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Technical Report

A case study of environmental assisted cracking in a low alloy steel under simulated environment of pressurized water reactor

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ABSTRACT

The electromechanical behavior of a pressure vessel grade steel A516 has been investigated using potentiodynamic polarization curves and slow strain rate test (SSRT) in simulated environment of pressurized water reactor. The anodic polarization behavior shows that the steel remains active in the solution till localized attack (pitting) starts. The cracks initiated at the surface propagate in a trans-granular mode. These cracks are initiated at the inclusion (MnS) sites and at the interfaces between local anode (ferrite) and local cathode (pearlite). It seems that the ultimate fracture occurs when the propagating surface cracks join the subsurface hydrogen induced cracks. The addition of oxygen in the testing chamber to supersaturation levels shifts the corrosion potential to anodic side and significantly lowers the strength and ductility. Compared to the room temperature properties, the UTS and tensile elongation in various simulated conditions are reduced by 10–25% and 25–75%, respectively.

1. Introduction

Steel is the most commonly used structural metal and has a wide range of alloys for specific engineering applications. One of the important applications of steels is in the fabrication of pressure vessels. Because of the high pressures that these vessels retain, the pressure vessel grade steels must meet the stringent requirements of high notch toughness and strict low limits for allowable imperfections. One of the widely used pressure grade steel is A516 G-70 which contains Mn as principal alloying element. Manganese is normally present in all commercial steels due to its multiple benefits. It deoxidizes the melt and facilitates hot working of the steel by reducing the susceptibility to hot shortness. Mn also contributes in strength and hardness, and has a strong effect on the hardenability of steel. A516 has the highest strength and ductility among other pressure vessel steels (containing slightly lower levels of Mn but relatively higher levels of S); moreover, it gives the longest time to fracture in corrosive environments [1]. Recent studies on this alloy show strong dependence of mechanical and corrosion properties on morphology of ferrite [2,3].

The pressure vessel grade steel used in pressurized water reactor (PWR) must meet an additional requirement of low susceptibility to SCC and HIC in the working environment. The fracture toughness (KIc) values drop significantly when the material under stress is also exposed to the aqueous environment in which electro-chemical reactions can take place. The water chemistry in such applications is carefully maintained within the safe regimes to minimize the effects of corrosion and corrosion related phenomenon e.g. HIC and SCC. One such controlling factor is the dissolved gaseous content of the solution [4–7]. Corrosion is an electrochemical process and proceeds with the formation of local anodes and cathodes at the surface exposed to the corrosive medium. At equilibrium, the rate of anodic reaction (oxidation) is equal to the rate of cathodic reaction (reduction). In aqueous environments, the reduction reaction consists of oxygen reduction reaction. An increase in the dissolved oxygen contents increases the rate of reduction reaction ($O_2 + 2H_2O + 4e^- \rightarrow 4OH^-$) and thereby the corrosion potential of the system. Since, the corrosion potential is decided at the point where the current produced by oxidation is totally used by the reduction reaction; an increase in the dissolved oxygen contents increases the corrosion potential, which is the driving force for the corrosion reaction. Cáceres et al. observed the presence of a critical dissolved oxygen content which separates the two distinct regions of high and low corrosion rates. At this critical oxygen content, the corrosion current density, corrosion potential and hydrogen evolution rate are significantly increased [8]. The dissolved oxygen contents also affect the composition of the corrosion products that is formed [9]. In pearlitic steels, depending upon the dissolved oxygen contents, the pseudo-passive range may be replaced with the active or passive range [10]. A removal of oxygen from the solution also lowers the susceptibility to stress corrosion cracking (SCC) [11].

The air contains about 209 ppm volume oxygen in gaseous form. Due to which, air readily oxidizes the elements in materials which have strong thermodynamic affinity to form oxides. The oxidation process is particularly enhanced at higher temperatures. The amount of oxygen that is dissolved in water or any other liquid depends upon the partial pressure of oxygen in equilibrium with

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