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Influence of Hydrogen on Fracture Mode API X60 Steel

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One of the applications of High Strength Low Alloy (HSLA) steel is its use in the manufacture of pipelines for transporting petroleum and its derivatives products [1]. These hydrocarbons produce hydrogen from hydrogen sulfide decomposition. Thus, hydrogen generated in the steel diffuses to regions such as grain boundaries, nonmetallic inclusions and other crystalline defects, and results in an embrittling effect, causing premature failure of the material [2]. The manufacture of HSLA steel involves getting a variety of microstructures which are produced from the transformation of austenite to phases such as ferrite, pearlite, and intermediate stages like bainite, martensite and acicular ferrite [3]. Intermediate stages can be obtained when the steel is subjected to high temperatures for long periods of time; conditions that promote the steel undergoes aging. Also, during welding, the melting zone shows a mix of microstructures. Each microstructure has a characteristic resistance to hydrogen embrittlement.

Purpose of this paper is to determine the hydrogen effect on the fracture mode. Therefore, the microstructure and the fracture mode were compared between a control API X60 steel annealed at 650 °C and steel containing hydrogen, and aged at 315 °C and 650 °C. Hydrogen was introduced in these steels through cathode charged by applying a current density of 50 mA/cm^2. After hydrogen charging, the specimens were tested in tension at a deformation rate of 10^{-4}/s. And finally, SEM study was performed, to reveal the microstructure, and fracture surface of tested specimens.

Results in Figure 1 (a) exhibits equiaxed microstructure with grains of polygonal ferrite corresponding to the annealing treatment. In contrast, the steel aged at 315 °C exhibited a mixture of steel microstructures of acicular ferrite, bainite and martensite as observed in Figure 1 (b). The steel treated at 650 °C exhibited grains of polygonal ferrite and acicular ferrite (Figure 1 c).

In addition, this study reavealed three different fracture modes in APIX60 steel. Annealed steel presents fracture mechanism caused by coalescence of pores (Figure 2 a), indicating that the fracture is ductile. Steel aged at 315 °C has intergranular fracture facets and cleavage (Figure 2 b), which is characteristic of brittle fracture. In contrast, the specimen aged at 650 °C with dissolved hydrogen, has a mixed fracture mode (Figure 2 c). In this study, we determined that steel APIX60 aged causes fracture changes from ductile to brittle. In particular, the steel aged at 315 °C has the least resistance to hydrogen damage.

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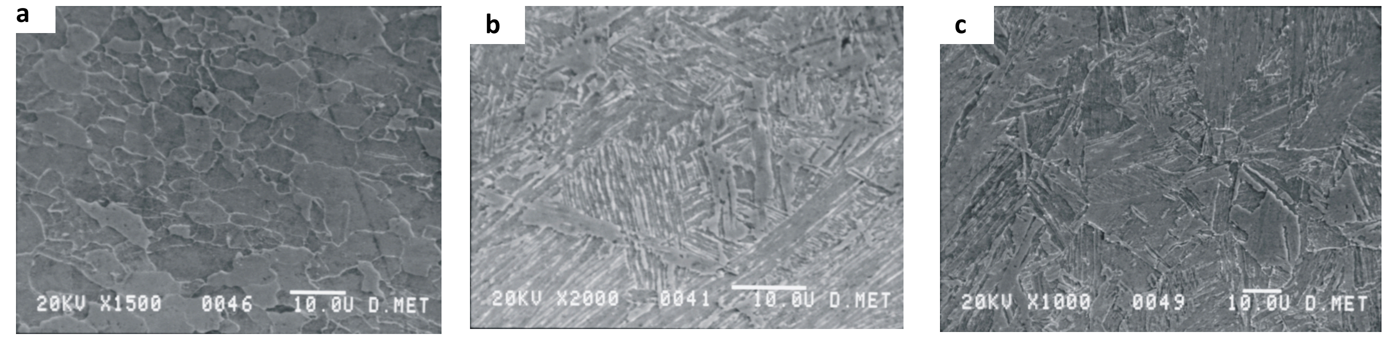

Figure 1. SEM images from API X60 steel pieces. 1 (a) Control sample annealed at 650 °C. 1 (b) Specimen aged to 315 °C shows mixture of microstructures consisting of acicular ferrite, bainite and martensite from. 1 (c) Steel aged at 650 °C reveals microstructure consisting of acicular ferrite and polygonal ferrite grains

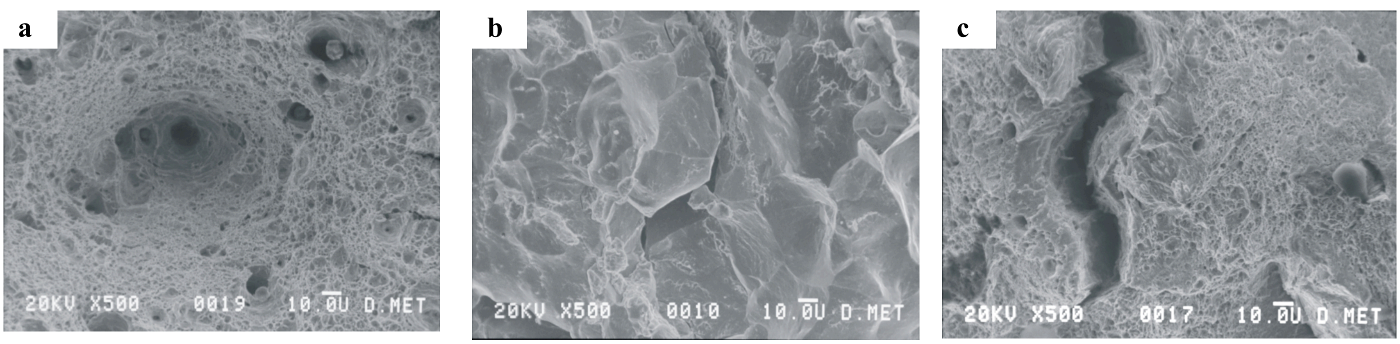

Figure 2. SEM micrographs, of the fracture mode from API X60 steel samples. 2 (a) Annealed sample at 650 °C shows coalescence of pores and ductile fracture. 2 (b) Steel aged at 315 °C presents brittle fracture. 2 (c) Specimen aged at 650 °C displays a mixed mode fracture.