THE INFLUENCE OF THE INTERCRITICAL QUENCHING TEMPERATURE ON THE MECHANICAL PROPERTIES OF A Nb-Ti MICROALLOYED LOW CARBON STEEL[1]

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Abstract

In this work, were available the influence of the quenching temperature on the mechanical properties of a Nb-Ti microalloyed low carbon steel containing Si and Mn. The intercritical temperature range and ferrite and martensite volume fractions, as a function of quenching temperature, were obtained by means computer simulation and validated by qualitative and quantitative metallography and dilatometry analyses. The steel samples were quenched from distinct temperatures in the intercritical region, followed by tempering at 610^{o}C to produces a dual-phase microstructure formed by different volume fractions of the ferrite and tempered martensite. The mechanical properties of the steel were available in the structural different conditions by tensile tests. The computer simulation results specify the intercritical temperature range among 697^{o}C and 833^{o}C, which are in a very good agreement with experimental observation. The mechanical results also showed that the heat-treated steel present better forming properties than those in the as-received condition.
Keywords: Dual-phase alloy; Microstructure; Mechanical properties.

A INFLUÊNCIA DA TEMPERATURA INTERCRÍTICA DE TÊMPERA NAS PROPRIEDADES MECÂNICAS DE UM AÇO BAIXO-CARBONO MICROLIGADO AO Nb-Ti

Resumo

Neste trabalho foi avaliada a influência da temperatura de têmpera, sobre as propriedades mecânicas de um aço baixo carbono microligado ao Nb-Ti contendo Si e Mn. A faixa de temperatura intercrítica e as frações volumétricas de ferrita e martensita, como uma função da temperatura de têmpera, e foram determinadas por simulação numérica e validadas por análises de metalografia qualitativa e quantitativa e ensaios de dilatometria. As amostras do aço foram temperadas a partir de diferentes temperaturas, dentro da zona intercrítica e posteriormente revenidas a 610^{o}C, com o intuito de produzir uma estrutura bifásica, formadas por diferentes frações volumétricas de ferrita e martensita revenida,. As propriedades mecânicas do aço foram avaliadas nas diferentes condições estruturais por ensaios de tração. Os numéricos resultados mostraram que a região intercrítica para este aço está entre 697^{o}C e 833^{o}C, os quais estão de acordo com aqueles obtidos experimentalmente. Os resultados mecânicos mostraram que o aço tratado termicamente possui melhores propriedades de conformação do que aquele na condição como recebida.
Palavras-chave: Aço bifásico; Microestrutura; Propriedades mecânicas.

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1 INTRODUCTION

Dual-phase steels have interesting characteristics for the automotive industry, associated to a combination of strength, ductility, and formability that allows achieving weight reduction while maintaining strength.[1-3] The dual-phase steel can be used instead of conventional low-alloy and high strength steel, because they have longer elongation in the same strength limit than classical steels. Mechanical properties such as strain hardening coefficient, fatigue and impact resistance are also higher than those of classical steels.[4-6] These properties derive of the microstructure formed by the mix of an excessively resistant phase (martensite) with another one very soft (ferrite), which is obtained by a specific heat treatment (quenched) from the intercritical region. The combination of the martensite and ferrite phases, allows that the steel reach low yield strength and high tensile strength as consequence of its high strain hardening coefficient, guaranteeing to the dual phase steels high resistance allied to a good formability.[7-10]

In this work, a non-conventional intercritical heat-treatment is conducted on a Nb-Ti microalloyed low-carbon steel containing Si (0.267%) and Mn (1.529%), so as to produce a dual-phase microstructure formed by different ferrite and martensite volume fractions. The intercritical region and the ferrite and martensite volume fractions, as a function of the quenching temperature, were determined by computer simulation using the THERMOCALC software associated to qualitative and quantitative metallography, and dilatometry investigations. In addition, was available the influence of the quenching temperature on the mechanical properties.

2 MATERIALS AND EXPERIMENTAL PROCEDURES

The Nb-Ti microalloyed low-carbon steel, containing Si (0.267%) and Mn (1.529%), used in this work was supplied by Companhia Siderúrgica Nacional (CSN) The intercritical region was determined by numerical simulations using the THERMOCALC software, and considering the effect of the main alloying elements on the phase transformation. The simulations were done with chemical composition shown in Table 1. The numerical predictions were validated by means qualitative and quantitative metallography method using an image analyses system, dilatometry experiments and SEM observation at high magnification.

Table 1. Chemical composition.

Element (%, weight)						
C	Mn	Si	Nb	Ti	P	S
0.111	1.529	0.267	0.048	0.072	0.018	0.0024
Cu	Ni	Cr	Al	Sn	N	B
0.020	0.012	0.016	0.039	0.001	0.0103	0.0001

Experimentally, for obtain samples with the microstructure formed by different volume fractions of the ferrite and martensite, samples of the steel were quenched from different temperatures, in accordance to the intercritical region temperature interval determined by computer simulation, followed by tempering heat-treatment. The samples were machined from plate steel in as-received condition, heat-treated at 680°C, 740°C, 780°C, 820°C and 860°C for 30 minutes, following by quenched in oil, and subsequent tempered at 610°C for 30 minutes and cooled in air. For the quantitative metallographic analyses, the samples were hot mounted, ground using silicon carbide paper (200 mesh – 1.200 mesh), polished with alumina suspension and chemically attacked with Nital solution, and the images were obtained with a Nikon optical microscopy equipped with a digital camera. In order was determined of the ferrite and martensite volume fractions using the image “J” software. The high magnification images at 5000x were obtained in a Scanning Electronic Microscopy, Zeiss DSM 962.

In order to evaluate the A_1, A_3, Ar_1 and Ar_3 temperature were conducted dilatometry experiments using an Adamel DT100 Dilatometer. The thermal cycle comprised of heating up to 1230ºC, holding for 360 s and subsequent cooling down to room temperature with heating and cooling rates being 1ºC/s.

The tension tests were realized in accordance with the ASTM A370 standards using a tensile test machine WOLPERT with capacity of 20 tons.

3 RESULTS AND DISCUSSION

The numerical simulation determined the region which austenite and ferrite are in equilibrium, allowing thus the determination of the temperature range for the intercritical heat-treatments. The numerical results showed in Figure 1 reveal that the intercritical temperature range is between 697ºC and 833ºC and the ferrite and austenite volume fractions as a function of intercritical heat-treatment temperature.

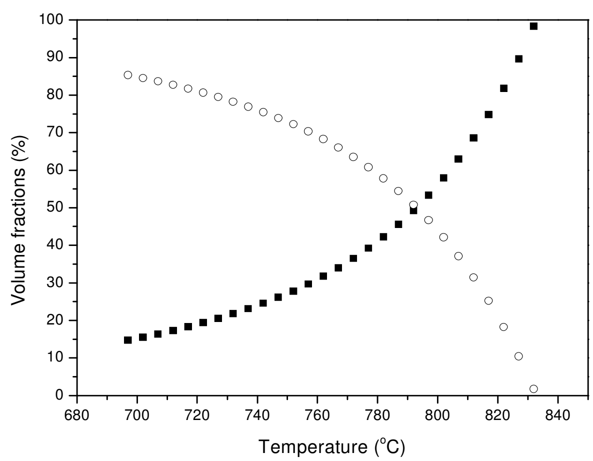

Figure 1. Ferrite and austenite volume fractions (%) as a function of intercritical temperature (O - ferrite (α); ■ - austenite (γ))

The numerical results (Figure 1) were adjusted by a linear fitting, in order to obtain the functions which describe the ferrite and austenite volume fractions as a function of intercritical heat-treatment temperature, as shown in equations 1 and 2.

$$\%\gamma = (25,88 - 0,0724\ T + 5,1x10^{-5}\ T^2)\ x\ 100 \quad (1)$$
$$\%\alpha = (-24,89 + 0,0724\ T - 5,1x10^{-5}\ T^2)\ x\ 100 \quad (2)$$

Figure 2 shows the intercritical temperatures ranges obtained by the transformation temperatures in the heating (A_1 = 732ºC and A_3 = 892ºC) and in the colling (Ar_3 = 700ºC and Ar_1 = 535ºC) during dilatometric test. However, the results between the numerical and experimental methods are different. This difference can be attributed to the numerical method used in the Thermocalc in this work, which not expected the heating rates and precipitated particles influence on the phase transformation during heating.

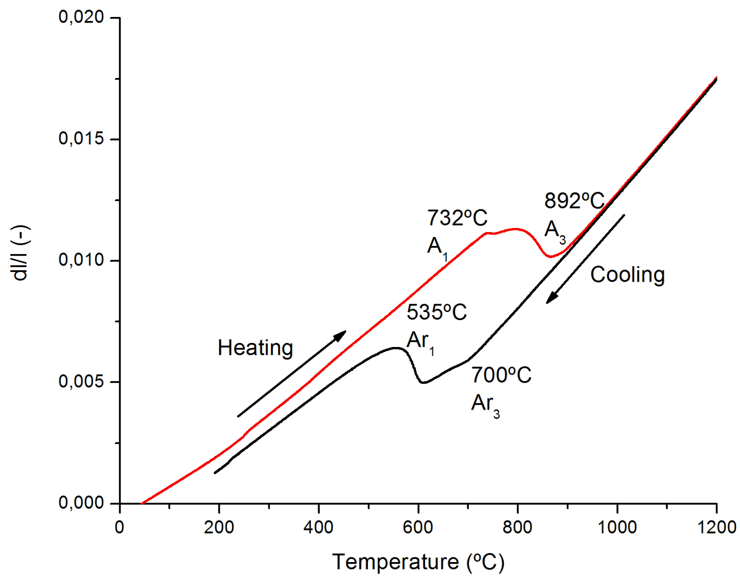

Figure 2. Transformation temperatures from dilatometry results. A_1: 732ºC; A_3: 892ºC; Ar_3: 700ºC; and Ar_1 – 535ºC.

Figure 3 shows the steel microstructure in study used in the quantitative metallography (optical microscopy) in following condition: as-received and quenched from selected temperature (680^{o}C, 740^{o}C, 780^{o}C, 820^{o}C and 860^{o}C) followed by tempering. In the normalized condition and heat-treated at 680^{o}C, this steel presents a microstructure formed by fine perlite and ferrite, heat-treated at 740^{o}C, 780^{o}C, 820^{o}C presents a two-phase microstructure formed by ferrite and tempered martensite, and heat treated at 860^{o}C presents a microstructure formed exclusively by tempered martensite. In addition, it can be observed that the volume fraction of martensite increases with the raise of the quenching temperature, in according to results presented by Thermocalc software (considering that all austenite transform in martensite).

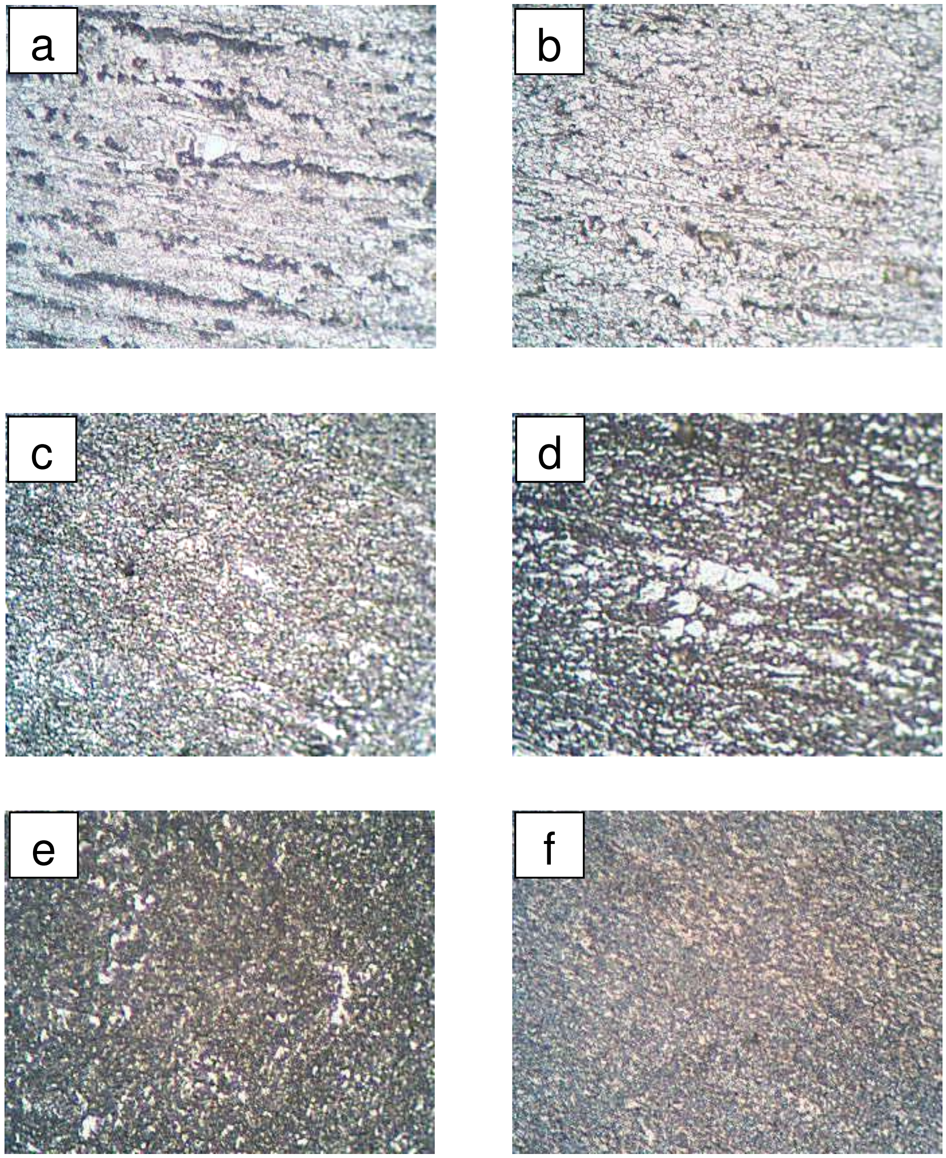

Figure 3. Microstructure from Optic Microscopy of ARBL steel in (a) as-received condition, and heat-treated from (b) 680°C, (c) 740°C, (d) 780°C, (e) 820°C and (f) 860°C. Ferrite - Bright regions. As-received and at 680ºC: Perlite – Dark regions. Upper 680ºC: Martensite – Dark regions.

The results of the quantitative metallography are shown in the Table 2 along with the results obtained by computer simulation. It can be seen that the experimental and calculated results are in a very good agreement.

Table 2. Ferrite and austenite/martensite volume fractions, obtained by computer simulation and quantitative metallography.

Quenching temperature (ºC)	Volume fractions (%)			
	Computer simulation		Quantitative metallography (±10%)	
	Ferrite	Austenite	Ferrite	Martensite
680	100	0	100	0
740	75	25	63	37
780	58	42	54	46
820	20	80	27	73
860	0	100	0	100

The microstructure was observed in SEM at high magnification (5.000x), as shown in Figure 4, exhibited the martensite and ferrite morphology aspects at distinct martensite volume fraction from samples quenching at 740°C, 780°C, 820°C and 860°C) followed by tempering. These results reveal that in the sample quenching at 860ºC remains some ferrite inside the martensitic matrix, that reinforcement the precipitates influence on the ferrite stabilization during transformation on heating,(11) in according to the A_3 temperature (dilatometric results shows in the Figure 2). Instead of, these observations not invalided the predictions calculated by Thermocalc, but that are useful to predict the material behavior.

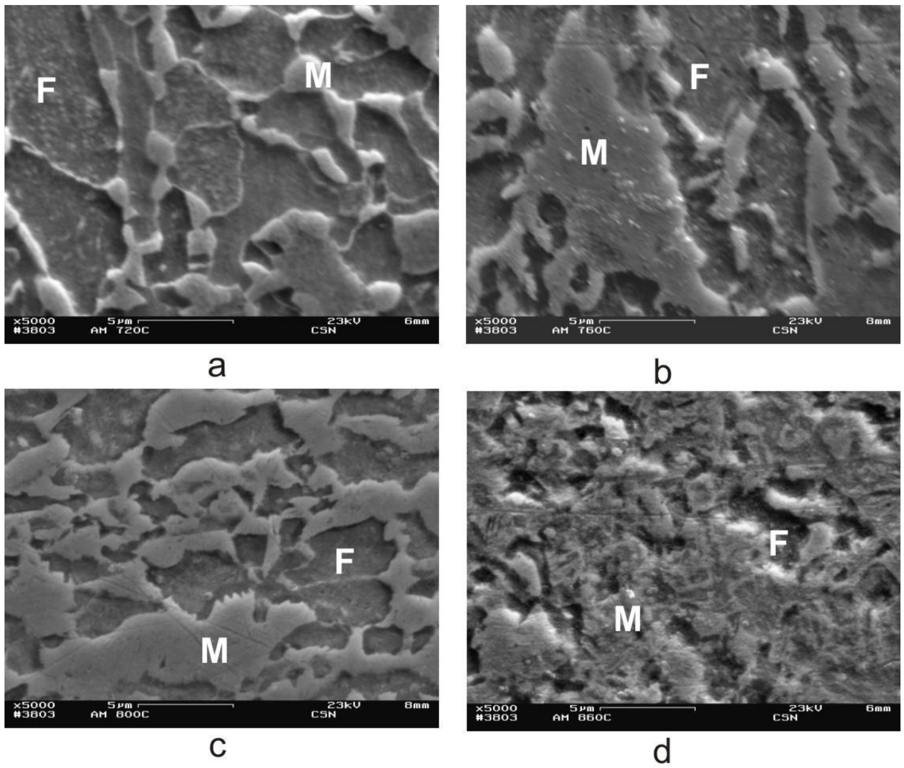

Figure 4. Microstructure from Scanning Electronic Microscopy of ARBL steel show the dual phase aspect details after heat-treated from (a) 740°C, (b) 780°C, (c) 820°C, and (d) 860°C. F - Ferrite. M - Martensite. 5000x.

The Figure 5 shows the curves stress-strain as-received condition and after complete heat treatment (quenching/tempering) at different temperatures (740°C, 780°C and 820°C). This Figure shows that the intercritical heat-treatment had a small influence on the mechanical properties of these steel. The Table 3 shows that the steel heat-treated in intercritical temperatures presented smaller yield strength (σ_e), ultimate strength (σ_R), and total elongation when compared to normalized condition, indicating betters performance in the forming process. However, it can be observed that the changing of the ferrite and martensite volume fractions do not changed significantly the mechanical properties, it can be associated to austenite grain size.

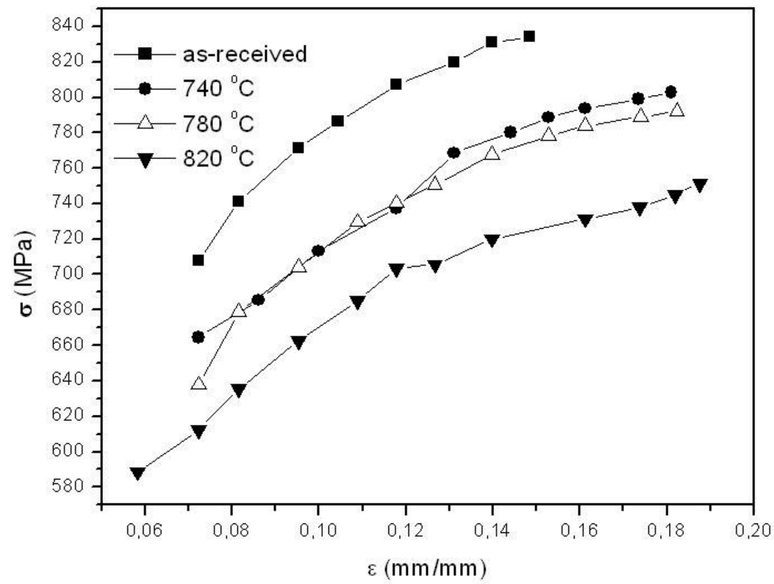

Figure 5. Experimental curves stress-strain in the as-received condition and quenching from the different temperatures (■ – As-received, ● - 740ºC; Δ - 780ºC; ▼ - 820ºC).

Table 3. Mechanical properties of the heat-treated and normalized as-received conditions of the steel with 0,11 % C to the Si and Mn.

Mechanical properties	Quenching temperature			Normalized condition (average of the three samples)
	740ºC	780ºC	820ºC	
σe (MPa)	625	600	555	668
σR (MPa)	677	667	626	721
σR/σe	1.08	1.11	1.13	1.08
Total elongation (%)	20.7	21.3	22.6	20.0

4 CONCLUSIONS

The results obtained by computer simulation and experimentally are in a very good agreement. The steel quenching from intercritical temperatures presented smaller yield strength (σ_e) and ultimate strength (σ_R) and larger total elongation when compared to normalized condition, indicating betters performance in the forming process. However, the increase of the martensite volume fraction does not increase the resistance o f the steel, due to large increase of the austenite-grain size with the quenching temperature.

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REFERENCES

1 AKSOV, M.; KARAMQ, M.B.; EVIN, E. An evaluation of the wear behaviour of a dual-phase low-carbon steel. Wear v. 193, p. 248-252, 1996.

2 KIM, SE-JONG; CHO, YI-GIL; OH, CHANG-SEOK; KIM, DONG EUN; MOON, MAN BEEN; HAN, HEUNG NAM. Development of a dual phase steel using orthogonal design method. Materials and Design. v. 30, p. 1251–1257, 2009.

3 AHMAD, E; MANZOOR, T.; HUSSAIN, N.; QAZI, N.K. Effect of thermomechanical processing on hardenability and tensile fracture of dual-phase steel. Materials and Design v. 29, p. 450–457, 2008.

4 CHAO, Y.J.; WARD Jr., J.D.; SANDS R.G. Charpy impact energy, fracture toughness and ductile–brittle transition temperature of dual-phase 590 Steel. Materials and Design, v. 28, p. 551–557, 2007.

5 AKAY, S.K.; YAZICI, M.; BAYRAM, A; AVINC, A. Fatigue life behaviour of the dual-phase low carbon steel sheets. Journal of materials processing technology. (in press).

6 TAVARES, S.S.M.; PEDROZA, P.D.; TEODOSIO J.R.; GUROVA. T. Mecchanical properties of a quenching and tempered dual phase steel. Scripta Materialia, v. 40, n. 8, p. 887–892, 1999.

7 AL-ABBASI, F.M.; NEMES, J.A. Micromechanical modeling of dual phase steels. International Journal of Mechanical Sciences. v. 45, p. 1449–1465, 2003.

8 JIANG, Z; GUAN, Z.; LIAN J. Effects of microstructural variables on the deformation behaviour of dual-phase steel. Materials Science and Engineering A, v. 190, p. 55-64, 1995.

9 MODI A.P. Effects of microstructure and experimental parameters on high stress abrasive wear behaviour of a 0.19wt% C dual phase steel. Tribology International, v. 40, p. 490–497, 2007.

10 MODI, O.P.; PANDIT, P.; MONDAL, D.P.; Prasad, B.K. ; YEGNESWARAN, A.H.; CHRYSANTHOU, A. High-stress abrasive wear response of 0.2% carbon dual phase steel: Effects of microstructural features and experimental conditions. Materials Science and Engineering A, v. 458, p. 303–311, 2007.

11 WATERSCHOOT, T.; VERBEKEN, K.; DE COOMAN, B. C. Tempering Kinetics of the Martensitic Phase in DP Steel, ISIJ International, Vol. 46 (2006), No. 1, pp. 138–146.