ITABIRITOS PROJECT: A BREAKTHROUGH FOR GERDAU OURO BRANCO IN DESIGN AND PRODUCTION OF API STEELS FOR IRON ORE PIPELINE*

Altair Lúcio de Souza [1]
Mariana Govoni Baccani Dantas [2]
Afrânio Marcio Costa [3]
Cleiton Arlindo Martins [4]
Gustavo Sales de Paula [5]
Antônio Adel dos Santos [6]
Antônio Augusto Gorni [7]
Marcelo Arantes Rebellato [8]

Abstract
As part of Gerdau's investment in a sustainable platform for mining operations, the Itabiritos Project iron ore pipeline was established to transport iron ore from its Miguel Burnier mine to the Ouro Branco steel plant. More than 3 kt of hot coils of steel grades API X52 and API X65, with a thickness of 12.7 mm, were developed and successfully produced in its own Steckel mill line. The alloy design was based on C-Mn steels microalloyed with Nb, Ti, and V, processed by TMCP (Thermomechanical Controlled Processing). A major challenge was achieving the specified level of toughness, evaluated by the shear area in Charpy tests. This was overcome by adjusting, among other operating parameters, the holding thickness before finishing rolling. A direct linear dependence of shear area on austenite hardening during the pancaking phase was observed. It was noted that a holding thickness/final thickness ratio of around four allowed full compliance with the 85% shear area criterion in these steels.

Keywords: Iron ore pipeline; API steels; Steckel mill; Toughness.

[1] *Metallurgical Engineer, M.Sc., UFOP/UFMG, R&D Specialist, TAG, Gerdau, Ouro Branco, MG, BR*
[2] *Metallurgical Engineer, FEI,Technical Applications Coordinator,TAG, Gerdau,Ouro Branco,MG, BR*
[3] *Metallurgical Engineer, M.Sc., UFMG, R&D Manager,TAG,Gerdau,Ouro Branco, MG, BR*
[4] *Metallurgical Engineer, D.Sc., UFOP, Process Specialist,HSM,Gerdau,Ouro Branco, MG, BR*
[5] *Metallurgical Engineer,UFOP, Process Specialist, HSM, Gerdau, Ouro Branco, MG, BR*
[6] *Metallurgical Engineer, D.Sc., UFMG, Consultant, DELMET, Ipatinga, MG, BR*
[7] *PhD, MSc., Materials Engineer, Independent Metallurgical Consultant, São Vicente SP, BR*
[8] *Metallurgical Engineer, FEI, Technical Consultant, Eurosport, SP, BR*

** Technical contribution to the 60º Seminário de Laminação, Conformação de Metais e Produtos, part of the ABM Week 9th edition, September 9th-11th, 2025, São Paulo, SP, Brazil.*

1 INTRODUCTION

There is increasing worldwide awareness in the industry about the need for environmental protection, along with pressure to reduce processing costs to remain competitive. In response, Gerdau has launched a sustainability platform for its mining operations, including a project to transport iron ore by pipeline from its Miguel Burnier mine to the Ouro Branco plant, replacing the movement of approximately 400 trucks per day on the BR-040 main road. This initiative will, of course, reduce greenhouse gas emissions by decreasing fossil fuel consumption, while also alleviating traffic congestion on that road. Additionally, improvements in safety, efficiency, and operating costs are expected.
The project was designed by a third-party supplier, who defined the steel grades API X52 and API X65 to be used along the 13 km route. Since Gerdau Ouro Branco had the capability to produce these steels in its hot strip mill, the task was to develop the unprecedented X52 and X65, which had not been produced before in a thickness of 12.7 mm.
The foundations for producing API-grade steel have long been established [1-3]. The key premises include a chemical composition with low carbon content and the addition of alloying elements such as Mn, Si, Cr, Ni, and Mo, as well as microalloying elements like Nb, Ti, and V. The TMCP process should be applied to maximize the beneficial effects of microalloying, notably Nb, by promoting austenite pancaking during finishing rolling and achieving a highly refined final microstructure. This allows for the attainment of high levels of both strength and toughness.
However, each new project involving API steels typically has specific requirements that necessitate adjustments to chemical composition and rolling parameters, even if similar steel grades have previously been produced by the same rolling mill. One major challenge, in this regard, is ensuring satisfactory toughness in terms of minimum shear area in impact tests, even though the requirements for iron ore pipelines may not be as strict as those for gas and oil transportation pipelines [4].
This paper focuses on metallurgical concepts and the properties achieved in the production of over 3 kt of API-grade X52 and X65 steels in Gerdau’s hot strip mill line, which is based on a Steckel mill, referring to the year 2024.

2 DEVELOPMENT

2.1 Itabiritos Project

Gerdau’s Itabiritos Project iron ore pipeline aims to optimize the transportation of iron ore from the Miguel Burnier mine, located in the Ouro Preto district, to the Gerdau Ouro Branco steel plant. It is part of Gerdau’s broader investment in a sustainable mining operations platform, totaling R$ 3.2 billion. This strategic initiative seeks to improve logistics efficiency, reduce operating costs, and minimize environmental impact by decreasing road transportation, which is estimated at approximately 400 trucks per day. Figure 1 shows the map of the pipeline project.

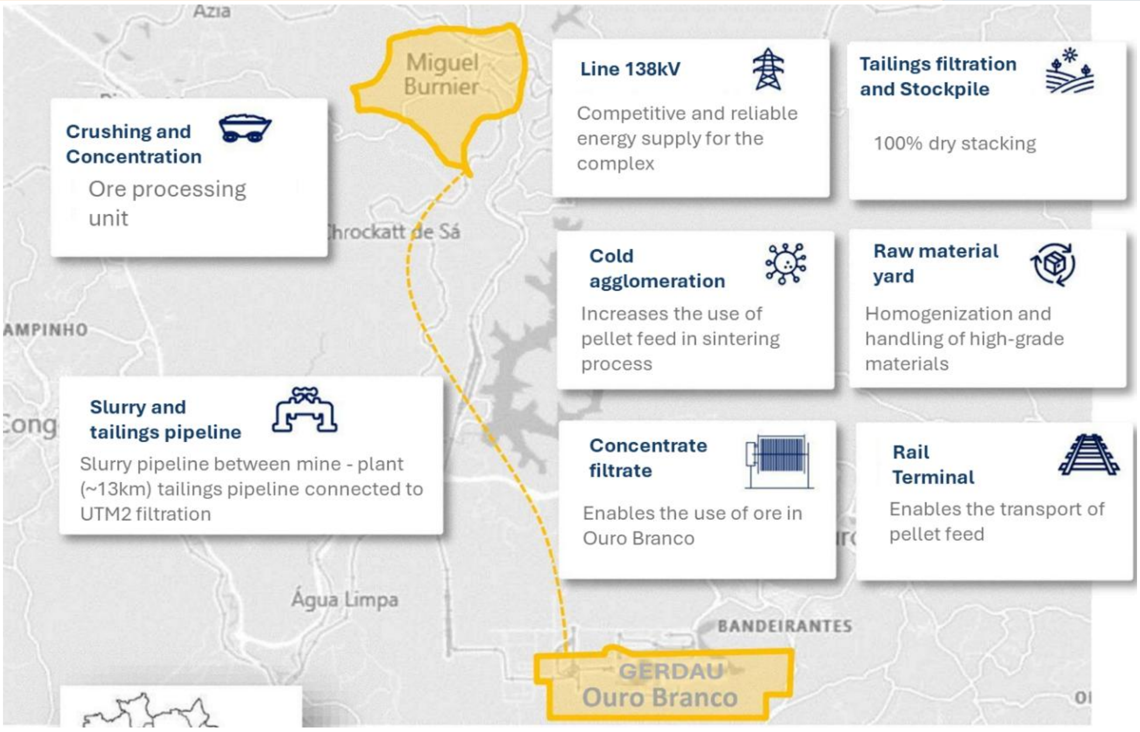

Figure 1. Iron ore pipeline description (adapted figure).

It is 13 km long, directly connecting the mine to the steel plant and operating continuously and safely, with a transportation capacity of 5.5 million tons of ore per year. Updated technologies will be implemented to ensure safety, environmental protection, and cost reductions, including 100% dry stacking of ore waste, filtering systems to guarantee high-quality iron ore, and water recirculation throughout the production route. Additionally, the entire system will be continuously monitored to prevent any negative impact on the environment and water sources.

2.2 Design and Production of Steels Used in the Project

Almost the entire pipeline length was designed to utilize API steels, specifically grades X52 and X65, with a thickness of 12.7 mm, produced via the hot strip mill route. The choice of steel coils over heavy plates offers significant advantages, including lower steel costs and higher productivity.

At the time of production, Gerdau's hot strip mill line consisted of a reheating furnace, a Steckel mill performing all hot rolling passes, followed by a cooling table and two downcoilers. These specific steel grades had not yet been developed in this mill, so efforts were concentrated on development, testing, and supplying the materials within the required timeframe and tonnage, while maintaining cost efficiency.

Table 1 presents the specifications for both steel grades as hot-rolled coils. It is important to note that the mechanical properties of coils must exceed those standardized for pipes to compensate for the Bauschinger effect, which occurs during pipe manufacturing.

Table 1. Tensile and toughness properties specification for the steels

Grade	Thickness (mm)	Tensile properties, Transverse				Toughness, Transverse				
		YS 0.5% (MPa)	TS (MPa)	EL (%)	YS/TS	T (°C)	Charpy Energy, average (J)	Charpy Energy, sample (J)	Ductile Area, average (%)	Shear Area, sample (%)
X52	12.0 ~ 13.0	405 ~ 505	480 ~ 580	≥ 32	≤ 0.87	-20	≥ 65	≥ 45	≥ 85	≥ 65
X65	11.0 ~ 13.0	500 ~ 615	590 ~ 710	≥ 28	≤ 0.90	-20	≥ 60	≥ 45	≥ 85	≥ 65

2.2.1 API X52 Steel

To achieve the desired properties, a hot band with a steel microstructure composed of fine ferrite grains and pearlite was deemed suitable. This steel developed is a C-Mn silicon-killed alloy microalloyed with Nb and Ti, as shown in Table 2.

Table 2. Chemical composition (mass percent) and main process conditions for X52 steel.

Ceq [%]	C [%]	Mn [%]	Si [%]	Slab Thickness [mm]	Reheating Temperature [°C]
≤ 0,38	≤ 0,15	≤ 1,00	≤ 0,40	250	> 1150

Steckel mills have the unique capability of enabling TMCP to be applied in a hot strip mill, similar to its application in plate mills. Therefore, this procedure was adopted to produce API X52 steels, using a holding thickness before finishing rolling. The main TMCP parameters and slab dimensions are also shown in Table 2.
The primary advantage of TMCP is grain size refinement, achieved through microalloying additions, particularly Nb, which delays austenite recrystallization and results in a pancaked austenite at the end of rolling. This process ultimately leads to a very fine ferritic microstructure. However, TMCP requires more time than conventional rolling, thereby reducing productivity.
An example of the final microstructure of the API X52 grade is presented in Figure 2.

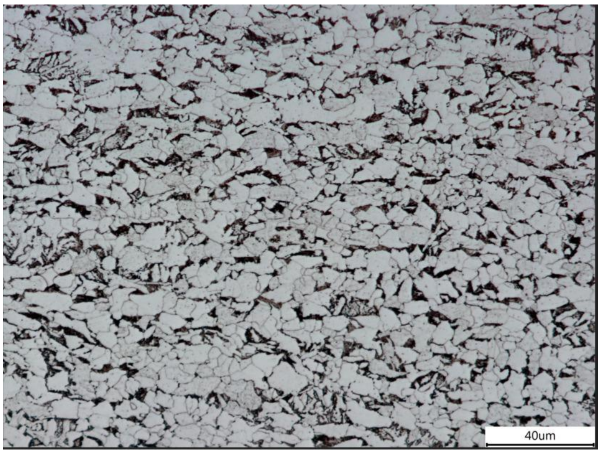

Figure 2. Optical image of the typical microstructure of X52 steel.

A refined microstructure is essential for achieving high tensile properties and high toughness simultaneously. Adjustments to process parameters and chemical

composition were made to ensure that the specified properties were consistently achieved, as illustrated by the graphs in Figure 3.
Both YS and TS were comfortably above the minimum requirement, while the absorbed energy significantly exceeded the specification. The average shear area was 92%, fully meeting the challenging prerequisite of a minimum of 85%. Additionally, the YS/TS ratio averaged 0.78, well below the maximum allowable value of 0.87.

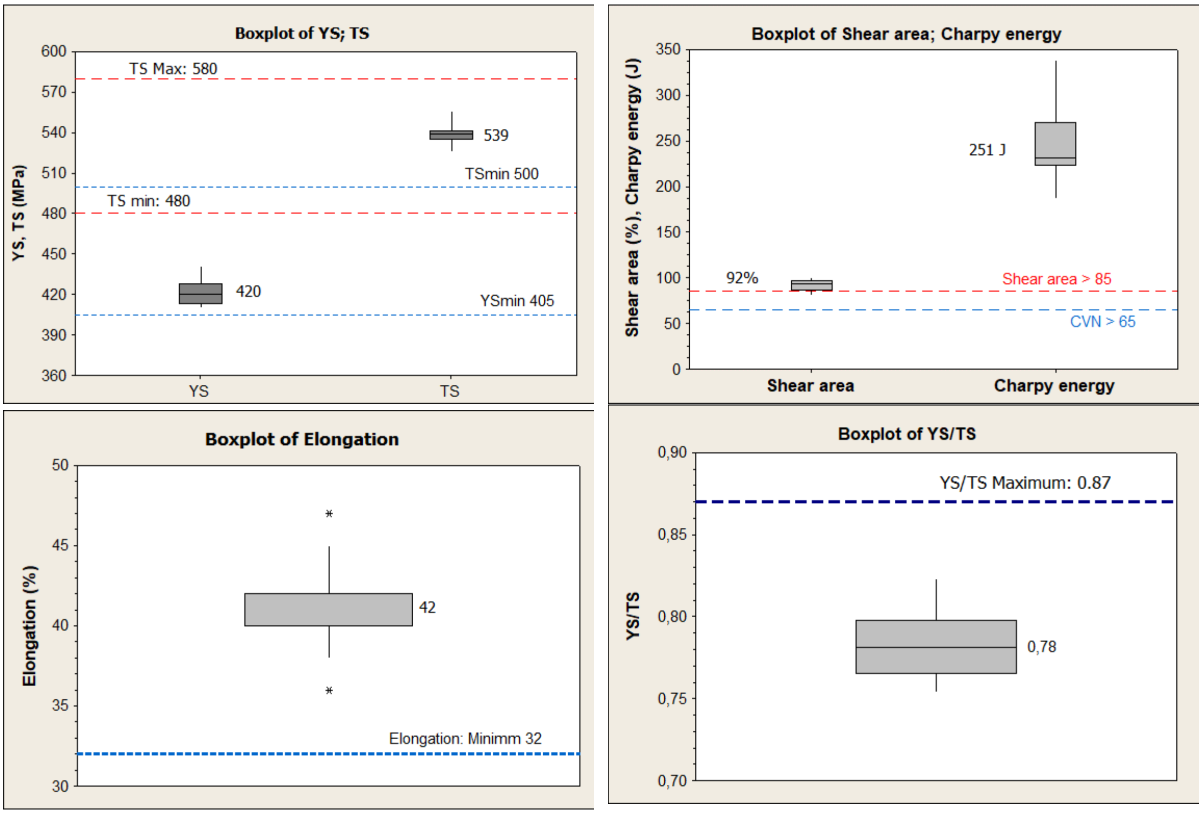

Figure 3. Boxplot graphs based on the average value of API X52 steel properties obtained during production.

2.2.2 API X65 Steel

The microstructure required to meet the X65 grade, a high-strength steel, must be very fine-grained, consisting of ferrite, pearlite, and possibly some bainite. This composition provides the necessary combination of high strength and high toughness while maintaining a low carbon equivalent.
It is expected that multiple strengthening mechanisms will contribute to achieving the required properties, including solid solution strengthening, grain size refinement, transformation hardening, dislocation density, and precipitation hardening. Among these, grain refinement plays the most significant role. The best way to achieve a refined microstructure is through TMCP, which is inherently linked to microalloying additions of Nb, Ti, and V. These elements delay austenite recrystallization, leading to a pancaked austenite at the end of rolling, which results in ultrafine ferrite grains after phase transformation.
In addition to C, Mn, and Si, other alloying elements such as Ni and Cr further enhance strengthening via solid solution hardening. Cr is also known to contribute to strengthening through transformation hardening and by promoting the formation of more acicular constituents, characteristic of low-temperature transformations.

Based on these principles, the chemical composition of API X65 steel has been generally defined, as shown in Table 3, including the reheating temperature used to dissolve all Nb and slab dimensions.

Table 3. Chemical composition (mass percent) and main process conditions for X65 steel

Ceq	C [%]	Mn [%]	Si [%]	Nb+Ti+V [%]	Others	Slab Thickness [mm]	Reheating Temperature [°C]
≤ 0,43	≤ 0,15	≤ 1,50	≤ 0,40	≤ 0,12	Cr, Ni	250	> 1200

The common practice of TMCP for producing HSLA steels relies on Nb microalloying and strict control of temperature and rolling schedule. After roughing phase, the transfer bar is kept for a holding time, at specific holding thickness, until its temperature drops below the non-recrystallization temperature, since onwards austenite will no more recrystallize, giving a deformed structure which ends up in a refined final microstructure. This way, Nb will exert its full potential in TMCP. Although providing several benefits, TMCP has a great drawback of productivity reduction due to the holding time.

Then, in this project, three different rolling schedules were used in the TMCP, seeking the best configuration to meet the requirements of mechanical properties and process conditions:

a) HTA = TMCP with holding thickness of > 40 mm
b) HTB = TMCP with holding thickness of < 40 mm
c) NH = TMCP without holding thickness

Figure 4 presents the typical microstructure obtained in the X65 steel, which consists of ferrite, pearlite and some bainite, as expected, and is very refined.

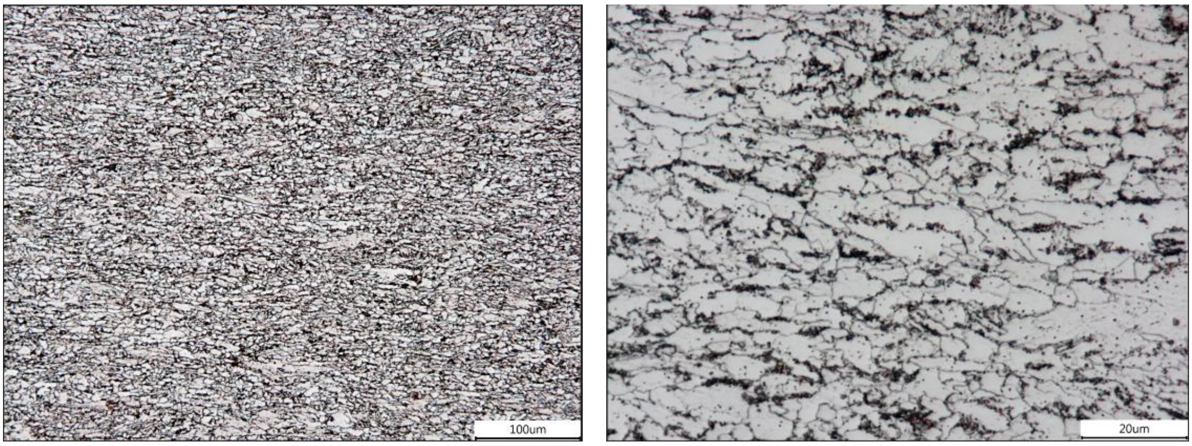

Figure 4. Optical images of typical microstructure in X65 steel.

Figure 5 shows the results of tensile and Charpy toughness properties obtained in commercial production. In terms of tensile properties, all three processing conditions lead to results fully meeting the requirements. It is noticeable that YS and TS values show an increasing trend in the order HTA, HTB, NH, while the elongation has an opposite tendency. It is also worth noting the high homogeneity of YS and TS results on HTA, evaluated by very the low scattering around the mean. In addition, it can be noticed that lower ratio YS/TS is favored by the TMCP condition, giving rise to values around 0.84 in a comfortable zone, while direct rolling without holding time provides that ratio near the maximum specified.

The higher values of YS, TS in the material rolled without TMCP maybe justified by the lower finishing rolling temperatures employed in this condition, but in-depth investigation should be carried out in order to explain it, which is out of scope in the present work.

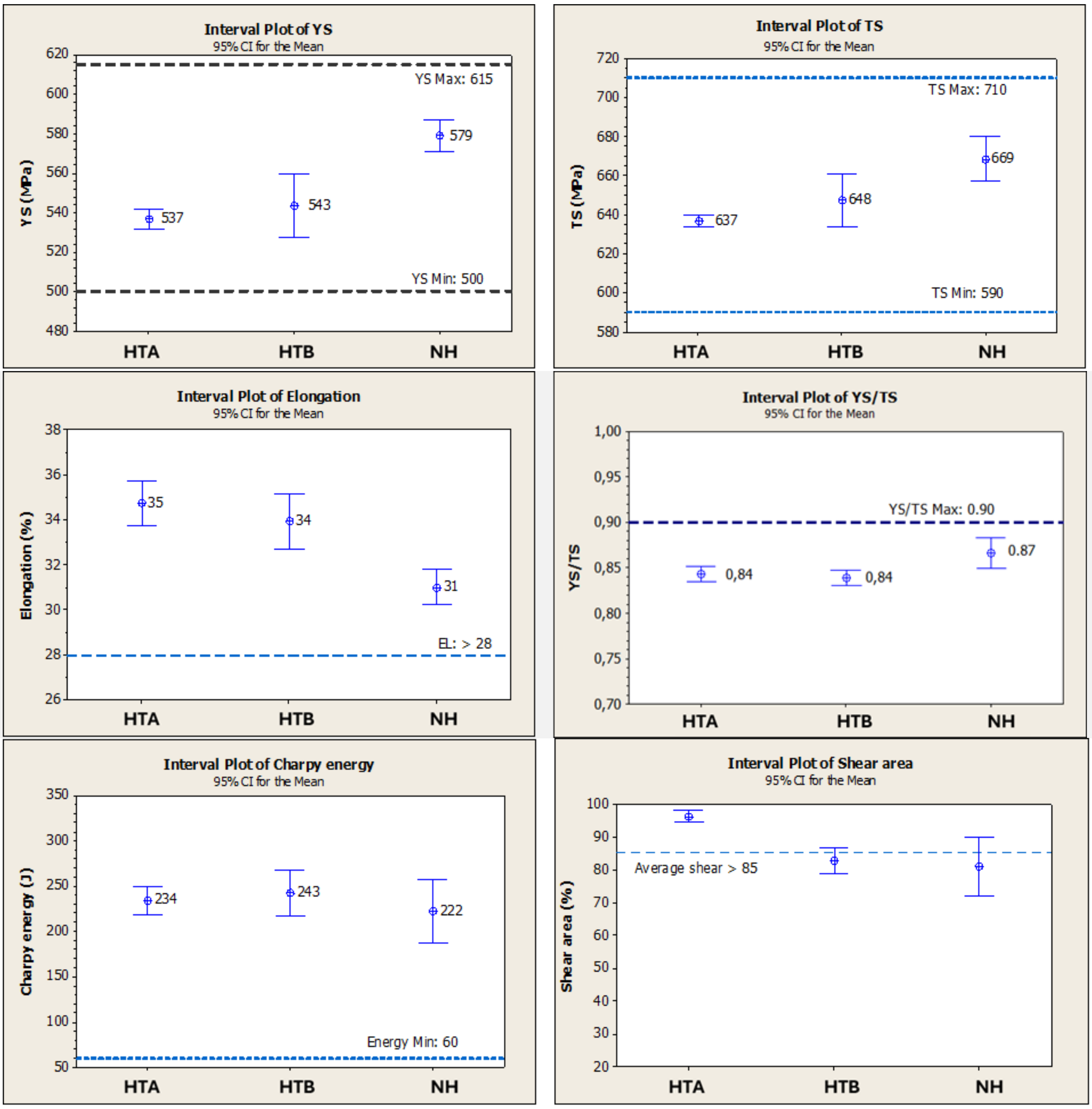

Figure 5. Interval of the mean graphs of tensile and toughness properties of X65 steel obtained during production.

In terms of toughness, the absorbed energy values in Charpy tests remained well above the minimum requirement of 60 J. The differences among the three processing conditions were significant, with values ranging from 220 to 240 J. It is known that TMCP steel, with its refined microstructure and high cleanliness achieved through good steelmaking practices, easily meets the required levels of absorbed energy. However, shear area is a more challenging property to achieve.

The last graph in Figure 5 demonstrates the substantial impact of processing conditions on shear area in Charpy specimens. For the HTB and NH conditions, the minimum average shear area of 85% was only partially achieved by the produced coils.

In contrast, all shear area values obtained in coils produced via HTA remained above the minimum requirement and exhibited a very narrow dispersion band.

To explain this result, the reasoning is that the amount of rolling deformation in the finishing phase, after holding time, increases with higher holding thickness. This leads to a more pancaked and uniform austenite microstructure before cooling and phase transformation [3,5,6]. Simulations using MicroSim software, developed by CEIT, were conducted to compare various predicted metallurgical parameters during the rolling of five slabs, including two slabs processed with holding thickness > 40 mm (HTA), two with holding thickness < 40 mm (HTB), and one with no holding thickness (NH).

Figure 6 illustrates the evolution of recrystallized fraction and accumulated strain. Five out of eleven passes showed no recrystallization for the HTA scheme, three out of eleven for HTB, and just two for NH. Consequently, the predicted accumulated strain at the end of rolling decreased in that order.

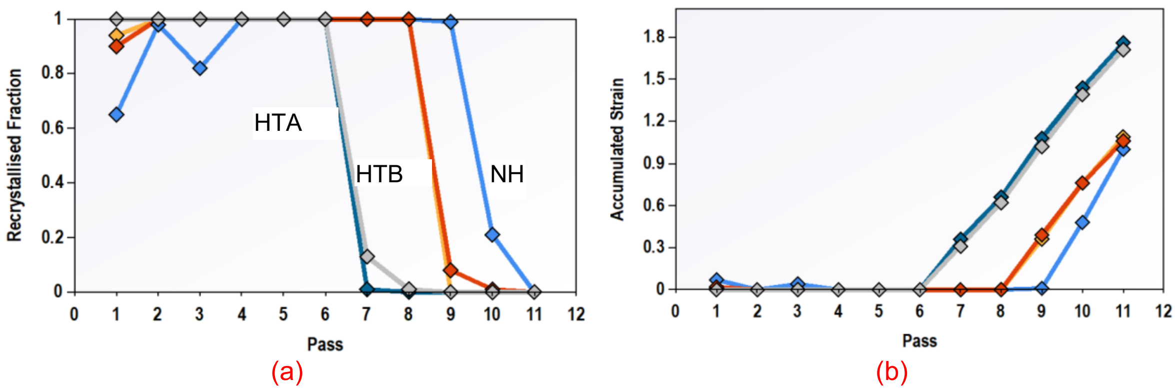

Figure 6. Evolution of recrystallized fraction, (a), and accumulated strain, (b) predicted by MicroSim in three rolling conditions.

To further analyze the effect of austenite hardening on toughness properties, the amount of reduction without austenite recrystallization—defined as less than 1% recrystallized fraction, as shown in Figure 6-a—was considered. As observed in the graph in Figure 7, the shear area exhibits a clear increasing trend with austenite conditioning, whereas Charpy energy remains relatively constant, forming a plateau.

This finding is particularly interesting because, as previously mentioned, achieving high levels of absorbed energy is relatively straightforward and is only slightly influenced by austenite conditioning, unlike shear area. Meeting the required shear area levels is significantly more challenging.

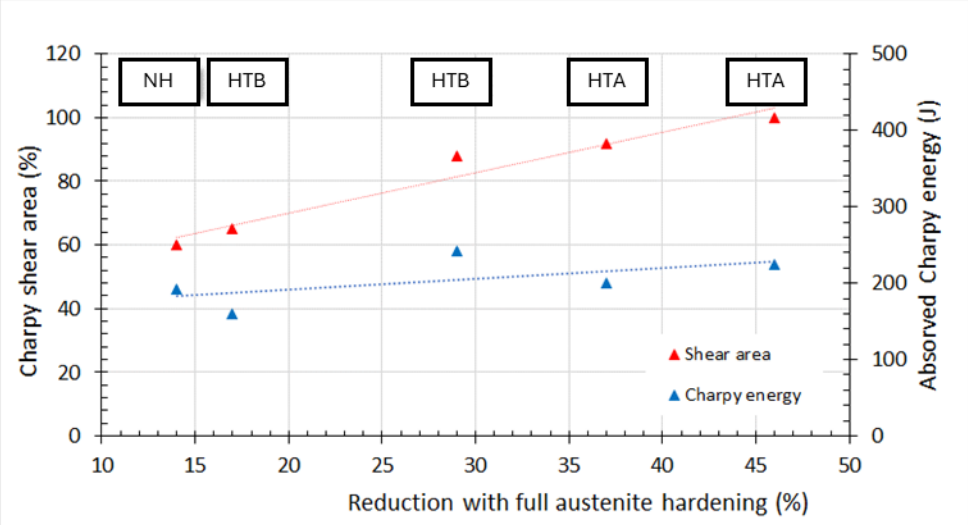

Figure 7. Influence of austenite hardening on Charpy toughness properties.

These findings align with the literature, which indicates that a minimum reduction in the finishing phase of TMCP rolling—defined by the ratio of holding thickness to final thickness—is necessary to meet toughness requirements, as schematically illustrated in Figure 8 [6,7].
Based on these analyses, the production of API X65 steel at Gerdau Ouro Branco for the iron ore pipeline was successfully carried out, meeting all specifications. It is important to note that increased holding thickness reduces productivity; therefore, a balance must be struck between product costs (productivity) and the desired level of toughness properties.

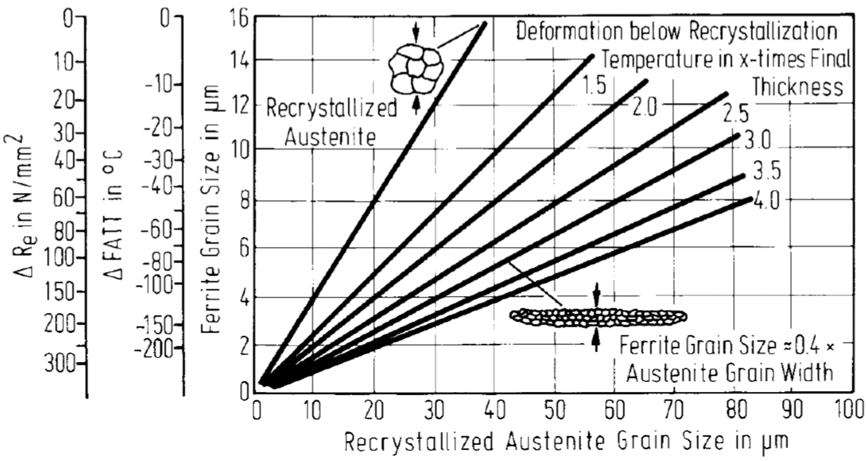

Figure 8. Schematic representation of austenite conditioning on fracture appearance transition temperature and ferrite grain size [6].

It is known that the material's ability to arrest unstable cracks is better predicted by the shear area obtained in the DWTT (Drop Weight Tear Test) than in the Charpy test, primarily because the DWTT uses full-thickness specimens. To confirm the high toughness of API X65 steel, DWTT tests were conducted on only a few samples, as they were not specified in the project.

In Figure 9, the fracture appearance of DWTT specimens tested at -20°C is superimposed on the graph of Charpy shear area. A holding thickness > 40 mm results in a shear area of 100%, indicating a high-toughness steel under this processing condition. As the holding thickness decreases, the shear area correspondingly declines.

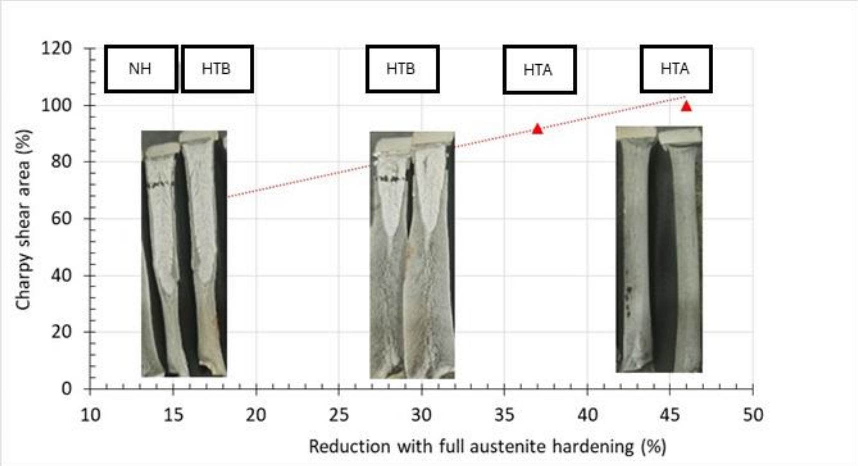

Figure 9. Influence of austenite hardening on fracture appearance in DWTT tests and Charpy shear area.

3 CONCLUSION

The Itabiritos Gerdau Project has been successfully executed through the design, development, and production of API steels in Ouro Branco's Steckel mill. Over 3 kt of X65 and X52 steel grades, with a thickness of 12.7 mm, were supplied to pipe manufacturers in Brazil, meeting all required tensile and toughness properties.
The Steckel mill has a unique capability that enables the production of high-strength steels through TMCP, similar to plate mills. Consequently, this route allowed for the production of API steels with relatively high productivity, a high yield ratio, and economic efficiency.
The use of microalloying elements in these steels, particularly Nb, is essential for achieving the desired combination of high strength and high toughness through grain refinement.
One major challenge in API steel production is meeting the shear area requirements in Charpy or DWTT specimens. The results indicate a linear increasing trend in shear area with austenite hardening during the finishing rolling phase. Thus, maintaining a holding thickness-to-final thickness ratio of approximately four was both sufficient and necessary to fully meet the minimum shear area criterion of 85%.
Despite the improvement in toughness, higher holding thickness negatively impacts productivity. Therefore, an optimal processing condition must be identified to balance productivity and material performance.

Acknowledgments

GERDAU would like to thank the consultants from DELMET, Eurosport and CBMM for their important contributions to the development of this work.

REFERENCES

1 Soeiro Junior JC, Rocha DB, Brandi SD. Uma Breve Revisão Histórica do Desenvolvimento da Soldagem dos Aços API para Tubulações. Soldagem e Inspeção, 2013:18(2):176-195.
2 Gras M, Kalwa, C. Development and production of high strength pipeline steels
3 Tamura I, Sekine H, Tanaka T, Ouchi C. Thermomechanical Processing of High-strength Low-alloy Steels. Butterworth, London, 1988.
4 Godefroid LB, Cândido LC, Toffolo RB, Barbosa LHS. Microestrutura e propriedades mecânicas de dois aços do tipo API para emprego em minerodutos.
5 Uranga P, Rodríguez-Ibabe JM. Thermomechanical Processing of Steels, Metals, 2020, 10(61):1-4.
6 Aleksandrov S.V. Metal Science and Heat Treatment, 2005.
7 Stalheim DG. Recrystallization behaviors in the production of structural steels. ABM Week 2015, 52º Seminário de Laminação, Rio de Janeiro, 17-21 Ausgust