULNb steel was more uniform than in the CMn steel, as both the $D_{c20\%}$ parameter (that is, the cutoff grain size at 80% area fraction in a grain-size distribution histogram) and the ratio $D_{c20\%}/D_{Mean}$ were lower for the first steel, respectively 11.5 µm versus 18.5 µm and 1.9 versus 2.3.

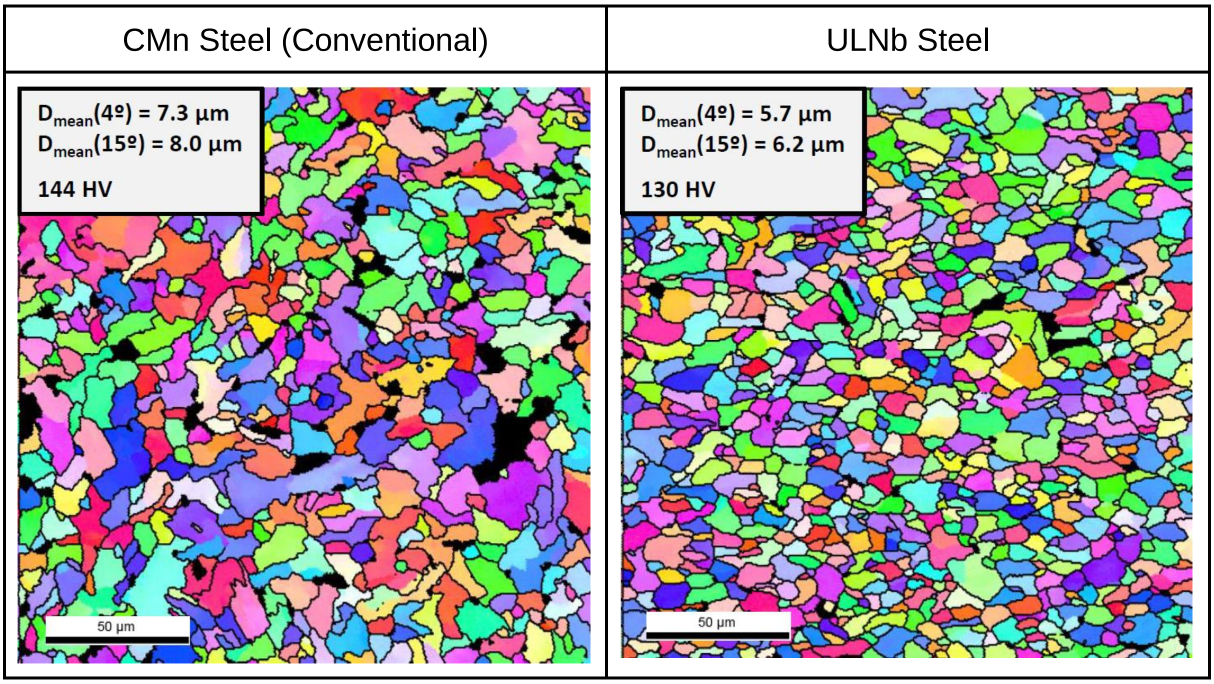


Figure 5: Analysis of the microstructures of the CMn and ULNb steels using EBSD, including average grain size.

2.4 Mechanical Properties

Figure 5 also indicates that the ULNb steel was softer (130 HV) than the CMn steel (144 HB). However, as shown in Table 2, this did not prevent the ULNb steel from reaching the targeted properties based on ASTM A36 standard. These results were very similar to those got in [8].

Table 2: Mechanical properties measured from the strips of CMn and ULNb steels studied in this work.

Steel	YS [MPa]	LR [MPa]	YR	Elongation [%]
CMn	328	450	0.73	31
ULNb	304	418	0.73	34
A36 (aim)	≥ 250	400 - 550	-	≥ 23

YS: Yield Strength; TS: Tensile Strength; YR: Yield Ratio; El: Elongation

3 CONCLUSIONS

As expected, the new alloy design for low carbon structural steels, with residual manganese contents compensated by a small addition of niobium, that is, the ULNb steel, allowed the production of hot coils satisfying the requirements specified by the

ASTM standard A36, with a microstructure with higher level of inclusionary cleanness and a grain size distribution more refined and homogeneous. Further activities are underway by ASA and CBMM to evaluate precisely the new ULNb steel, regarding cost reduction and minimization of carbon footprint, as well to check performance at final customers, with special attention to its formability and weldability.

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