PRODUCTION OF CA-50 SPOOLED REBAR USING NIOBIUM-VANADIUM MICROALLOYED STEEL*

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Abstract

Spooled rebar offers several advantages to the end user compared to loose-wound coiled rebar (also known as “wild coil”), which is more common in the market. However, in some scenarios, the performance of the rebar spooling process is better if the bar, at the end of the rolling process, is subjected to lower cooling rates, increasing the temperature at which this process occurs and, consequently, lowering the strength and increasing the ductility of the steel. In order to achieve this, without affecting the final properties of the rebar, it is necessary to use more sophisticated steels, which have more active strengthening mechanisms. This is the case of NbV microalloyed steels, where a more refined grain size provided by the first element is combined with the precipitation strengthening promoted by the second. This work shows a successful case where NbV microalloyed steel replaced a conventional CMn alloy used in the production of CA-50 grade spooled rebar.]

Keywords: Spooled rebar; NbV microalloyed steel; Microstructural evolution; Austenite transformation.

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1 INTRODUCTION

Loose-wound coiled rebar, seen in the left side of Figure 1, which is used in automatic bending machines, is a well-stablished product. During its production, rebar comes out of the mill in the form of a continuous spiral, which is coiled up and, after cooling, is compacted, forming the so called “wild coil”. However, this kind of product is somewhat problematic, as its coiling process is poorly controlled. So, it shows higher internal stresses and twists.

Figure 1: Rebar as “wild coil” in the left side and spooled rebar in the right side (Source: https://industrializaremconcreto.com.br/Edicoes/Exibir/mais-produtividade-em-processos-industrializados).

For its turn, spooled rebar, as shown in the right side of Figure 1, and in detail in Figure 2, is a more sophisticated product, as the bar exits the mill and is evenly and compactly wounded under tension, without forming spirals. So, it offers several advantages:

- Meets higher requirements of flatness and straightness;
- Higher speeds of cutting and bending at the customer;
- Less twisting when using bending machines and less problems in straightening twisted rebar;
- Less tangles during decoiling;
- Productivity is higher due to fewer change-outs and the ability to work with multiple strands;
- Higher safety, as it allows more stable stacking and easier storage;
- Higher consistency in spool lengths and dimensions, simplifying fabrication processes;

- Larger, compact spools increase the linear feet per spool with lower yield losses.

Figure 2: A detailed view of a GG50 grade spooled rebar (Source: https://mais.gerdau.com.br/produtos/vergalhao-gg-50-carretel).

However, the production of spooled rebar requires changes in the chemical composition of the steel and in the parameters of the hot rolling and cooling processes of the bar to ensure good performance during its compact vertical spooling. The main objective was to develop an alloy that would allow a post-rolling QST-type cooling that would not be so severe, thus keeping relatively high the temperature of the bar during its coiling and ensuring an adequate level of ductility during this operation, without affecting the final properties required for this product.

These requirements can be met by steels that present additional strengthening mechanisms in relation to those acting in CMn steels normally used in the manufacture of rebar. For example, the VN precipitation strengthening which is additionally provided by V microalloyed steels [1]. However, the relatively high amounts of V and N needed to produce high strength rebars lead to excessive VN precipitation before austenite transformation, which can lead to excessive ferrite formation in the final microstructure, resulting in a decrease in the TS/YS ratio [2,3]. This problem can be solved by reducing V and N contents of the steel, which must be compensated through the micro-addition of Nb [2,4,5]. This element reduces the amount of N available for VN precipitation and provides strengthening by increased grain size refining, compensating for the loss of precipitation strengthening, as shown in the flowchart in Figure 3 [5]. In addition, there is less ferrite formation in the microstructure, leading to a better balance between the fractions of this phase and pearlite in microstructure, which increases tensile strength and, therefore, the TS/YS ratio, which reaches values greater than 1.10 [5].

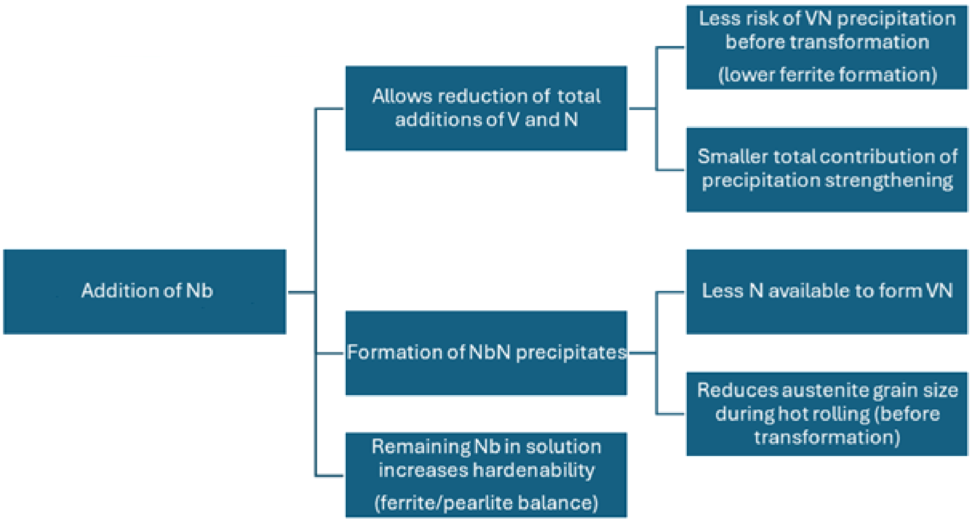


Figure 3: Role of niobium in the alloy design used in rebar production [5].

2 DEVELOPMENT

This work focused on the production of spooled rebar with diameter of 25 mm, grade CA-50, according to the NBR 7840 Brazilian standard. The CMn steel originally used in this application did not contain microalloys; its typical chemical composition was 0.27% C, 0.85% Mn and 0.20% Si. Billets of this steel with square cross-section and 160 mm edge were heated to 1150°C and rolled until the bar reached 25 mm in diameter, when it was then cooled using the QST approach and coiled into a spool. The microstructural evolution of austenite during the rolling process was calculated by the MicroSim for Bars ® software, which revealed that the final average austenite grain size before transformation was equal to 34.5 µm. Figure 4 shows the austenitic grain size distribution obtained at the end of the rolling process.

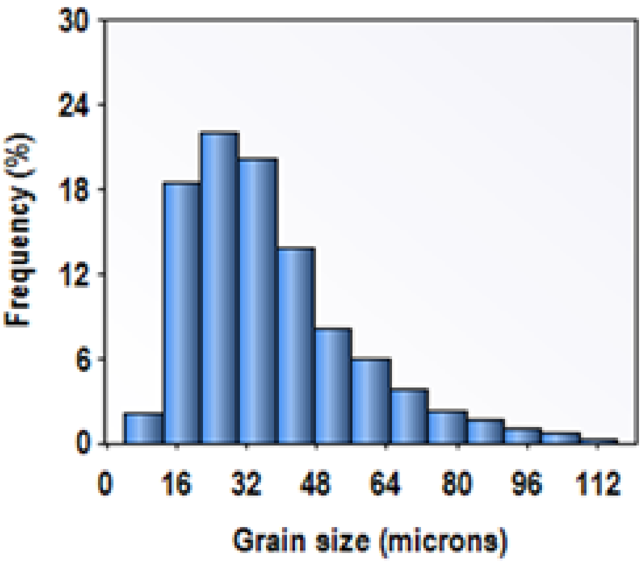


Figure 4: Final austenite grain size distribution after hot rolling of the CMn steel, as calculated by MicroSim for Bars ®.

The PhasTranSim ® program was then used to determine the CCT diagram of the CMn steel, considering the effect of hot rolling, which is shown in Figure 5. The same program was used to calculate the final microstructure of the rebar core, assuming a relatively high cooling rate. The model results indicated that core final microstructure was composed of 66% ferrite plus 33% pearlite, ferritic average grain size equal to 10.3 μm and hardness of 191 HV. Yield and tensile strength of the rebar core were equal to 376 MPa and 564 MPa, respectively. The contributions of the several strengthening mechanisms to yield and tensile strength can be seen in Figure 6; it can be seen that, in this case, there was no precipitation strengthening, only contributions from grain size, solid solution and microstructural constituents like ferrite and pearlite. The actual yield strength of this quenched and self-tempered rebar was higher than 500 MPa; this higher value is justified by the martensite ring formed on the rebar surface during the QST treatment, which was not taken into account by the PhasTranSim ® simulation.

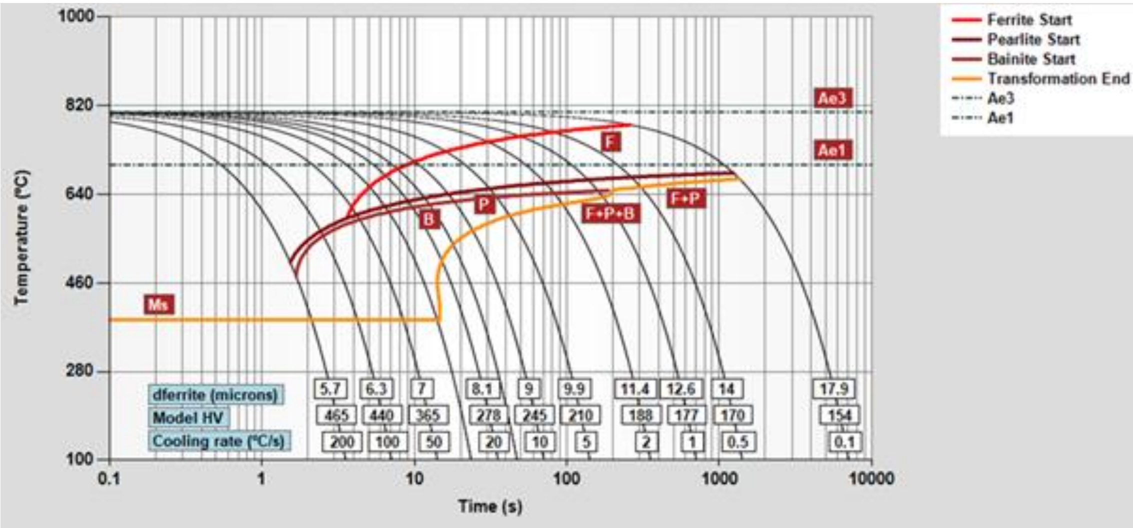
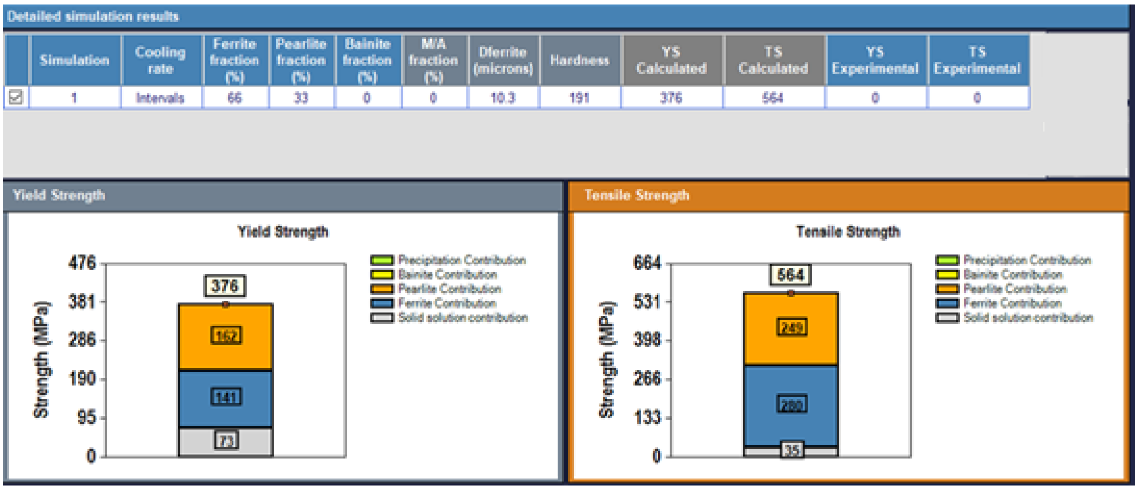


Figure 5: CCT diagram for the CMn steel, considering the effect of hot rolling, as calculated by PhasTranSim ®.


Detailed simulation results

Simulation	Cooling rate	Ferrite fraction (%)	Pearlite fraction (%)	Bainite fraction (%)	M/A fraction (%)	Dferrite (microns)	Hardness	YS Calculated	TS Calculated	YS Experimental	TS Experimental
1	Intervals	66	33	0	0	10.3	191	376	564	0	0

Figure 6: Contributions of the several strengthening mechanisms to yield and tensile strength of the CMn steel, as calculated by PhasTranSim ®.

As the production of CA-50 spooled rebar required the use of lower cooling rates after rolling, it was proposed the use of a new steel, microalloyed with Nb and V, which would reach the desired levels of mechanical strength to be obtained even under such milder conditions. The C and Mn contents of this new steel were the same used in the original alloy; the added amount of Nb plus V was lower than 0.05%. The rolling process parameters were the same used in the previous case. The evolution of the austenitic grain size during the hot rolling process was calculated for the new steel, using the MicroSim for Bars ® software. Figure 7 shows the austenite grain size distribution at the end of the rolling process. In this case, due to the presence of Nb, the calculated average final austenite grain size was slightly more refined than that observed for the CMn steel, 32.6 µm, which is somewhat reflected in the histogram of Figure 7.

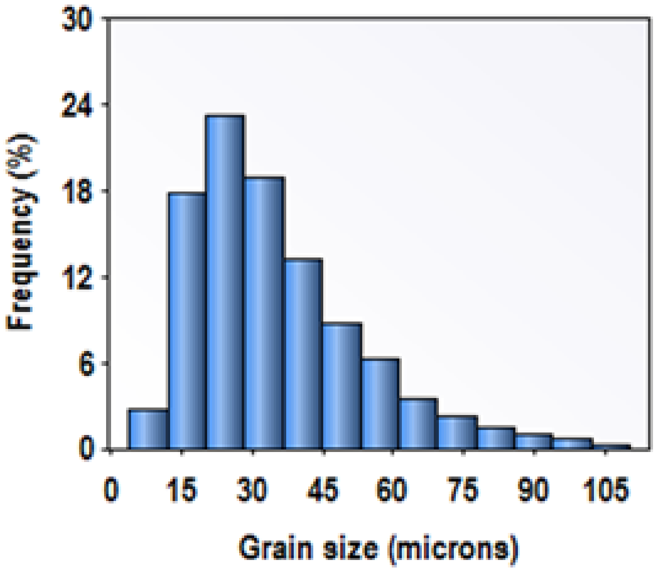


Figure 7: Final austenite grain size distribution after hot rolling of the NbV steel, as calculated by MicroSim for Bars ®.

The PhasTranSim ® program was used again, this time to determine the CCT diagram of the NbV steel considering the effect of hot rolling, which is shown in Figure 8. The formats of the transformation curves are similar in both graphics, but one can note that final hardness of the CMn steel was higher than the NbV steel for cooling rates higher or equal to 50°C/s; but this trend is inversed for cooling rates below or equal to 10°C/s, probably due to the fact that there is more time available during cooling for VN precipitation to occur. Or, in other words, rebar strength is higher for lower cooling rates after hot rolling, which is exactly what is favorable for rebar spooling.

The PhasTranSim ® model was also used to calculate the final microstructure of the rebar core of NbV microalloyed steel, now assuming a lower cooling rate. The model results indicated a final microstructure and ferritic grain size similar to the CMn steel, but with a slightly higher hardness of 197 HV. Yield and tensile strength of the rebar core were higher for the NbV microalloyed steel, being equal to 400 MPa and 587 MPa, respectively. The contributions of the several strengthening mechanisms to yield and tensile strength can be seen in Figure 9; but, in this case, in addition to the contributions already mentioned from grain size, solid solution, and ferrite plus pearlite fractions for the CMn steel, both properties also include the contribution of precipitation strengthening. The actual yield strength of this QST rebar was also higher than 500 MPa, like the spooled rebar made with CMn steel. However, as the final spooling temperature for the NbV microalloyed rebar was about 50°C higher, steel was more ductile during this operation, making it easier, improving mill line performance and ensuring product quality.

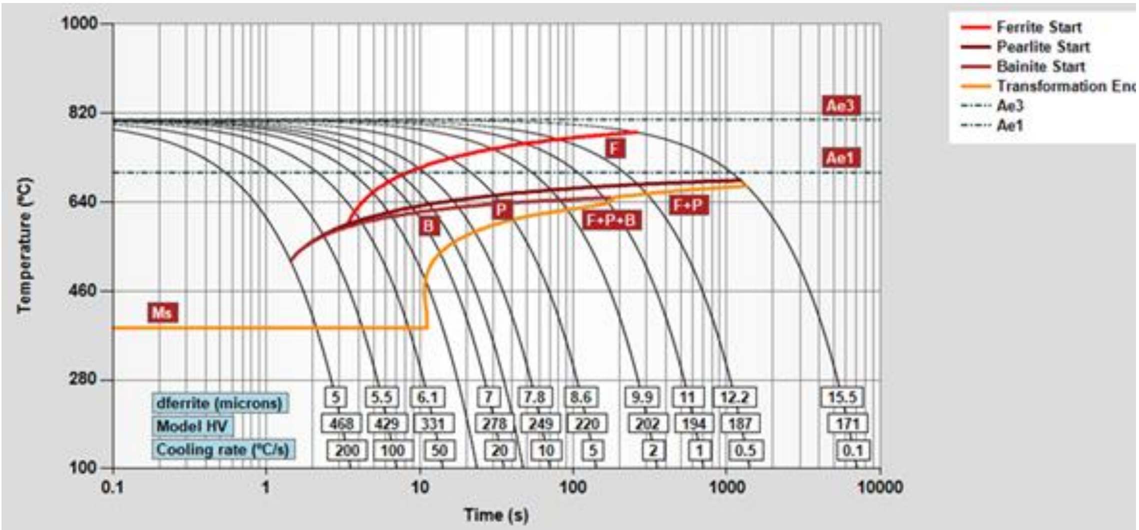


Figure 8: CCT diagram for the NbV steel, considering the effect of hot rolling, as calculated by PhasTranSim ®.

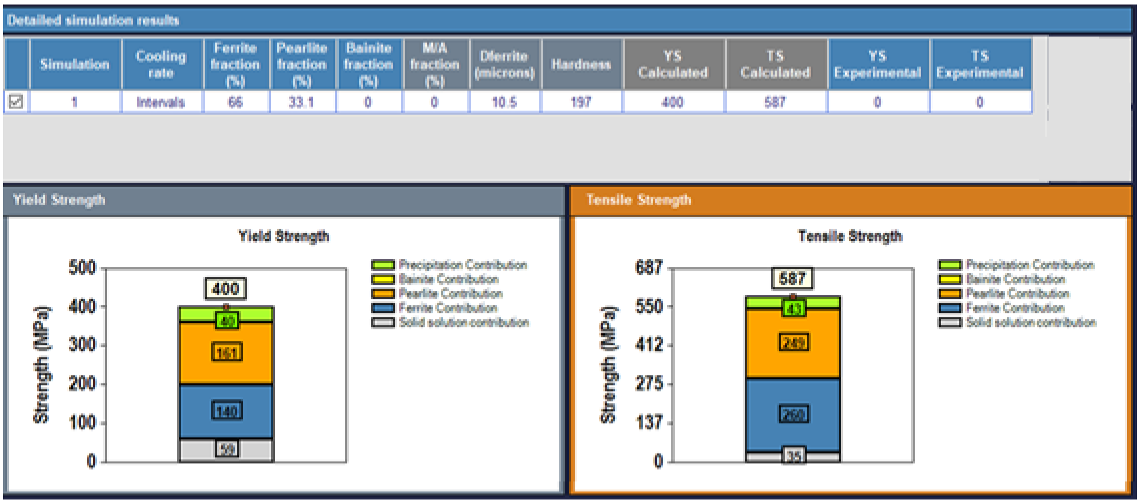


Figure 9: Contributions of the several strengthening mechanisms to yield and tensile strength of the NbV microalloyed steel, as calculated by PhasTranSim ®.

3 CONCLUSION

The replacement of a conventional CMn steel by another one, microalloyed with NbV, allowed for more reliable and higher quality production of CA-50 grade spooled rebar. The microalloyed steel allows the application of lower cooling rates during the spooling

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process, which results in an increase of approximately 50°C in the temperature of the bar during this operation, when compared with the use of a plain CMn steel. This increases the ductility of the bar during the spooling process and, therefore, improves its performance, without any changes in the mechanical properties of the final product.

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