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Original Article

Study of the corrosion behaviour of S32101 duplex and 410 martensitic stainless steel for application in oil refinery distillation systems

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ABSTRACT

The corrosion behaviour of S32101 duplex and 410 martensitic stainless steel was studied through weight loss and potentiodynamic polarization in 1–6 M HCl solutions. Results show that S32101 steel has significantly lower corrosion rates than 410 steel from both tests at all concentrations with highest values of 0.04586 mm/y and 0.234 mm/y in comparison to martensitic steel with corrosion rates of 0.827 mm/y and 19.84 mm/y at 6 M HCl concentration. Micrographs from SEM and EDS analyses showed a less corroded morphology for S32101 steel with fewer pits and slight depletion in the percentage composition of chromium and other alloying elements.

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1. Introduction

Stainless steels are corrosion-resistant ferrous metals due to the thin, protective film formed on its surface, a combination of iron and chromium compounds. The film being passive protects the steel from corrosion coupled with the property of self-healing. The presence of chromium within the steel microstructure significantly enhances their corrosion resistance. Research by Hashimoto et al. [1] showed that the protective film consists of chromium oxy-hydroxide. Its durability with respect to corrosion resistance depends on the percentage content of chromium and other alloying elements responsible for its stainless metallurgical structure. As a result chromium–nickel stainless steels are currently the

most extensively applied materials in corrosive environments both at ambient and elevated temperatures, however they are prone to localized corrosion such as pitting in the presence of chloride or other aggressive anions [2–5]. Pitting corrosion is one of the most major causes of deterioration of stainless steel in petrochemical industries [6].

The petrochemical industry coupled with its difficult production operations experiences huge corrosion problems. Corrosion, the degradation of a metal or alloy and its inherent properties, destroys most parts/component at every stage within the industry [7,8]. The major causes of corrosion in the oil industry are chlorides, carbon dioxide, ammonia, hydrogen chloride, sulfuric acid, hydrogen, sulphur, etc. Within the industry corrosion in crude distillation overhead systems is a recurrent problem in refineries due to the presence of acid

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which attacks component structures. Under-deposit corrosion and fouling from acid neutralization and desalter operations is also responsible for component deterioration and breakdown. In the crude overhead systems the corrosion is due to the presence of HCl acid vapor present from hydrolysis of salts in the atmospheric crude distillation unit. The major source of HCl is the hydrolysis of calcium and magnesium chloride salts at temperatures 121 °C and the decomposition of organic chloride compounds [9–18]. HCl is generally the most complex acid to control from the corrosive point of view. It requires extraordinary precaution during its use and in the selection of materials to contain the acid. It is highly corrosive to most of the common metals and alloys [19]. HCl moves into the crude unit overhead condensing systems where it is readily absorbed into condensing water.

Some HCl boils overhead in the fractionating column and dissolves in the water as it precipitates in the condenser. The resulting low pH water, being very corrosive causes frequent overhead condenser tube failures. Hydrogen chloride also condenses in the heat exchanger in the atmospheric fractionating column overhead forming highly corrosive hydrochloric acid [20,21]. Other acids such as sulfur-oxide compounds and organic acids contribute to corrosion in addition to conditions that upsets the process conditions resulting higher acid content which causes the dissolution of protective iron sulfide/hydroxide scales [17].

At present the cost of corrosion is estimated on the order of 3–4% of gross domestic product (GDP) of developed countries necessitating so many studies on it and the development of corrosion resistant alloy materials to reduce its impact and consequences [21,22]. Duplex stainless steels are the steels developed with high strength and chloride stress corrosion cracking resistance in aggressive environments. It has high chromium content with other alloying elements which provides good resistance to localized and general corrosion coupled good fatigue strength, pitting formation resistance, good machinability and weldability. The steel consists of balanced ferrite and austenite phases coupled with versatile applications where good corrosion resistance and mechanical properties are required. They are used in biodiesel and ethanol plants and tanks, waste water handling systems, ethanol production components, desalination system chambers and evaporators, chemical processing, pressure vessels, piping, heat exchangers, etc. It is highly suitable for service in environments containing chlorides and hydrogen sulfide, such as marine applications and the oil and gas extraction and processing industries and mining industries [23,24]. Martensitic stainless steels are general-purpose steels containing chromium, which provide good corrosion resistance properties. They are generally used for applications involving mild corrosion, heat resistance; adequate ductility, toughness and high strength such as in are used in various industries such as in chemical plants, power generation equipments in gas turbines and compressor blades and discs, aircraft engine components and fittings in marine components [25]. Numerous researches have been done to evaluate the corrosion resistance and susceptibility of duplex and martensitic stainless steel in corrosive environments. Souto et al. [26] studied the passivation and the resistance to pitting corrosion of duplex stainless steel in neutral and alkaline buffered solutions, with and without chloride

ions. The presence of NaCl enhanced the metal's electro-dissolution through the passive layer. Antony et al. [27] showed the aggressiveness of sulphate-reducing bacteria in a marine environment, which plays an important role in the corrosion of duplex. Jeffrey et al. [28] compared the corrosion behaviour of 2205 duplex stainless steel with AISI type 316L stainless steel in NaCl solution. Results show that 2205 has a longer passivation range and higher corrosion resistance than 316L. Siow et al. [29] studied the pitting corrosion of SAF2507, SAF2205 and SAF2304 duplex stainless steels by electrochemical tests and concluded that SAF2507 had the highest pitting corrosion resistance followed by SAF2205. Hussain and Robinson [30] studied the erosion–corrosion of 2205 duplex stainless steel in flowing seawater containing sand particles. Results showed that the highest erosion–corrosion rate occurred in the stagnation region, immediately beneath the jet, where sand particles impacted the surface. Wang et al. [31] showed that chloride ions had a strong effect on the nano-mechanical parameters of the corroded surface layer of 00Cr22Ni5Mo3N duplex stainless under cavitation in chloride solutions. Prawoto et al. [32] studied the effect of pH and chloride concentration on corrosion behaviour of duplex stainless steel UNS32205 and concluded that decrease in pH and increase in temperature increases the corrosion rate of the steel at different solutions with different temperatures and periods of immersion with the pitting corrosion preferentially attacking the austenite phase of the steel. The corrosion of DIN 1.4035 martensitic stainless steel DIN 1.4035 in ethanol-containing gasoline mixtures with chloride and acetic acid concentrations was studied by Jörg and Sannakaisa [33] at room temperature. Pitting corrosion was detected at extremely low chloride-concentrations which propagated with increase in chloride concentration. Kimura et al. [34] studied the corrosion resistance of martensitic stainless steel OCTG was studied at a high CO₂ and simulated acidizing condition. No localized corrosion was observed during the exposure hours. The pitting corrosion resistance of 16Cr-2 Ni steels after austenitizing at various temperatures followed by double tempering was studied by Rajasekhar and Reddy [35]. The results show that double austenitization followed by double tempering resulted high pitting corrosion resistance as compared to single austenitization temperatures. The electrochemical corrosion behaviour of martensitic-austenitic stainless steel was investigated in 0.5, 1, 3 and 5 wt.% HCl solutions. Results show that the increase of acid concentration shifts the corrosion potential to more negative values and increasing the corrosion current and pitting corrosion was observed [36]. This research aims to study and compare the electrochemical corrosion behaviour of S32101 duplex stainless steel and 410 martensitic stainless steel specific concentrations of HCl acid for application in crude distillation overhead systems in petrochemical refinery.

2. Materials and methods

2.1. Material

S32101 duplex (DSS) and 410 martensitic (MSS) stainless steels purchased from the Steel Works, Owode, Nigeria and analysed at the Materials Characterization Laboratory, Department of

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