FABRICATION OF MICROSTRUCTURES BY THERMOMECHANICAL SEQUENCES FOR INCREASING FRACTURE TOUGHNESS OF API 5L X80 STEEL

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Abstract. *Modern HSLA (High Strength Low Alloy Steels) have been improved by development of chemical composition and mainly by the use of advanced manufacturing processes as TMCP (Termomechanical Controlled Process). In this work, different thermomechanical sequences were carried out for an API 5L X80 steel in order to obtain microstructures for toughness increasing. After austenitizing at 950 ºC for 15 min, the specimens were hot-rolled, below austenite non recristalization temperature, at a deforming rate of 1,6* s^{-1}*. Immediately, after deformation, specimens were quenched in water, and others, rapidly cooled in a lead bath for one minute for isothermal decomposition at different temperatures (ranging from 450 to 600 ◦C). The acicular ferrite microstructure was predominantly found in continuous cooling condition. This microstructure has been known as an excellent combination of high strength and good low-temperature toughness. Isothermal treatments within conditions of this work result in a complex microstructure with presence of polygonal ferrite, bainite ferrite, granular ferrite and also acicular ferrite. Results show that parameters, such as degree of deformation, bath temperature and cooling rate are important factors that influence the type of microstructure obtained.*

Keywords*: Thermomechanical sequence; Acicular ferrite; API 5L X80 Steel.*

1. INTRODUCTION

The boom of petroleum, in Brazil, in recent years has lead special attention of companies and researchers for studding steels applied to offshore structures and pipelines, which is one of the important factors in infrastructure for petroleum industry. Low-carbon micro-alloyed steels with a polygonal ferrite microstructure are usually applied for those purposes, but its mechanical properties can be improved by changes in microstructure in a relatively low cost process (Zhao et al, 2002).

In modern industry, the developing tendency for productions of HSLA (High Strength Low Alloy) steels is to modify and refine microstructure, to further improve its strength and toughness (Tang, Z., 2007). In order to realize this aim, the thermo-mechanical control process (TMCP) has been applied as an important method (Kim et al, 2008).

In pipeline steel with acicular predominant ferrite microstructure, more than in polygonal ferrite, it can be achieved good properties combination, such as high strength, excellent toughness, and superior fatigue behavior (Wang.et al, 2009), (Kim et al, 2008). The excellent combination of properties has led to the application of this type of steels, with smaller thickness, in large dimension pipes for gas and oil transportations even in low temperature area.

2. MATERIALS AND METHODS

2.1 Chemical composition

Samples of steel API 5L X80 were provided by the steel company Usiminas. The chemical composition of the steel (Tab. 1) was achieved using an ARL optical emission spectrometry device model 3460.

Table 1-Chemical composition of steel API 5L-grade X80

Chemical composition **(% weight)**												
C	S	Al	Si	P	Ti	V	Cr	Mn	Ni	Cu	Nb	Mo
0,07	0,004	0,036	0,27	0,016	0,018	0,022	0,17	1,55	0,01	0,01	0,069	0,019

2.2 Thermomechanical Sequence

Specimens were machined with dimensions of 100 x 9.5 x 6.0 mm, obtained from plates of 19.5 mm thickness. The faces to be rolled have a dimensional finishing of 6.0 ± 0.2 mm.

The specimens were heated in electric resistance furnace to a temperature of 950 °C, which is below non-recristalization temperature (Tang, Z., 2007), and hot rolled, in a duo cylinder with 80 mm in diameter. The percentage of deformation applied to the specimens ranged from 10 to 35%, followed by continuous cooling or isothermal treatment.

In continuous cooling treatments the specimens were cooled in water at room temperature. In isothermal treatments, the specimens were kept at constant temperature for 1 min by immersion in a lead bath.

2.3 Microscopy

The samples for microscopic analysis were obtained from cross sections of samples avoiding the regions of the extremities. The samples have been properly sanded, polished with diamond paste and finally etched with nitric acid at 3%. The scanning electron microscope used was a JEOL model JSM 5900.

3. RESULTS AND DISCUSSION

3.1. Continuous cooling deformation-free

The steel under study, as provided by Usiminas, has a microstructure with well designed polygonal ferrite grains with, with average grain size of 3.6 ± 0.3 μm as shown in Figure 1. (a). The material shows no apparent lamination texture.

Specimens were austenitized at 950 º C, maintained for 15 minutes followed by different cooling conditions do compare its effect to the effect of thermosequeces. Figure 1 shows micrographs of steel as received (Fig. 1 (a)), cooled in calm air (Fig. 1 (b)) and quenched in water (Fig. 1 (c)).

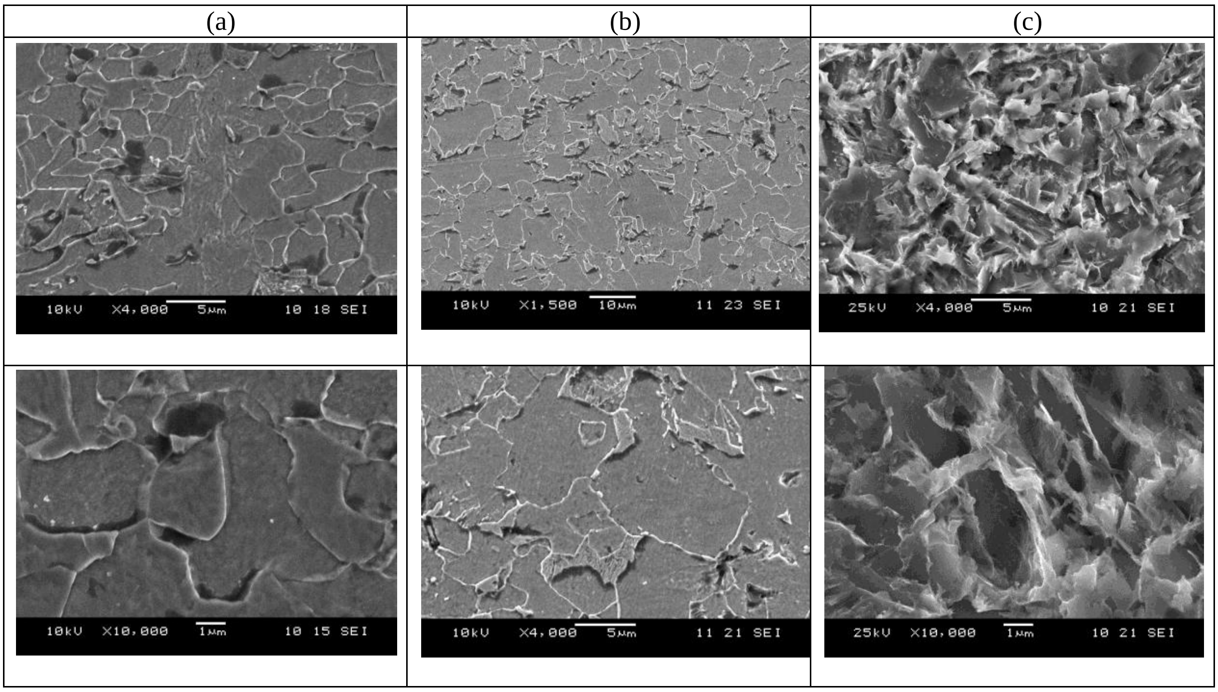

Figure 1. Micrographs of specimens subjected to different cooling conditions: (a) as received, (b) calm air, (c) quenched in water.

The specimen, cooled in air, maintained the boundaries of polygonal grain of the austenitic phase. Tempered sample presented morphology of a chaotic lamellae structure with acicular characteristic in some regions, similar to what has been reported in literature as acicular ferrite (Yang et al, 2010), (Xiao, F., 2005), (Bahadeshia, 2002), Magdariaga et al (2001).

3.2. Thermo mechanical treatment with continuous cooling

Deformed samples, subjected to quenching in water, eliminated the predominance of polygonal ferrite grains. The morphology of the sample subjected to 10% deformation (Fig. 2 (a)) differed little over the sample tempered without plastic deformation (Fig. 1 (c)), showing, in the first one, a finer structure and greater presence of acicular morphology. Samples deformed at 25 % and 35% showed considerable differences in their morphology compared to the one deformed at 10%. In samples deformed more intensely, there was predominant presence of acicular ferrite, characterized by bundles of ferritic laths interwoven in a chaotic distribution. In a few isolated areas occurred the presence of parallel bundles or small islands of polygonal ferrite grains with diminished grain size compared to the original ferritic grain.

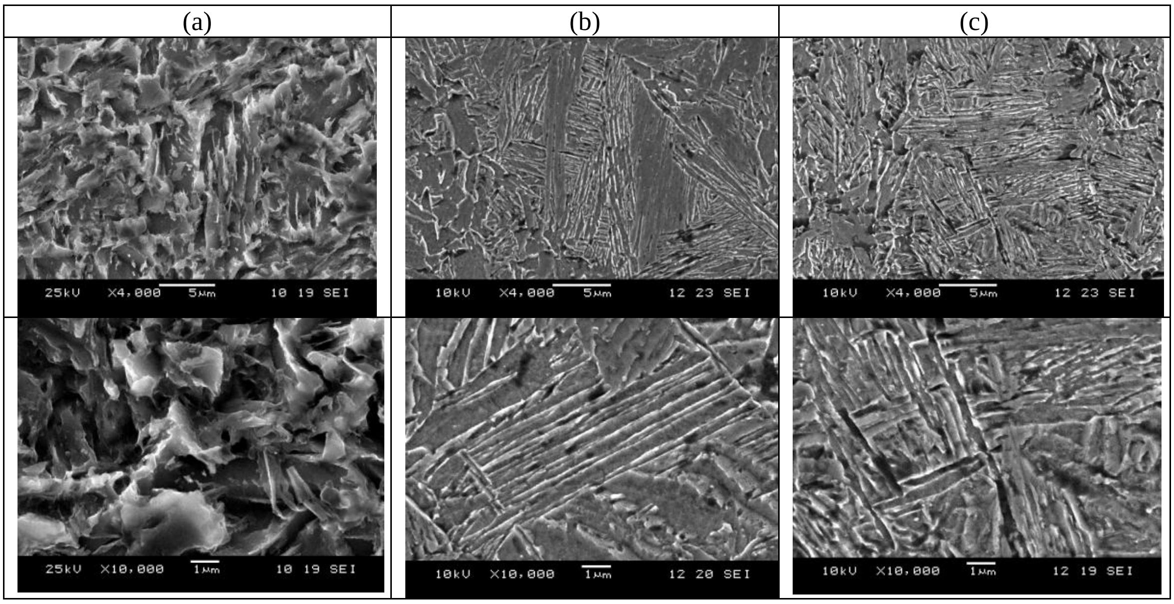

Figure 2. Micrographs of samples subjected to different deformation conditions: (a) deformed at 10%, (b) deformed at 25%, (c) deformed at 35%.

The predominance of acicular ferrite, in specimens more intensely deformed, can be attributed to plastic deformation of austenite below non-recrystalization temperature, once dynamic recrystalization temperature, for the steel under study, is around 1100 ° C (Tang Z, 2007), The high density of dislocations, in deformed austenite, appears to be beneficial to the formation of acicular ferrite in detriment of the nucleation of bainite. Although both microstructures were predominantly a shear transformation, plastic deformation of austenite suppresses the formation of bainitic structure from the outline of grains and favors the formation of acicular structure stimulated by intragranular nucleation (Tang and Stumpf, 2008).

This result concurs with that obtained by Kim (2008), which using termomechanical treatments in bainitic X80 steel, came to obtain a structure with 90% acicular ferrite, using for that, the increment of plastic deformation of austenite at non-recrystalization temperatures.

Wang et al (2009) studied high strength pipeline steels and compared mechanical properties of predominant acicular ferrite steel to a predominant polygonal ferrite one. Higher strength and better toughness achieved in the acicular ferrite steel were attributed to its finer grain size and higher density of dislocations and subunits. In accordance with Shanmugam (2007), the change in the microstructure to predominantly acicular ferrite with increase in cooling rate is responsible for the high strength–toughness combination of Nb-microalloyed steels at high cooling rate.

3.3. Isothermal thermomechanical treatment

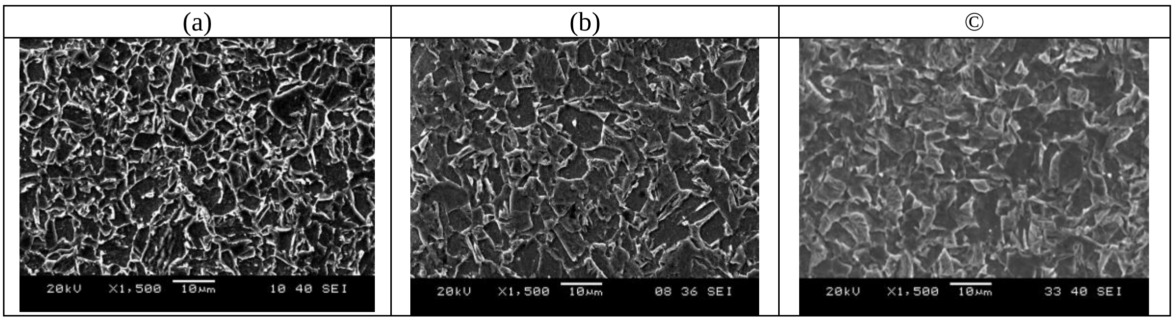

Figure 3. Micrographs of samples deformed at 10% in non-recrystallization region and followed by isothermal treatment for 1 min at: (a) 400 ° C, (b) 550 ° C and (c) 600 ° C.

Samples austenitized at 950 ° C and deformed 10% in non-recrystalization region were followed by isothermal treatment in bath of lead. Figure 3 shows the micrographs of samples treated at 400 º C, 550 º C 600 º C.

Samples subjected to isothermal treatment presented complex structures formed of various ferritic morphologies. Samples treated at 400 º C showed a predominance of polygonal ferrite and bainite ferrite (Fig. 4) in addition to the occurrence of granular ferrite in regions delimited by polygonal grain boundaries (Fig. 5). According to Mazanková, (1997), the presence of granular ferrite in ultra low carbon steels is associated with low cooling rates. This study reinforces such evidence since granular structure was not found in none of the others samples subjected to continuous cooling, with quenching in water.

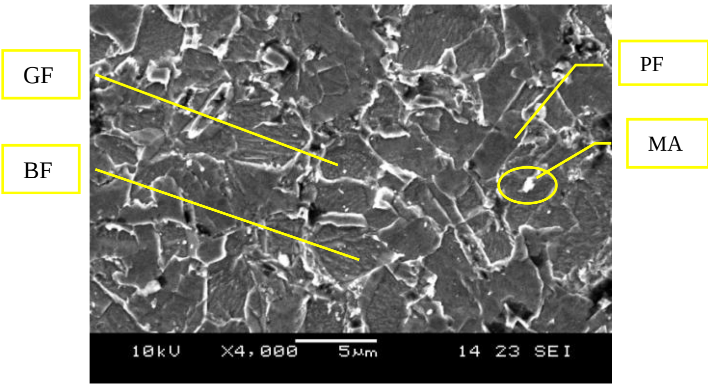

Figure 4. Micrograph
of sample deformed at 10% followed by isothermal treatment at 400 º C. PF-Polygonal Ferrite, BF- Bainitic Ferrite, GF-Granular Ferrite; MA- MA constituent.

Reports of other studies (Silva, 2010), (Mazanková, 1997) and the observation of morphology presented in Fig. 4 leads us to the conclusion that the white spots dispersed in the matrix are typical of the MA constituent. These regions are enriched of carbon and its origin is attributed to the separation of the carbon from the austenite during its transformation to ferrite (Tang, Z, 2008).

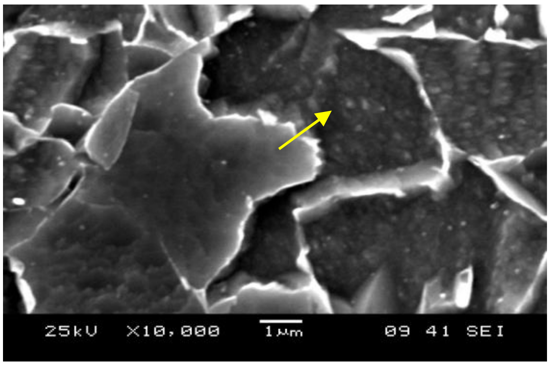

Figure 5. Presence of granular ferrite in sample deformed at 10% followed by isothermal treatment at 400 º C

Silva et al (2010) improved the yield of strength and elongation of an API 5L X70 steel, attributing this improvement to the formation of granular ferrite and presence of MA constituent dispersed in the matrix

Samples isothermally treated at 550 ° C and 600 ° C presented traces of acicular ferrite (fig. 6) in agreement with study developed by Kim (2008) that, based on the results of isothermal holding treatments, found out that acicular ferrite forms at approximately 600 ◦C, above the formation temperature of bainite.

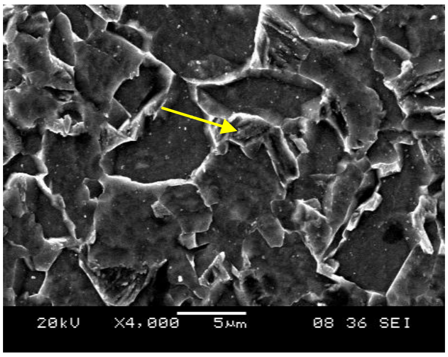

Figure 6. Acicular ferrite in sample deformed at 10% followed by isothermal treatment at 550 ° C.

3. CONCLUSIONS

Termomechanical sequences with plastic deformation below non recristallization temperature and continuous cooling can be applied to a polygonal ferrite dominated X-80 steel to obtain a predominant acicular ferritic microstructure. The increasing of plastic deformation contributes to decrease the length of laths and increase the interwoven structure of acicular ferrite microstructure.

Isothermal treatments in termomechanical sequences seem to be less effective to achieve acicular microstructure than continuous cooling with same conditions of plastic deformation.

Isothermal treatments within conditions of this work result in a complex microstructure with presence of polygonal ferrite, bainite ferrite, granular ferrite and acicular ferrite, which amounts depend on the temperature of treatment.

4. ACKNOWLEDGEMETS

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