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Simulation of Cooling Curves of the Heat Affected Zones of API 5L X80 Steel of Welds Made by Flux Core Arc Welding Self Protecting

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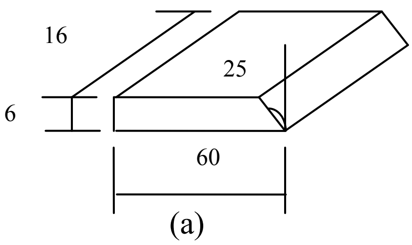
Abstract. The simulation of cooling curves of the heat affected zones (HAZ) of API 5L X80 steel was based on the cooling rates of welds made by the process named FCAW-S (Flux Core Arc Welding Self Protecting). The specimens were analyzed by macroscopy, light microscopy (LM) and scanning electronic microscopy (SEM) to investigate the effects of cooling conditions on the tensile test and Vickers hardness. A thermo-mechanical simulator showed be able to reproduce the different thermodynamics conditions of points in the HAZ and allowed the reproduction of the thermal cycle obtained by welds were applied to the specimens of API 5l X80 steel. The values of the yield strength, ultimate strength and hardness found in the specimens were lower than those presented by the material as received.

Introduction

The steels with the classification API 5L are the materials most commonly used in pipeline transport meshes due to their high mechanical strength and withstand high pressures [1]. According to Y. M. Kim et al [2], the current trend is to increase the yield strength for the manufactured products with these steels can carry increasingly corrosive fluids and lower costs, which makes the analysis of the behavior of these steels welded together one topic of great interest. I.S.Bott et al [3], in turn, tells the extent and magnitude of changes in properties depend mainly on the characteristics of the base metal and addition of a welding process involved and by the amount and concentration of heat generated and its subsequent cooling. Thus, each type of joint must be studied separately, since the experimental results obtained are unique and specific. Given the above, this paper versa by applying cooling rates equal to those obtained in actual welding conditions, in samples of API 5L X80 steel welded with self-protecting tubular wire to simulate the actual cooling curves occurred in the HAZ.

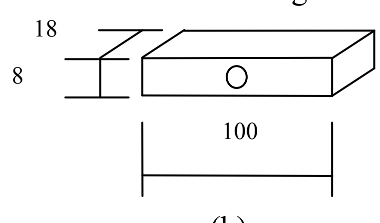
Experimental Methodology

The material object of this study was originated by fractionation of steel pipe rings sewn API 5L X80, where specimens with dimensions below were produced as follow in figures 1 and 2:



(a)

Fig. 1 - Welded samples geometry



(b)

Fig. 2 - Cooling curves samples geometry

Fig. 3 - Thermal cycle reproducing equipment

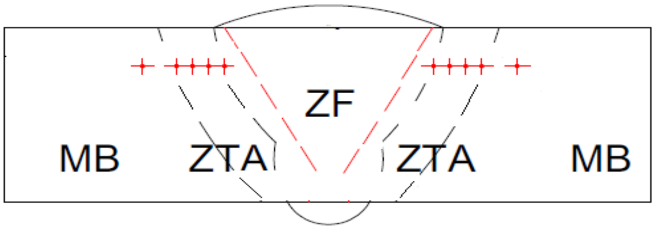


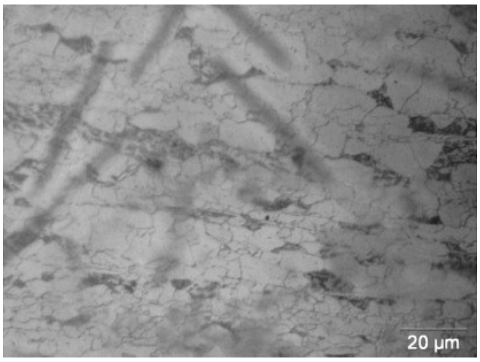
Fig. 4 - Scheme dot placement print hardness profile studied

Figures 3 and 4 present the aparatus used to achieve the cooling curves and the scheme dot placement print hardness profile studied.

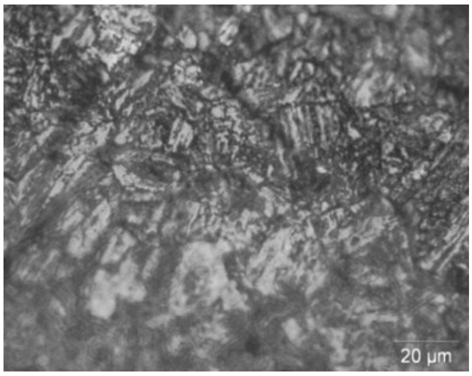
Results and discussion

Figures (5a) to (5f) have the characteristic results of the optical microscopy of the API 5L X80 steel samples studied.

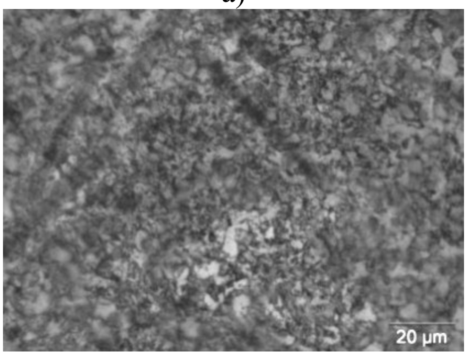
Initially we can verify that the material as received presents a ferritic microstructure consisting primarily of grains of various sizes (F) and grain boundaries slightly enriched by pearlite (P), as shown in figure (4a). The figure (4b) shows the microstructure for a cooling rate of 15 ° C / s from a real welding, where the matrix phase of the sample was due to changes in the bainitic type, or shear followed by diffusion, characteristic of acicular ferrite (AF). For samples of simulated events, figures (5c) to (5f), the microstructure consists of a mixture of the phases found in the material as received and the actual welding, i.e. characteristic features of a mixture of the granular microscopy and acicular ferrite. As the cooling rate decreases, there is a tendency of returning to the microstructure of the as-received state.



a)



b)



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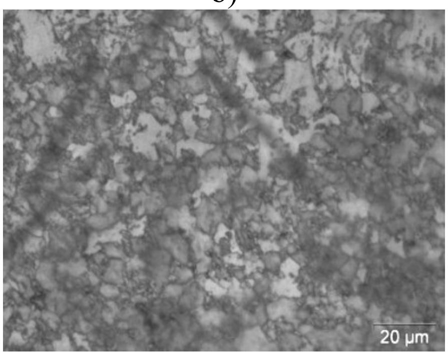
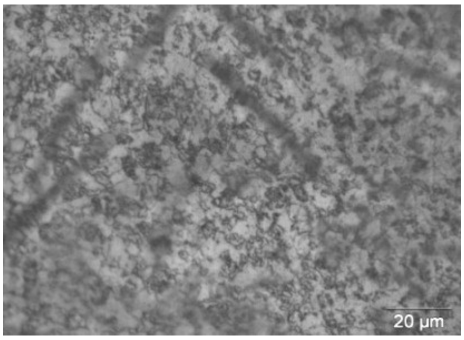
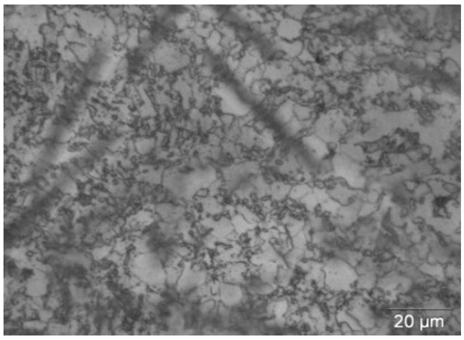


d)



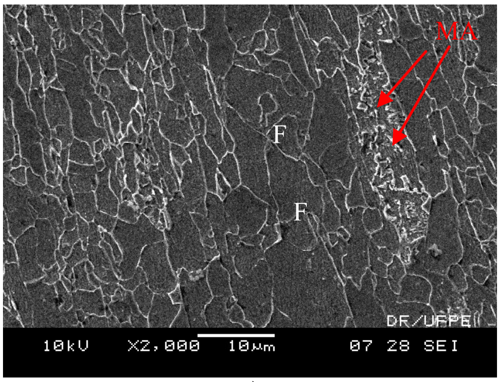
e)



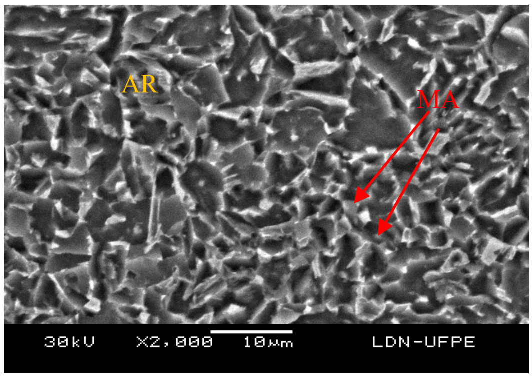
f)

Fig. 5 - Optical microscopy of API 5L X80 steel with 1000x magnification: a) as received; b) a real weld HAZ at 15 ° C/s; c) Sample simulated at 15 ° C/s; d) Sample simulated at 11º C /s; e) Sample simulated at 10 ° C/s; f) simulated sample to 8 ° C/s

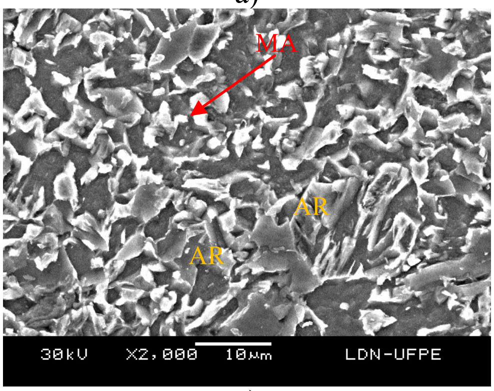
Figures (6a) to (6f) show SEM images where one can see that the matrices structures of the samples are formed substructures with characteristics of retained austenite (RA) and microconstituent martensite - austenite (MA)



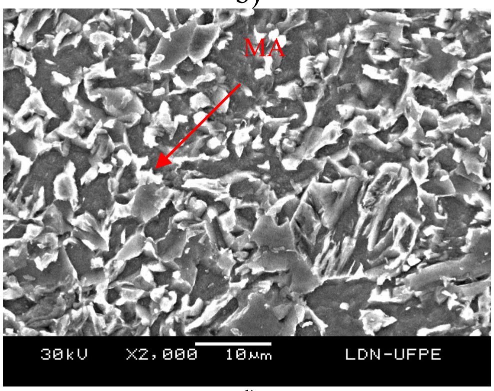
a)



b)



c)



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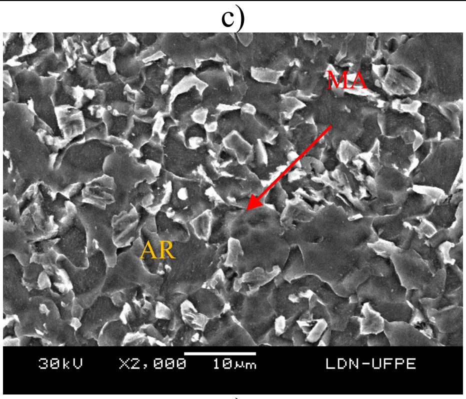
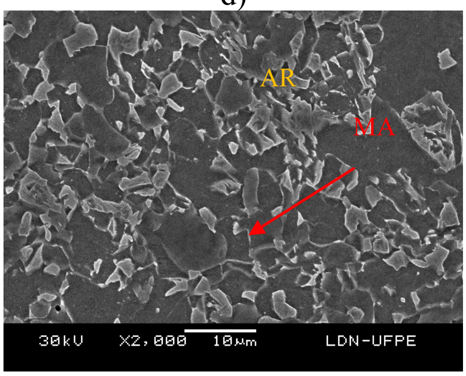


e)



f)

Fig. 6 - Scanning Electron Microscopy (SEM) of API X80 steel: a) As received;. b) a real weld HAZ at 15 ° C/s; c) Sample simulated at 15 ° C/s; d) Sample simulated at 11ºC/s; e) Sample simulated at 10 ° C/s; f) simulated sample to 8 ° C/s

The phases found in the experiment after application of cooling rates, notes - a similar granular ferrite microstructure, acicular ferrite, pearlite, retained austenite and microconstituent M / A. In this case, a steel composed only of acicular ferrite would be ideal [4]. The morphology of acicular ferrite is composed of a set of ferrite strips with a high density of disagreement and carbonitride precipitates dispersed. In actual welding, the microstructure arising from bainíticas transformations is better defined. For the tensile test, the properties of interest were the endurance limit (Lr) and percent elongation (ε), relative yield strength and endurance limit conventional (Ln / Lr), with the results summarized in Table (3). The samples subjected to tensile test showed that the values found in the yield strength does not meet the minimum required by the standard API 5L value, with values of the order of 50% lower than that found in the material as received. Furthermore, the tensile strength results showed that caters to the limit specified by the standard API 5L, but with values below those found in the material as received, decreasing with decreasing cooling rate.

Table 3 - Properties obtained by the tensile test

Tensile test on X80				
Samples	**Lr (MPA)**	**Ln (MPA)**	**ε (%)**	**Ln / Lr**
Standard API 5L	625	555	18	88.80
As-received	690	570	30	82.60
Cooling at 15ºC/s	686.43 ± 2.96	$(314.70 \pm 15.63)_{95\%p}$	(30.36±0.94)	45.84
Cooling at 11ºC/s	648.54	$(306.53 \pm 9.46)_{95\%p}$	(32,84±2,29)	47.26
Cooling at 10ºC/s	639.10	$(301.84 \pm 4.59)_{95\%p}$	(33,01±1,49)	47.22
Cooling at 8ºC/s	624.77	$(293.91 \pm 13.33)_{95\%p}$	(30,67±2,02)	47.04

The reduction in the values of tensile strength and yield strength comes from the fact that the material has received such a level of hardening produced by rolling and expansion inherent in the manufacturing process of the tube where the samples [5,6] were removed. Thus, the samples treated in this STM lose hardening decreasing the values of the results, the loss being more pronounced values for the yield strength than for the tensile strength. However, the results obtained in the Vickers hardness test are given in table (4), and analysis by comparing the values obtained with the simulated samples and the hardness profile found in the actual weld HAZ.

Table 4 - Results obtained by testing Hardness

Vickers Hardness test	
Samples	**HV(20 Kgf)**
HAZ Profile at 15ºC/s	$(256.17 \pm 0.67)_{95\%p}$
HAZ Profile at 11ºC/s	$(245.16 \pm 2.91)_{95\%p}$
HAZ Profile at 10ºC/s	$(248.27 \pm 4.33)_{95\%p}$
HAZ Profile at 8ºC/s	$(252.17 \pm 2.55)_{95\%p}$
Simulated at 15ºC/s	$(255.29 \pm 4.83)_{95\%p}$
Simulated at 11ºC/s	$(242.19 \pm 7.17)_{95\%p}$
Simulated at 10ºC/s	$(245.45 \pm 5.45)_{95\%p}$
Simulated at 8ºC/s	$(248.14 \pm 5.64)_{95\%p}$

For the hardness test, the trend of behavior is presented slightly lower values, but similar to those found in real welds. The good mechanical properties found are assigned to the refined microstructure, which hinders the propagation of cracks due to the presence of a large number of ferritic grains per unit length [5,7].

Conclusions

Based on the experimental results can be concluded that:

1. The microstructures obtained by thermodynamic routes imposed on simulated samples exhibit a tendency to mix the granular microstructure and acicular ferrite as matrix constituents, and substructures of these phases with characteristics of retained austenite and martensite-austenite. Regarding microstructures mentioned above, the experiment is much closer to the actual condition obtained by the real welds.
2. In all cases, the values of yield strength, hardness and rupture limit found in the samples were lower than those presented by the material as received.
3. The yield strength was the only mechanical property that presented a result that differed in the order of 50% less than the values found for the material as received. The hardness values found in the simulated samples were similar but lower.

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