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Experimental investigation of flow induced corrosion on the smooth elbows

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Masin Muhammadu[1,*], A. Bello[1]

[1] Department of Mechanical Engineering, Federal University of Technology, P. M. B. 65, Gidan-Kwanu, Minna, Nigeria

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ABSTRACT

In the present study, the turbulent flow downstream a 90^0 pipe bend is investigated by means of flow induced corrosion (FIC). The hydrodynamic effects of single-phase flow on flow accelerated corrosion (FAC) in a single 90-degree elbow were investigated at the various velocities (1.5, 2.0 and 2.5 m/s). Experiments were performed to determine the surface wear patterns using elbows fabricated from low carbon steel. The wear patterns indicated the development of surface wear in the form of uniform corrosion over most of the elbow surface. Afterward, surface degradation of the bends was studied by visual inspection and field emission scanning electron microscope (FESEM) analysis. Finally, from experimental conducted, it was observed that inner diameters are areas of highest FIC behaviour for 30^0 in the bends.

1. Introduction

Damage of fluid handling equipment due to erosive wear can cause significant operation and reliability problems in oil and gas, coal, slurry, aerospace, pneumatic conveying, bulk material handling and other industries [1]. Severe erosion takes place on the pipe due to the impact of solid particles on the pipe wall, particularly at its elbow. The erosion phenomenon is highly complicated due to a number of parameters affecting the erosion severity, such as production flow rate, entrained solid rate in production fluid, fluid properties, flow regime, solid particle properties, particle geometry, and wall material of equipment, and geometry of the equipment as stated by [2,3]. Solid particle velocity which affected by fluid velocity and fluid property has been recognized as the most significant factor for erosion by some investigators and several models were proposed based on that for single-phase liquid or gas flow contained solid particles [3,4,20]. To prevent process equipment failure and downtime, it's necessary to identify the puncture point location. Experimental investigations were carried out by [2,5,14] and [6] to characterize the location and magnitude of erosion in elbow specimens. Experiments were conducted in gas–liquid (mixture) single vertical

* *Corresponding author.*
E-mail address: masin.muhammadu@futminna.edu.ng (Muhammadu Masin Muhammadu)

annular flow with quartz particles, and during [3] investigation, experiments were conducted in both single and multiphase flows in elbows to identify the location of maximum erosion. A mechanistic model for multiphase flow was proposed in [5,12,16]. In our previous work [7,18], the concrete pumping process was modelled with the location of maximum erosive wear damage in elbow predicted. The experiment results showed that the wear pattern in an elbow depended on the magnitude of the interaction forces and the frequency of interactions between particles and wall. Research into the bend failure on a pneumatic conveyor undertaken by [8,19] mentioned that the puncture locations of the bends might vary with different bend geometry. From the research [9,10] conducted experiments with four bend orientations to investigate the effect of bend orientation on puncture point location, finding that the puncture point location is indeed significantly influenced by the bend orientations.

The current paper presents result of an experimental study on the hydrodynamic effects of flow on flow accelerated corrosion in a single 90-degree mitre bend. The specific objective is to experimentally quantify the time evolution of the wall wear patterns in a single 90-degree mitre bend and to characterize the flow structures within the bend. The experiments were conducted a 25 mm diameter bend with a radius of curvature of 50 mm diameters at different Reynolds number. This study aimed at determining how common exposure environments affected the corrosion behaviour of elbow joint, specifically uniform corrosion, and general corrosion with three different designs of the welded mitre joint. The purpose of this study was to also observe changes to the various corrosion mechanisms on true welded mitre bend, similar to those environments experienced by welded structure. The findings can be determined by weight loss, visual inspection, corrosion rate, and surface morphology using FESEM based on FIC test environment.

2. Experimental procedure and method

The commercial low carbon steel was selected for the present study. Corrosion test by FIC was conducted to determine corrosion rate using weight loss method in which a specimen with known initial weight is exposed to the corrosive environment for a specified period. By the end of the test, the specimen was cleaned and weighed to determine the weight loss and the corrosion behaviour. The method for specimen preparation is in accordance with ASTM G1 and the FIC test is in accordance with ASTM G31.

The test solution used was 3.5% NaCl that was simulated seawater solution having a salinity of 3.5% (35 g/l or 599 mM). This means that every kilogram or roughly one litre by volume of seawater has approximately 35 grams of dissolved salts [predominantly sodium (Na^+) and chloride (Cl^-) ions]. Average density at the surface was 1.025 kg/l, the pH solution ranges between 7.0 and 7.5.

The corrosion test was based on the guidelines of the ASTM G31 standard; the testing procedure involves the evaluation related to weight-loss and location of the corroded area. This technique proved useful by revealing uniform by microscopy. Before the FIC test, all the specimens were cleaned and the weight of each specimen had been recorded. All specimens were then exposed to the test solution.

The experiment was conducted using three pipe bends with pump for recirculation of the stimulated 3.5 % NaCl solution. The fabricated low carbon steel bends were connected to PVC pipes as shown in Figure 1 that represents the amount of datum that was expected to be collected. The total exposure period was 1, 2 and 3 months. The first time interval was after one month, followed by two months and three months as the second and third time interval, respectively. This was followed by three months as the third time interval respectively. Figure1shows experimental set-up for flow-induced corrosion test.

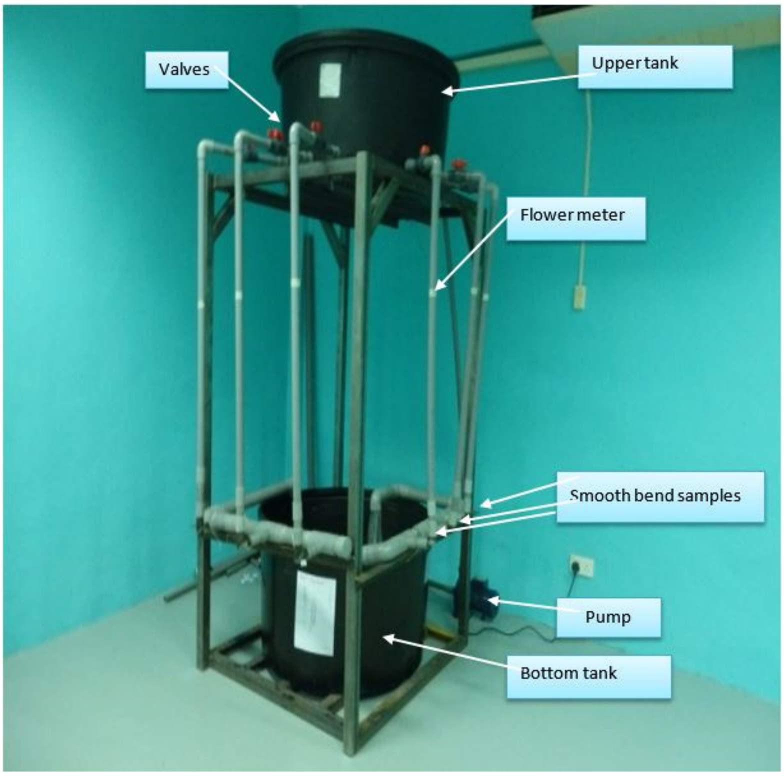

Fig. 1. Experimental set-up for flow-induced corrosion test.

3. Results and discussion

The variation of amount of corrosion product as well as weight loss can be attributed to the reaction of the samples towards the environment as shown in Fig.2 for visual inspection of the surface and cross section of corroded samples of a, b and c before cleaning after one, two and three months.

It was found out that samples exposed to the flowing fluid for three (3) months were severely corroded with trick brownish corrosion product observed. It was also observed that as the time exposure increases from one to three months, there was increase in brownish corrosion product covering the surface area of the samples.

(a) (b) (c)

Fig. 2. Visual Inspection of the Surface and cross section of corroded samples (a) One month (b) Two months and (c) Three months exposure of the bends.

(a) (b) (c)

Fig. 3. Visual inspection after cleaning of smooth bend samples (a and b) inner diameter and (c) outer diameter.

It was found that both samples show a uniform corrosion rate. This was due to the formation of corrosion product on the metal surface and therefore inhibits the metal from further corrosion and corrosion product act as barrier towards corrosion. As expected, it was found that the bend shown higher corrosion rate in the first one month than 2 and 3 months due to the effect of sudden impact of the fluid flow as shown in Fig.4. It was also found that after the samples exposed for period time, the type of corrosion that form was uniform corrosion after cleaning of the samples. Also, as the exposure increases, the rate of corrosion degradation decreases.

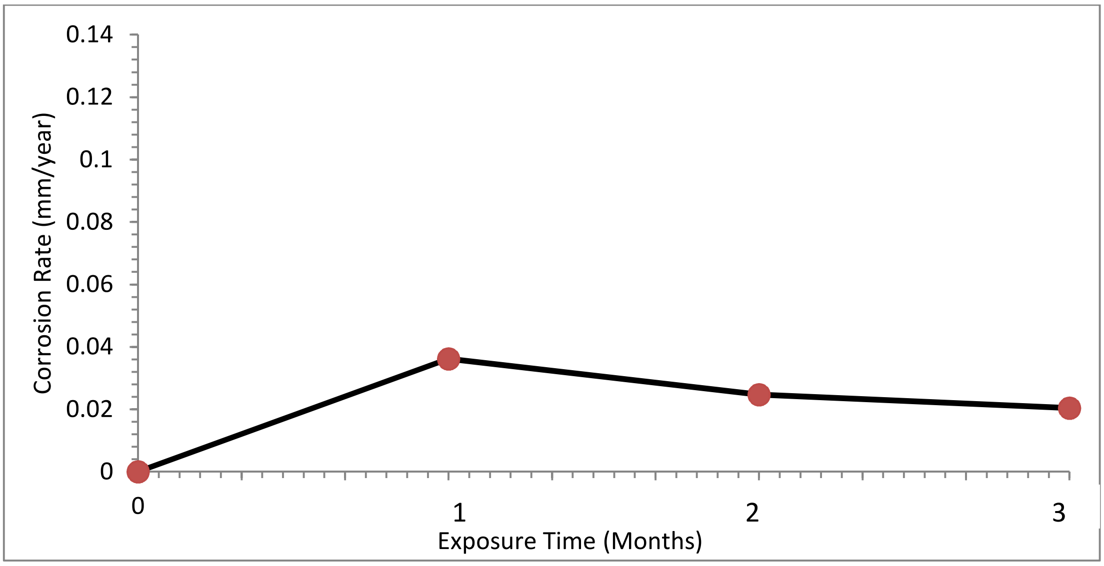

Fig. 4. Corrosion rate (mm/year) of samples for 1 to 3 months of exposure to 3.5 % NaCl solution.

4. Form of corrosion

Figure 5 shows the changes in individual uniform characteristics of uniform depth and uniform surface area. Significant uniform that can be clearly observed after one-month exposure for FIC. This was due to different mechanism of uniform corrosion initiation and growth. Fig.5 shows three different magnifications of 100x, 500x and 1000x and Energy dispersive x-ray (EDX) spectrum illustrating the elemental composition of the regions for the bend samples after one to 3 months. This was after one to three months of flow-induced corrosion test. This also shows that surface morphology indicating presence of uniform corrosion with many pits. The higher magnification of FESEM images reveals details of the corroded area. The EDX analysis carried out on some locations shows the area contains mainly iron (Fe) and with small amount O, C and Cl. These elements are the main composition of the carbon steel samples with traces of oxygen from the corrosion product and Cl from the NaCl solution.

The XRD analyses spectrum, after corrosion confirmed that the corrosion product of mitre samples test mainly consist of either or totally γ-FeOOH and Fe_3O_4. Fe_3O_4 is structurally similar to a mixture of FeO and Fe_2O_3. The formations of both compounds were due to ferrous iron being oxidized upon exposure to oxygen. The oxygen was absorbed and reacted with the dissolved iron to form insoluble ferric oxide or as known as iron oxide (red rust) [3,10].

The previous researchers [11-15], revealed that the rust layer formed on carbon steels has a complex morphology which is in agreement with the FIC test results. It is generally porous, with poor adherence, and cracked in its outer part.

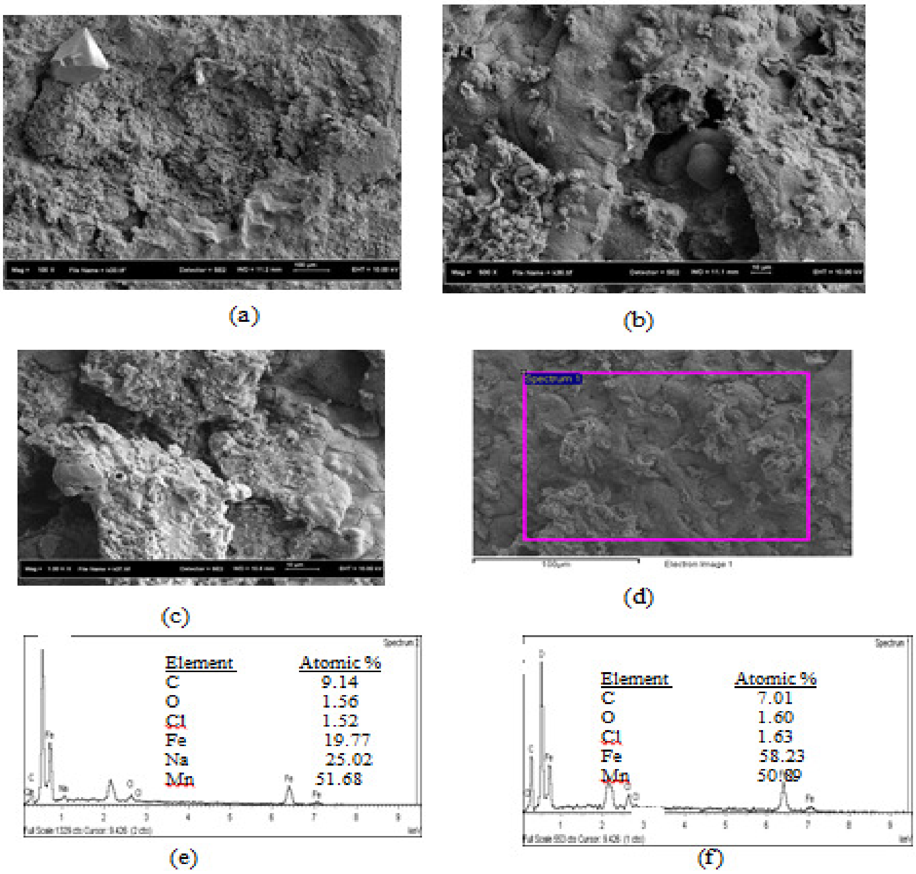

Fig. 5. FESEM and micro chemical composition of the corrosion product at the mitre elbow of 3.5% NaCl solution with different magnifications (a) 100x (b) 500x (c) 1000x (d) area of analysis - EDX (e and f) main compositions of the sample.

5. Conclusion

Comprehensive experimental analysis by FIC show decreases in corrosion rate as Reynolds number and exposure time increases. It also observed that the coupons (samples) corrodes uniformly and suffers from localized attack namely cavitation and uniform corrosion. Furthermore, from the experimental conducted, it was observed that inner diameters are areas of highest FIC behaviour of 32^0 mitre bends. From the visual inspection shows the corrosion product from flow-induced corrosion test. The heat affected area has higher deposited corrosion product compare to base and weld metal. Recommended that squeeze film model should be develop which can accurately describe particle rebound for small degradation angle (less than 10 degree) and X- ray photoelectron spectroscopy (XPS) should be used in order to understand the elemental composition of the passive film on the steel coupon surface after exposure to NaCl.

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