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Corrosion resistance study of 439L ferritic stainless steel subjected to high temperature variation

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Abstract: Automobile production plants have advanced the utilization of stainless steel alloys for the production of exhaust mufflers due to corrosion failures associated with their operating lifespan and conditions of application. Corrosion vulnerability of as received and heat treated (500oC and 1000oC) 439 L ferritic stainless in 3.5 M H_2SO_4 electrolyte at 0% to 6% NaCl concentration was evaluated with potentiodynamic polarization, potentiostatic measurement, open circuit potential measurement, and optical microscopy characterization. Potentiodynamic polarization results show heat treatment improved the general corrosion resistance of the steel. Heat treated 439 L steel at 500°C displayed the lowest corrosion rate trailed by the heat treated steel at 1000°C. However, potentiostatic measurement shows that heat treatment decreases the resistance of the steel to localized corrosion deterioration from inspection of the metastable pitting current and passivation potential values. Results from open circuit potential measurement show heat treatment increases the thermodynamic tendency for 439 L steel to corrosion while improving its corrosion resistance. Optical images of the as-receive and heat treated steels show the presence of numerous corrosion pits and corrosion along the grain boundaries. However, the extent of deterioration is significantly higher for the as-received steel.

Roland Tolulope Loto

ABOUT THE AUTHOR

Loto Roland Tolulope is a Professor at the Department of Mechanical Engineering, Covenant University, Ogun State, Nigeria. He is the head of the corrosion and materials research cluster. Roland has over one hundred and ninety190 (190) research publications including reviews in top international journals and has consistently served as reviewer in respectable journals due to his in-depth knowledge and technical expertise. He has a lot of experience in research experimentation basically aimed at proffering solutions to the current depreciating effect of metallic degradation and failure in various engineering applications. He is a registered member of the Council for the Regulation of Engineering in Nigeria, South African Institute of Mining and Metallurgy and the Corrosion Institute of Southern Africa.

PUBLIC INTEREST STATEMENTS

The economic impact and problems resulting from corrosion have drawn strong attention from scientists and engineers worldwide. Corrosion in industrial environments is a major concern in chemical processing plants, oil and gas industry, manufacturing, automobile industry, marine operations, boiler plants and power generation plants due to the considerable cost involved in the replacement of metallic parts in their various applications. The consequence often leads to plant shutdowns, breakdown of industrial equipment, reduced efficiency, industrial downtime, high maintenance cost due to replacement of damaged part, wastage of valuable resources and expensive overdesign. Appropriate selection of engineering with desirable corrosion-resistant properties significantly reduce corrosion damage thus prolonging the lifespan of the material and subsequently reducing cost of corrosion prevention.

Subjects: Chemistry; Materials Science; Metals & Alloys

Keywords: corrosion; pitting; steel; chloride; sulphate

1. Introduction

Automobile production plants are one of the most significant sectors of a nation's economy (Vaz et al., 2017). Automobile exhaust system is an important component of an automobile vehicle. The automobile exhaust structure consists of parts such as exhaust manifold, muffler, catalytic converter and extension pipes. Exhaust manifold connects to the engine cylinder, collecting the exhaust gas from each cylinder into the exhaust collector (Seabra et al., 2016). It operates under astringent conditions, alternating between high and room temperature. The exhaust system is prone to problems such as high-temperature oxidation, localized corrosion, stress corrosion cracking and intergranular corrosion (Zhang & Cen, 2011). The major factor responsible for the premature failure and limited lifespan of an automobile exhaust system is the cognate debilitating impact of corrosion and fatigue. The system is subject to thermal stress coupled with surface oxidation and vulnerability to corrosive anions from the toxic waste gases and environment (Valarmathi et al., 2017). The corrosion mechanisms are divided into two, (a) internal corrosion due to condensation of harmful acid constituents and (b) external corrosion due to chlorides, sulphates, etc., especially in coastal areas and high levels of acid rain. The hot end of the exhaust system is where oxidation breakdown of the surface oxide layer is a major problem. At this end formation of porous oxide occurs leading to accelerated deterioration of the material. At the cold end, localized corrosion deterioration is prevalent and condensation of gaseous products produces (H_2SO_4 and small concentrations of HCl acid) create environmental conditions which results in corrosion of the inner components (Dai et al., 2011; Douthett, 2006). The exhaust component is exposed to high temperatures (950°C and above), NaCl and exhaust precipitates during automobile engine operation (Sarda & Bindu, 2014). Choice of material for application in automobile exhaust system is crucially important. The material with the least tendency to react with its operating environment while maintaining its mechanical, metallurgical and physical properties is most likely to have a longer lifespan. However, it must be noted that selected materials have threshold limits to corrosion, stress and high temperature (Aniekan et al., 2017). Other factors such as cost, expected lifespan, warranty requirements, prevailing market trends, customer demands, etc., influence the choice of materials for the manufacture of automobile exhaust system (Varma et al., 2011). Carbon steel was previously the material of choice. However, its poor corrosion resistance limited it durability especially when exposed to chlorides and exhaust condensate. Alloys such as aluminized carbon steel, ferritic chromium steels and ferritic chromium molybdenum steels are presently used in the manufacture of exhaust mufflers. The earlier steels mentioned are metallic alloys resistant to corrosion due to the initiation and growth of a protective, inert and impenetrable oxide on its surface. Collapse of the oxide by corrosive anions such as chlorides, sulphates, etc., at sufficiently positive anodic potential and temperature lead to gradual metallurgical deterioration and mechanical failure of the steels. 409 and 304 stainless steels are used in exhaust mufflers because they are cost effective and with good weldability. However, operating temperature conditions most often go beyond their oxidation limit resulting in shortened operational lifespan. 439 L ferritic steel is a Ti stabilized, 18% percent Cr alloy with the specific purpose of resisting corrosion in oxidizing environments. The steel has very low vulnerability to H_2 embrittlement, excellent weldability, high thermal conductivity and minimal thermal expansion properties. The steel is gradually replacing the conventional stainless steels and other alloys as the material of choice in automobile exhaust system due to its high oxidation resistance. The steel has threshold limit to chloride-sulphate attack prevalent in simulated exhaust working conditions which has been established to a certain degree (Loto, 2019, 2017; Loto & Loto, 2018; Loto & Oghenerukewe, 2016). However, details are scarce on the corrosion behaviour of the steel when subjected to conditions that alter the metallurgical and microstructural properties of the steel. This research