Original Article
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HIGH TOUGHNESS, 510 MPA STRENGTH CLASS MICROALLOYED STEEL PLATES WITH PRODUCED BY T.M.C.P. IN GERDAU OURO BRANCO

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Abstract

The Gerdau Ouro Branco Works has started to develop high complexity products three years after the implementation of its new heavy plate rolling mill. The evolution of its learning curve is increasingly challenging since products are being developed to their highest grades. This paper aims to present the first results of the development of steels of the strength class of 510 MPa produced by TMCP (Thermomechanical Controlled Processing). These results show the potential and advantages of the accelerated cooling process after rolling for the production of steel plates with high mechanical strength and high toughness, associated with a low equivalent carbon.
Keywords: Plate mill; Controlled rolling; Accelerated cooling; Toughness.

PRODUÇÃO DE CHAPAS GROSSAS DA CLASSE DE 510 MPA E ALTA TENACIDADE, PRODUZIDAS ATRAVÉS DE TRATAMENTO TERMOMECÂNICO DE AÇO MICROLIGADO, NA GERDAU OURO BRANCO

Resumo

A usina Ouro Branco da Gerdau iniciou o desenvolvimento de produtos com alta complexidade três anos depois da implementação de seu novo laminador de chapas grossas. A evolução de sua curva de aprendizado é cada vez mais desafiadora, uma vez que estão sendo fabricados produtos com especificações extremas. Este trabalho apresenta os primeiros resultados do desenvolvimento de chapas grossas da classe de 510 MPa produzidos por laminação controlada seguida de resfriamento acelerado. Eles mostram o potencial e as vantagens decorrentes do uso deste processo na produção de aços com alta resistência mecânica e alta tenacidade, cuja composição química apresenta baixos valores de carbono equivalente.
Palavras-chave: Laminador de chapas grossas; Laminação controlada; Resfriamento acelerado; Tenacidade.

1 INTRODUCTION

The controlled rolling of heavy plates made from microalloyed steels is a thermomechanical treatment established several decades ago, but its technical evolution is continuous, as there is an increasing need to produce sophisticated products at ever smaller costs to cope with the strong competition that exists in the global steel industry [1].

Figure 1 shows the relationship between market requirements and the role of thermomechanical treatment [2].

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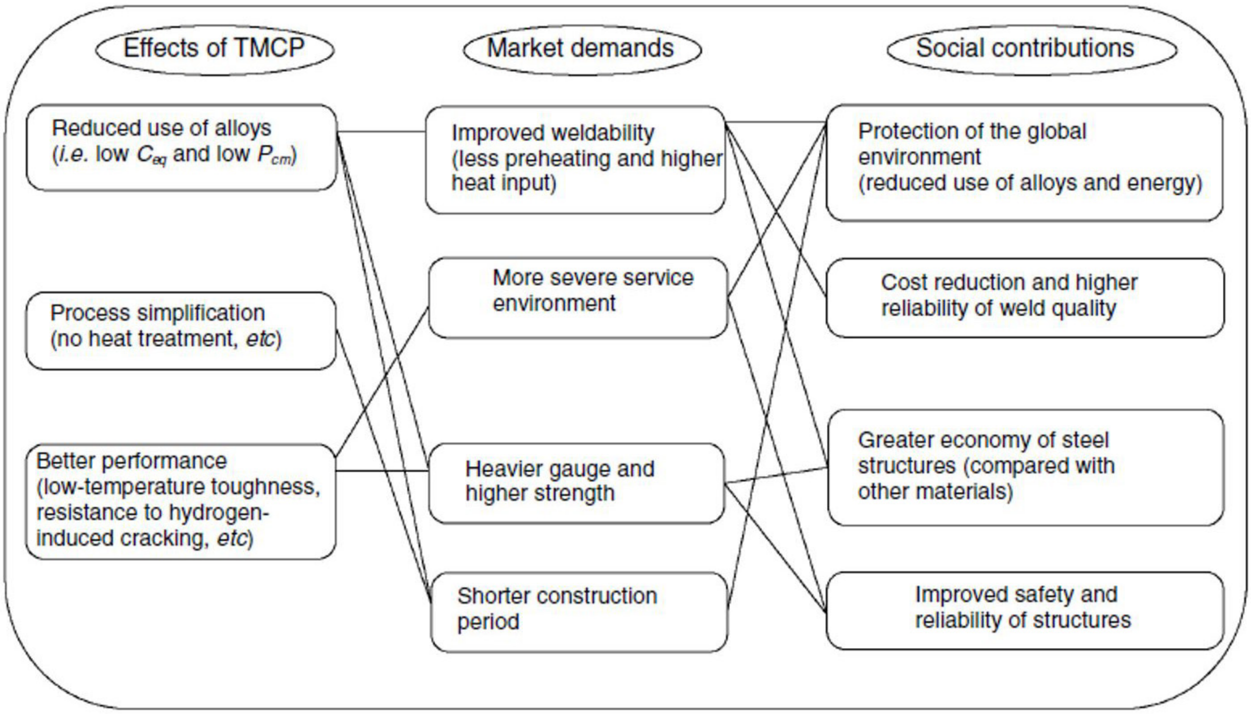

Figure 1. Relationship between market requirements and the roles of thermomechanical treatment [2].

Since the first application of this process in the naval industry, its products have been applied in many plate markets, as shown in Table 1 [2]. Its popularity reflects the advantages of microalloyed steels processed by TMCP (Thermomechanical Controlled Processing), such as better mechanical strength and toughness, associated with excellent weldability. Another key factor that reflects the advantages of this thermomechanical treatment is the fact that alloy design, control of impurities during the steelmaking process, reduction of segregation, removal of hydrogen, reheating of plates and the processes of rolling and cooling are considered both in previous and post-rolling processes.

The advent of controlled rolling allowed to reduce the equivalent carbon of structural heavy plates without affecting its mechanical characteristics, since the effects of the alloying elements were replaced by an intense grain size refining. In fact, this feature allows to increase both yield strength and toughness, but does not increase tensile strength so much, a fact that limits the possibilities of adopting leaner chemical compositions [3-5].

The next step in this evolution was the accelerated cooling of heavy plates after rolling through the application of water. This metallurgical resource was only feasible after the resolution of several complex technical and operational problems. This only occurred in the early 1980s, thanks to the efforts of several mills, mainly Japanese [6]:

- Ensure good flatness in the rolling stock to prevent uneven accumulation of water on its upper surface;

Table 1. Tensile strength classes and applications of thick plates processed through TMCP [2]

Application	Tensile Strength Class [MPa]				
	490	590	690	780	900-950
Naval	○	○	-	-	-
Offshore Structures	○	○	-	●	-
Large Diameter Tubes	○	○	○	○	○
Construction	○	○	-	○	-
Bridges	○	○	-	○	-
Gates	○	●	●	●	●
Low Temperature Tanks	○	○	-	-	-
Cryogenic Tanks	○	-	○	-	-
Earthmoving Equipment	○	○	●	●	●

- Surfaces of the rolled stock totally free from coarse scale to maintain uniform cooling;
- Adequate level of line automation to ensure accuracy and uniformity at the temperature of the plate before accelerated cooling;
- Development of water application control systems that promote consistent and uniform cooling rates throughout the plate.

Today the use of water as an alloying element is a well-established technology, as demonstrated by the spread of plate accelerated cooling lines around the world. This process allows the most adequate microstructures to be obtained according to the required mechanical characteristics, as well as to reduce the contents of the alloying elements and to make the controlled rolling process less rigid, contributing to increase the productivity of heavy plate rolling.

The accelerated cooling allows the reduction of alloying element contents, directly impacting the production cost of the steel. This makes it possible to obtain steel plates with more refined and homogeneous microstructures than those obtained through conventional rolling without accelerated cooling, besides a range of mechanical properties and microstructural constituents, depending on the cooling condition.

For accelerated cooling to be effective, a thermomechanical rolling is required to obtain a larger fraction of elongated and refined grains, which will later serve as nucleation points of ferritic grains. After this procedure, the application of the accelerated cooling allows to control the transformation of phases, to obtain the desired microstructure [2].

The new Gerdau Plate Mill has state of the art equipment and process technology: a compact line of 900 meters in length with a capacity of 1.2 million t/year of heavy plates in thicknesses between 6.0 and 150 mm and widths between 900 and 3,700 mm. The rolling line is comprised of a plate reheating furnace, a heavy plate mill, pre-leveller machine, accelerated cooling system (Mulpic) and hot leveller. Such equipment is used to obtain high strength and low alloy steels with high toughness requirements.

2 MATERIAL AND METHODS

The alloy design adopted in this study was a NbTi microalloyed steel with additions of Cu and Ni. Its steelmaking route included treatment in ladle furnace, RH degassing and Ca injection for globulization of inclusions.

The slabs were reheated up to a temperature high enough to fully dissolve Nb precipitates, according to the value predicted by the Irvine equation [7], but considering the nitrogen content that must have been consumed due to the stoichiometric reaction with titanium. The rolling was carried out with a holding period between the roughing and finishing phases. After the holding phase, finishing rolling was started under temperatures below the non-recrystallization temperature, according to the value calculated by Boratto et al. [8], with the final rolling occurred in the fully austenitic field, that is, at temperatures above Ar_3, as calculated by Ouchi et al. [9].

The accelerated cooling started shortly after the exit of the plate from the mill, at temperatures above B_s. Therefore, the temperature at the end of the accelerated cooling was just below B_f, as calculated by Steven and Haynes [10].

The slabs were hot rolled in plates with thicknesses of 25.40 and 50.80 mm, and the values proposed for the evaluation of mechanical properties for the plates of this study were: minimum yield strength of 400 MPa; tensile strength between 510 and 650 MPa; and minimum total elongation of 20%, considering a measurement basis of 5.65 $\sqrt{A_0}$. The results of Charpy impact strength were determined under temperatures of -20°C, -40°C and -60°C, requiring a minimum energy value of 40 J.

The tensile tests were carried out using specimens machined in the cross section of the plates. For its turn, the Charpy impact tests were performed using 10 mm × 10 mm specimens, machined in the longitudinal direction of rolling of the plates and using "V" shaped notches.

3 RESULTS AND DISCUSSION

Tables 2 and 3 show the results obtained in the tensile tests of the plates analyzed in this study. As can be seen, the proposed mechanical properties requirements were fully met. It is noteworthy that the maximum difference in mechanical properties between the top and bottom of the plates was 31 MPa for the 25.40 mm plates, a fact that demonstrates the good operational stability of the accelerated cooling process, as can be observed in thermographs presented in Figures 2 and 3.

Table 2. Tensile tests results of the 25.40 mm plates

Plate	Thickness (mm)	Tensile Test (Transversal Specimen)					
		YS Avg. (MPa)	TS Avg. (MPa)	YS/TS Avg.	EL 5.65 $\sqrt{A_0}$ Avg. (%)	Δ YS T and B (MPa)	Δ TS T and B (MPa)
1	25.40	455	556	0.82	27	29	28
2		472	566	0.83	27	28	27
3		480	570	0.84	27	2	13
4		470	563	0.82	29	31	27

Table 3. Tension tests results of the plates with 50.80 mm thickness

Plate	Thickness (mm)	Tension Test (Transversal Specimen)					
		YS Avg. (MPa)	TS Avg. (MPa)	YS/TS Avg.	EL 5.65 $\sqrt{A_0}$ Avg. (%)	Δ YS T and B (MPa)	Δ TS T and B (MPa)
1	50.80	443	546	0.81	26	13	14
2		445	555	0.80	26	0	6
3		439	553	0.79	26	4	10
4		449	557	0.80	25	16	0

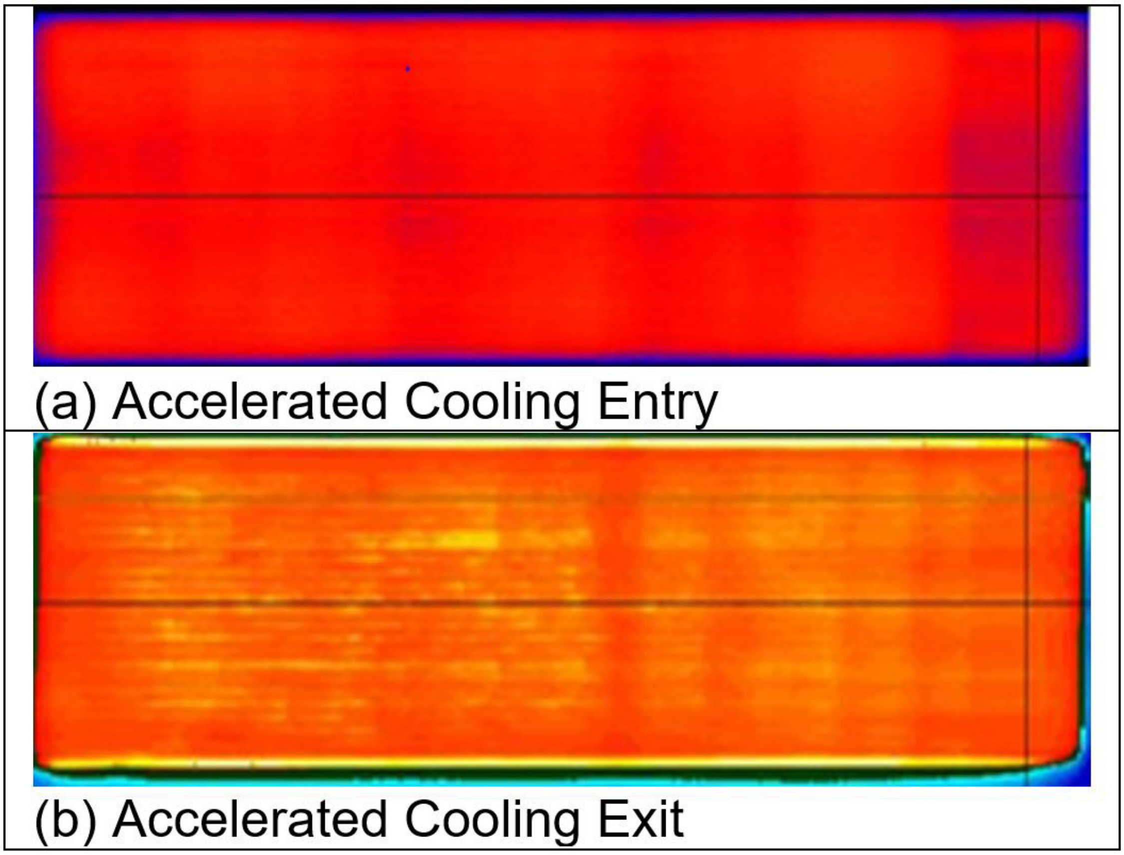

Figure 2. Photographs of entry (a) and exit (b) of the accelerated cooling process of the plate with 25.40mm thickness.

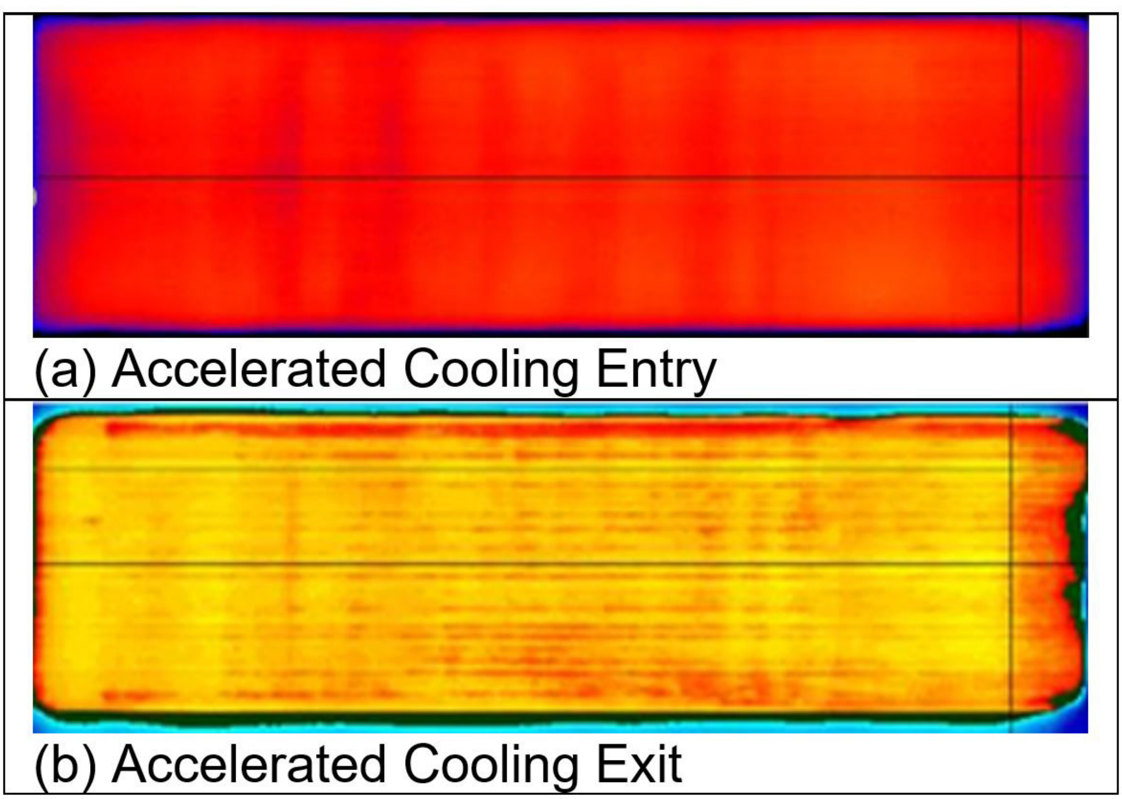

Figure 3. Photographs of entry (a) and exit (b) of the accelerated cooling process of the plate with 50.80 mm thickness.

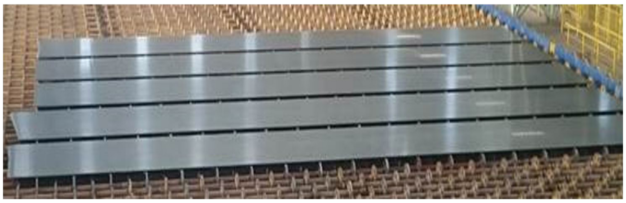

Figure 4. 25.40 mm thick plates in the cooling bed.

Table 4. Charpy impact tests results of the 25.40 mm thick plates

Plate	Thickness (mm)	Average Energy Absorbed (J)		
		-20°C	-40°C	-60°C
1	25.40	418	409	220
2		418	378	234
3		431	434	169
4		411	418	118

Table 5. Charpy impact tests results of the 50.80 mm thick plates

Plate	Thickness (mm)	Average Energy Absorbed (J)		
		-20°C	-40°C	-60°C
1	50.80	412	391	98
2		315	269	132
3		415	409	121
4		416	409	116

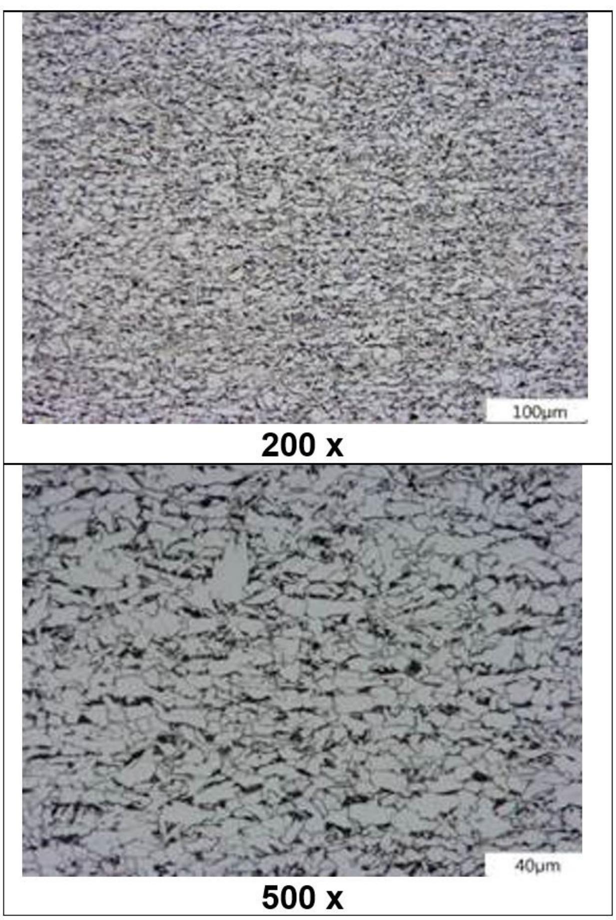

Figure 5. Typical microstructures at ¼ of the thickness of thick 25.40 mm plates. Nital etching 3%.

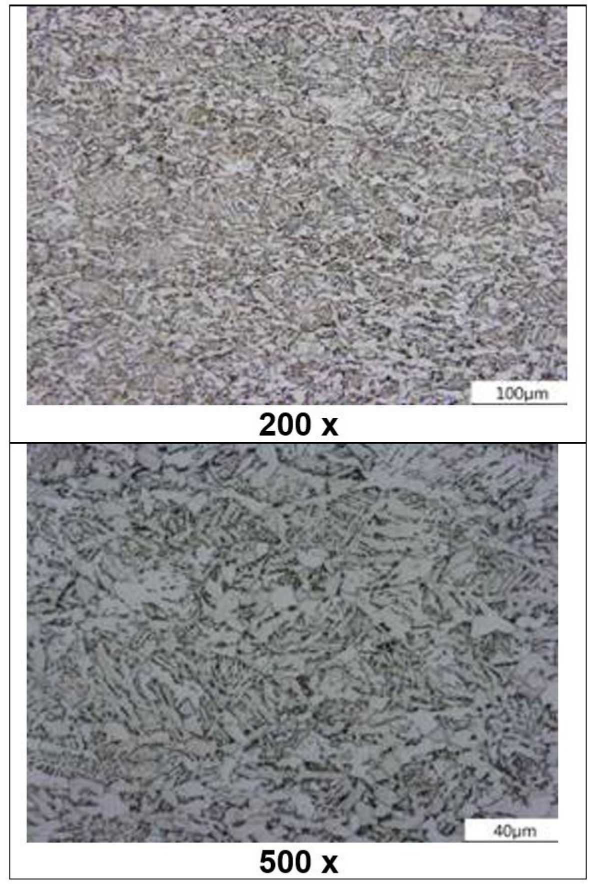

Figure 6. Typical microstructures at ¼ thickness of 50.80 mm thick plates. Nital etching 3%.

Figure 4 shows the photos of some 25.40 mm thick plates in the cooling bed, where its good flatness can be noticed.

Tables 4 and 5 show the results got in the Charpy impact test of the samples extracted from the plates of this study. As it can be seen, the proposed mechanical properties have been fully met. It is noteworthy that, even in tests conducted under the minimum temperature of -60°C, the results of absorbed energy remained above 90 J.

Figures 5 and 6 show two microstructures of different samples from heavy plates of 25.40 and 50.80 mm thickness, respectively, seen under different magnifications. The microstructures presented a mixed character with well refined acicular constituents, similar to what is expected for microalloyed steels subjected to the thermomechanical treatment described here, as well as polygonal ferrite grains.

4 CONCLUSION

Information related to mechanical strength, toughness, microstructure and thermomechanical rolling followed by accelerated cooling of NbTi microalloyed steel plates were presented in this work.

The mechanical properties results were compatible with those expected for a microalloyed C-Mn steel, processed through controlled rolling and accelerated cooling.

The differences in mechanical strength between top and bottom, as well as the flatness of the rolled plates, have demonstrated the good stability of the accelerated cooling process, which is of utmost importance for the microstructure and mechanical properties consistency of the final product.

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