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Hydrogen effect on a low carbon ferritic-bainitic pipeline steel

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ABSTRACT

Hydrogen effect on an API 5L X65 low carbon ferritic-bainitic steel is investigated, by evaluating the fracture toughness parameters in air and in hydrogen environment. The hydrogen environment is manifested by in situ hydrogen charging of the X65 steel, using the electrolytic solution NS4, which simulates the electrolyte trapped between the pipeline steel and the coating in a buried pipeline. The fracture toughness results of the X65 are compared to two other pipeline steels with different microstructures, namely an X52 and an X70, possessing a banded ferritic-pearlitic and banded ferritic-mixed bainitic-pearlitic microstructure, respectively. The X65 steel exhibits significant reduction of fracture toughness parameter J_0 integral due to hydrogen charging and insignificant variation of fracture toughness parameter K_Q. Comparing the three steels, the lowest reduction of J_0 integral due to hydrogen charging, is met on the X52 and the highest in the X65.

Introduction

The energy production mixture of the rest of the 21st century is going to differentiate substantially from the fossil based practices of the 20th century. Many forms of energy production are becoming mainstream and contributing to the overall mix (renewable, nuclear, shale gas, etc.). In the light of the aforementioned fact there is a need for a uniform energy carrier for distribution and consumption. For this purpose two technologies have been intensively pursued for the last 15 years, electric and hydrogen, both having advantages and drawbacks. Hydrogen is pursued rigorously for automotive applications and generally for the transportation sector. One of the means for delivering hydrogen to refueling stations and generally to the consumers is the natural gas pipeline grid. The steels used for the high pressure natural gas pipeline grid generally follow the API (American Petroleum Institute) 5L specifications [1]. This specification has guidelines regarding yield and ultimate strength, chemical composition, etc. for each X grade. There is no limitation regarding the microstructural composition and characteristics of a steel grade. While the API 5L is clearly intended for steels used for carrying hydrocarbons, the use of hydrogen introduces unknowns in terms of corrosion and degradation effects on the pipeline steel. Hydrogen effects on steels are governed by their microstructure and several works have studied this phenomenon [2–10]. Furthermore hydrogen also poses a threat as defect incubator, in pipelines transporting hydrocarbons due to presence of H_2S in the hydrocarbons (sour), high cathodic protection current densities and failed coatings on the pipeline, etc. Lastly the trend in manufacturing of high pressure pipelines is to move to higher

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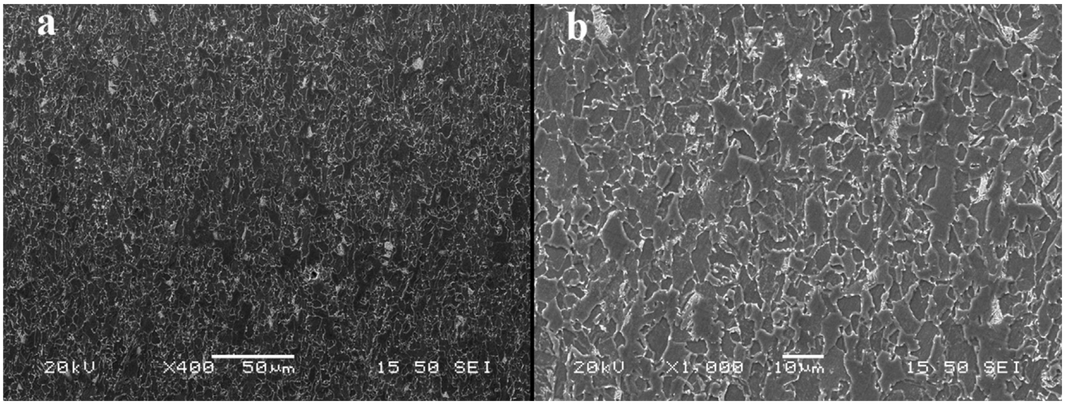

Fig. 1 – SEM micrographs of nital etched X65 base metal at two magnifications.

strength grades (e.g. X80, X100, X120, etc.) and low carbon ferritic-bainitic microstructures, especially for the improved weldability that low carbon steels offer.

In a previous paper [11] two other pipeline steels, namely an X52 and an X70, with microstructures composed mostly of ferrite and pearlite arranged in bands, were tested in hydrogen environment. Furthermore the weld metals of the X52 and X70 were also tested in hydrogen environment and compared to the results from their parent metals, respectively. Lastly an in situ hydrogen charging scheme was developed, while the specimen is being monotonically deformed. In this work, a pipeline steel with a different microstructure is tested, namely a low carbon ferrite-bainite X65, against the same in situ hydrogen charging conditions used in Ref. [11]. This steel is representative of the current trend in pipeline steel manufacturing.

The goals in this work are, a) to assess the susceptibility to hydrogen of a low carbon ferritic-bainitic pipeline steel, namely the X65 and b) compare the X65's performance to two other pipeline steels with different microstructures, namely an X52 and an X70 base metal studied in Ref. [11] which were tested in the same hydrogen environment. In this sense three different steels representing three different microstructures are compared and the best steel for hydrogen service is identified.

To that end the hydrogen effect on fracture toughness parameters J_0 integral and K_Q of an API X65 low carbon ferritic-bainitic steel is investigated. The fracture toughness parameters of specimens tested in air and electrolytically hydrogen charged, under three current densities, are compared. The tests in the hydrogen environment are conducted with in situ hydrogen charging in order to simulate the constant hydrogen-steel interaction, in case of hydrogen transport through a pipeline. The hydrogen effect on the various microstructural characteristics of the X65 steel is investigated. The variation of fracture toughness parameters values on the X65 steel due to hydrogen is then compared to the effect of hydrogen on the fracture parameters values on an API 5L X52 and X70 steel, with ferritic-pearlitic and ferritic-mixed pearlitic-bainitic microstructures, respectively.

Experimental procedure

Materials

X65 steel

Microstructure. The X65 base metal possesses a ferritic-bainitic microstructure with some pearlite islands, as illustrated in Figs. 1 and 2a and martensite/austenite (M/A) islands and stringers as shown in Figs. 2b, 3 and 4. The presence of M/A islands and stringers, which exist in ferrite and bainite grain boundaries and also in pearlite islands (Figs. 3 and 4), is indicated in the SEM micrograph of Fig. 2(b). The existence of M/A

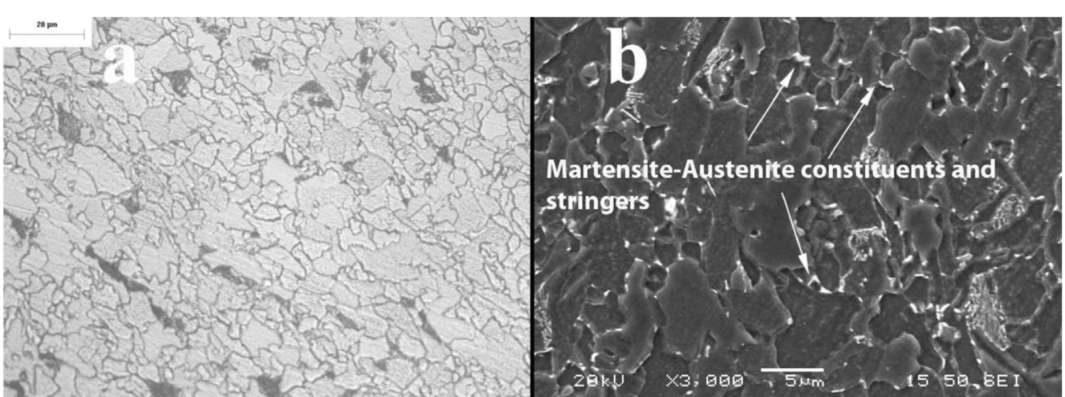

Fig. 2 – Optical micrograph a) and SEM micrograph b) of nital etched X65.