

FRACTURE TOUGHNESS ASSESSMENT X80 PIPELINES STEELS WITH DIFFERENT CHEMICAL AND MICROSTRUCTURAL FEATURES

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Abstract. X80 steels are broadly used in the gas and oil industry as pipelines, which are usually fabricated by thermomechanical controlled process, have low carbon content and some alloy elements. This pipeline grade steel presents high strength-to-toughness ratio, such as yield strength above 555 MPa and ductile-brittle transition temperature around -100°C . However, differences in chemical composition and plates processing result in different microstructures and mechanical properties. Microstructure features and mechanical properties of two low alloy rolled steels produced by different routes were compared in this study. One steel presented a homogenous bainite matrix and the other presented banded microstructure composed of elongated ferrite grains. Microstructure and toughness were correlated analyzing the crack tip opening displacement tests results and samples. Light optical and scanning electron microscopy were used to perform the microstructural characterization. The steel with bainite matrix presented better fracture toughness behavior than the ferrite matrix steel due to less anisotropy and microstructural homogeneity.

Keywords: Fracture toughness, microstructural features, pipeline steels, X80 steels

1. INTRODUCTION

Among the many microstructures of different pipelines steels, two main structures are presented in this study. The first steel air-cooled after the last rolling pass in the intercritical region (ferrite and austenite). This steel presented a banded microstructure and segregations, e.g., elongated manganese sulfides in the center of the plates, suspected of contributing to delaminations occurrence (Joo et al., 2012). The second steel, accelerated-cooled, after the last rolling pass (Militzer, 2014; Nishioka and Ichikawa, 2012), presented bainitic matrix and equiaxed microstructure.

High toughness and strength are paramount for pipelines service requirements (Militzer, 2014; Nishioka and Ichikawa, 2012). Hence, this work aims to pinpoint via microstructure and mechanical characterization aspects influencing the toughness in two X80 steels.

2. EXPERIMENTAL PROCEDURE

Two X80 steels were used in the present study, both thermomechanical processed (TMCP); the first, air-cooled (Air) having a banded microstructure and the second accelerated-cooled (ACC) showing a homogenous bainitic matrix. The chemical compositions are shown in Table 1.

Table 1: Chemical composition for ISO 3183 standard (ANSI/API, 2009). *ppm and Carbon Equivalent.

Steel	C	Mn	V+Nb+Ti	Ti	Si	Mo	Ni	P*	S*	CE _{Pcm}
ACC	0.05	1.73	0.06	0.01	0.26	0.18	0.25	90	4	0.18
Air	0.08	2.07	0.12	0.01	0.22	0.18	0.01	50	22	0.22

Crack tip opening displacement tests (CTOD) were performed and validated according to the ASTM 1820 standard (ASTM-E1820-13, 2014). Rectangular (Bx2B) single edge bending notch samples with different thicknesses (B) were assessed, such as 7 mm and 15 mm. The samples width is $W=2B$. Tests were conducted at 25°C, 0°C, -20°C and -40°C.

3. RESULTS AND DISCUSSION

CTOD results showed that ACC steel presented higher toughness than the air steel, as shown in Table 1. In addition, the air steel presented a higher difference in properties between the transversal and longitudinal directions than the ACC steel. CTOD average results from the ACC steel were higher in all temperatures than the Air steel, as shown in Table 1, that could be related to a homogeneous microstructure and less anisotropic properties.

For thicker specimens (15 mm) samples presented low toughness CTOD values due to delaminations (Ávila et al., 2015; Joo et al., 2012), which were manifested as pop-ins in the CTOD test curves. Most of ACC and Air steel samples showed delamination during the CTOD assessment under -20 and -40° C temperature tests. However, only in two cases for Air steel these delaminations were considered significant according to ASTM 1820 standard (ASTM-E1820-13, 2014), representing the two worst values presented at -40°C. Among the ACC samples, three significant delaminations were found, at -20°C and -40°C, with CTOD values of 0.39 mm, 0.52 mm and 0.19 mm, respectively.

Table 1: Crack tip opening displacement (CTOD) tests results for ACC and Air steels. Tests performed in the L-T and T-L direction in SE(B) samples. The integral J (J) was calculated for the minimum CTOD reported for each condition.

B (mm)	Steel	Crack direction	T (°C)	a/W (%)	CTOD _{Average} (mm)	CTOD _{Minimum} (mm)	J _{Minimum} (kJ/m ²)
7	ACC	L-T	25	58	0.97±0.13	0.83	933
		T-L		58	0.92±0.20	0.71	803
	ML	L-T		0.58	0.56±0.04	0.53	618
		T-L		0.57	0.30±0.06	0.23	290
15	RA	T-L	0	52	1.01±0.08	0.93	1017
			-20	52	0.59±0.18	0.39	452
			-40	54	0.66±0.60	0.19	226
	ML	L-T	0	0.55	0.42±0.09	0.34	392.9
			-20	0.55	0.36±0.30	0.13	149.8
			-40	0.53	0.23±0.20	0.11	119.4

4. CONCLUSIONS

- Thermomechanical process (TMCP) with accelerated-cooling (ACC) and air-cooling in the final stage, resulted in different mechanical and toughness properties, due to anisotropy and heterogeneities in the microstructure. The ACC steel showed a granular bainitic microstructure, which caused raising in hardness and fracture toughness.
- Occurrences of delaminations in both steels were mainly due to the presence of brittle plane (001) perpendicular to the plane of fracture.
- Occurrences of delaminations in air-cooled steel were related in its majority to the presence of (001) planes, and the presence of a banded microstructure, with clusters of secondary phases and elongated inclusions such as MnS played a minor role.
- Grain morphology and secondary phases showed greater influence on fracture toughness than effective grain size.

5. ACKNOWLEDGEMENTS

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