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Effect of coating on induced thermal and tensile stress on the fracture of exhaust pipe material

D.T. Oloruntoba *, A.P.I. Popoola *

Department of Chemical, Metallurgical and Materials Engineering, Tshwane University of Technology, Private Bag X680, Pretoria, South Africa

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ABSTRACT

Engineering materials disintegrate in divers' ways that can later result in service failure. The service life of automobile silencer depends typically on the heat generated through the pipe and on the variability of harsh conditions component is exposed. Regular use and long time in service of any part could result into unexpected buildup of stresses that can result in ruinous failure or crack of structure. Automobile exhaust pipe is made up of steel; four representative samples of this material were subjected to thermal cycles and tensile loading with the aim of inducing stress. Metallic zinc was used to coat the stressed steel samples for the purpose of arresting cracks before subjecting them to seawater environment to check their electrochemical response. Experimental results indicated that the zinc coated steel samples (both thermal and tensile stressed) displayed anti-corrosion properties resisting fret cracking whereas the uncoated induced thermal and tensile stressed samples performed less. Coating offered some restrictions to the failure of engineering materials subjected to induce thermal and tensile stresses; this is attributed to the ability of zinc acting as a sacrificial anode to steel in the chloride environment.

1. Introduction

Failure of engineering materials means out of service function that could be catastrophic at times. Automobile exhaust pipe serves as a conveyor of combusted gas out of the engine system; minimizing engine noise as well as extracting dust out of the engine system. Materials used for the construction of exhaust systems ranges from mild carbon steel to stainless steel. In the open literature, numerous studies are geared towards developing surface coatings for mild steel using ceramic/metallic materials for the purpose of reinforcement protection against thermal and corrosion degradation [1,2]. The operating temperature of the exhaust line could be in the range of 250–1150 °C [3]. The start, slow running, high motion and temporary or final stop of the motor engine can likely be responsible for extreme temperature gradients [4] that could result into failure of exhaust pipe. Likewise, the temperature between 730 °C and 1150 °C can cause a microstructural change in ferrous alloy of the exhaust and also changes in the response to corrosion, thermal degradation and stress level performance. Exhaust condensate, exposure to road salt and dynamic excitation of the system may also lead to pipe failures. Likely failure modes are cracking and leakage of the pipe.

In developing countries, automobile shops displayed second-hand exhaust pipe retrieved from used or wrecked cars for sale, typically sold as the replacement of failed pipes. Second-hand exhaust pipes have a short life span due to initial thermal

* Tel.: +27 123823513.
E-mail addresses: toyinoloruntoba@gmail.com (D.T. Oloruntoba), PopoolaAPI@tut.ac.za (A.P.I. Popoola).

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and loading stress that might have been induced in the pipe while in use. Thermo-mechanically treated reinforcement bars constitute an important turning point in the construction industries due to their capacity to envelope high strength, high ductility and low cost simultaneously [5]. Thermal stresses arise in materials when they are heated or cooled; the failure of many brittle materials has been shown to be dependent upon stress distribution within the body rather than upon the maximum stress criteria [6,7]. Investigation on carbon steel operating at temperatures below the creep range in water/steam conditions has shown that thermal shock contributed to damage mechanism for pressure vessel [8]. Retained austenite has also been found to have influence on the fracture toughness of tempered steel [9].

This research aims at reducing failure due to corrosion of exhaust pipe material under high temperature and chloride environment. Electroplating technology offers corrosion protection to metallic materials. In this work, zinc electroplating was carried out on thermally and tensile stressed steel pipes. Zinc is a metallic material that could prevent or act as an anode for corrosion protection of low carbon steel in a corrosive environment [10]. Paying attention to changes in the functions of the exhaust pipe is crucial for the safety and health of the driver and service life longevity and performance of the vehicle.

2. Methodology

2.1. Sample preparation

Low carbon steel of 40 mm × 25 mm × 4 mm was prepared for heat treatment and zinc electrodeposition. The chemical composition of the low carbon steel was carried out by polishing the surface of the sample to get a mirror like surface then mounted on the spark stand in Atomic mass spectrometer. Three different spark tests were carried out while ensuring they are not on the same point on the surface. The average of the results produced was obtained to ensure homogeneity within the material, and the results are as shown in Table 1.

2.2. Thermal stress experiment

The low carbon steel substrate was heat treated in the muffle furnace to austenitic temperature of 750 °C, 800 °C, 850 °C, 900 °C, 950 °C and 1000 °C and held for 30 min before quenching with water to induce internal stress in low carbon steel. Two set of samples was prepared for each temperature while one other control sample was kept ready.

2.3. Tensile stress experiment

Another set of the carbon steel substrate was machined to standard tensile test samples. A load of 50 kN was applied on the steel samples to induce tensile stress using universal tensile testing machine at various time intervals but without fracturing. The applied load was stopped at the specified time to prevent the samples from necking to fracture. Time rate was from five seconds to 10 s. Two set of samples was prepared for each time intervals while one other control sample was made ready.

2.4. Zinc electrodeposition on the thermal and tensile stressed low carbon steel samples

One set of thermally and tensile stressed sample was zinc electroplated in the prepared zinc bath solution, composition shown in Table 2 with plating parameters stated therein.

2.5. Microhardness tests

Hardness test is performed on 750 °C, 800 °C, 850 °C, 900 °C, 950 °C, 1000 °C heat treated samples that are then compared to a control substrate. The test is done using a load of $HV_{0.1}$ 100 g on Emco-test (Dura scan model 20) machine. The values of the hardness are taken by placing three indents on the surface of the sample horizontally; thus, the average is then taken.

2.6. Surface morphology of thermally treated uncoated and zn-coated samples

An Optical Microscope (OPM) with attached digital Nikon DS-FI1 Optical Camera was used to study the surface morphology of the thermally treated uncoated and zn-coated samples. The microscope has the advantages of assessing surface morphology of samples without prior metallographic preparation of the substrate and very adaptable to all kinds of sample systems, gas, liquid, solid systems at all forms and geometry. Two sample pictures were taken at the 10× and 20× magnifications.

Table 1
Chemical composition of the thermally and tensile stressed low carbon steel samples.

Element	C	Mn	Si	P	S	Ni	Cr	Mo	Fe
% Composition	0.16	0.3	0.25	0.03	0.03	0.3	0.3	0.08	Balance