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Erosive wear performance of API X42 pipeline steel

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ABSTRACT

The need to transport petroleum products through pipelines has resulted in the increased erosion of the pipeline materials used in the petroleum industry. In this study, dry erosion test was performed using sand blaster erosion machine to investigate the erosive behavior and mechanism relative to API X42 pipeline steel. Different particle velocities in the range of 20 to 80 m/s were applied at different test durations, while the incident angle was kept constant. The results showed that the plowing mechanism was prevailing at higher velocity and longer test duration. Plastic deformation, embedment of the erodent particle on the target material surface and plowing were observed at lower velocity. Understanding the transition in the erosion mechanism as the particle velocity increases may be a vital importance to the petroleum industry. This will also aid in the erosion models employed for future erosion analysis.

1. Introduction

The corrosion of oil and gas transmission pipeline continues to be a great concern to the petroleum industry because of increasing pipeline maintenance cost and failure [1–3]. Carbon steel is used as pipeline materials in oil and gas transportation due to its ability to withstand pressure [4,5]. However, the pipeline steels are often subjected to severe erosion due to transportation of petroleum products which is accompanied by erodent particles [6,7]. The transportation of the petroleum product process results in mechanical removal of the oxide film particles formed on the pipeline surface, subsequently, subjecting the exposed surface to more stress and degradation [8]. Erosion of oil and gas pipeline is a complex phenomenon characterized by erodent particles impacting on the pipeline walls due to solid–liquid flow, flow restrictions or change in flow direction. Efforts have been made towards understanding the erosion mechanisms at different environmental conditions [1,4,5]. The general results reveal that the target material, temperature, impact angle and particle velocity, properties, shapes and sizes play critical roles in the erosion mechanisms. The angle at which the erodent particles impinge the target material accounts a greater percentage of the erosion damage [9–12]. Studies have shown that erosion rate increases with increasing impact angle up to 90° for brittle materials, while maximum erosion rate occurs between 15 and 45° in ductile materials [13]. According to literature [10], individual erosion events at oblique angles are expected to cause more destruction on the target surface than those at the normal incidence angle. Hutchings [14,15] revealed that cutting mechanism can occur in different angular shapes depending on the erodent particles as they impinge the target material and the subsequent direction of the erodent particles after striking the target surface.

Several studies have been carried out to understand the erosion mechanisms of different steels with focus on the low carbon steels [16–19]. Levy [20] studied the solid particle erosion behaviors of 1020 and 1075 low carbon steels using SiC particles as erodent at different impingement angles and speeds. The results showed that the microstructure of the steels plays a significant role in the crack growth observed on the eroded steel surfaces. In a similar study, Green [19] investigated the erosion mechanisms

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of low carbon AISI 1050 steel in relation to the carbon content and microstructure. The results also revealed that thermally hardened martensitic structures behave better than the pearlitic steels of the same carbon content at 30 °C where maximum erosion rate was observed. McCabe [17] also studied the effect of microstructure on the erosion of AISI 1078 and 1050 steels at different angles and speeds using 240 grit $A1_2O_3$ particles as erodent particle. The results indicated that the erosion mechanisms tend towards a brittle mode with increasing velocity. Liebhard and Levy [21] conducted a study on the erodent particle characteristic impact on the erosion of 1018 steel. The authors concluded that angular particles cause erosion of higher order of magnitude than the spherical particles.

For higher carbon steels, the erosion mechanisms may be different and erosion mechanism can extend beyond the proposed region on the target surface. Recent study of API X65 using acoustic method by Ukpai et al. [22] have shown that a stage is reached below which no significant damage occurs to the X65 carbon steel exposed to erosive wear. Al-Bukhaiti et al. [23] identified plowing mechanism on the eroded AISI 1017 and white cast iron material between impinging angle of 15 and 75°. However, the impact of these parameters on the steel surfaces exposed to erosive environments and the resulting mechanisms significantly depend on the material pairs and testing equipment [21,24]. A number of studies have been proposed to explain erosion at different particle velocities, material pairs and angles of impingements [9,25–28]. Most of these works have focused on lower carbon steel [9,10,25,26,29]. However, detailed understanding of the erosion mechanisms of high carbon steel at normal incidence angle is lacking. So far limited research has been conducted to study erosion of API X42 steel with detailed analysis on its interaction with aluminum oxide (AI_2O_3) particles at different velocities to reveal erosion characteristics and mechanisms. Understanding of particle velocity and erosion behavior associated with the API X42, while applying similar contact condition to those experienced in the oil and gas transportation pipeline is necessary to minimize the rate of erosion in the petroleum industry. This knowledge could be applied in pipeline material selection, thereby increasing the life of pipeline materials used in oil and gas transportation. Thus, in this study, a new erosion test facility was used to investigate the erosion mechanisms in the velocity range of 20 to 80 m/s, during dry erosion of API X42 steel against AI_2O_3 solid particles. The impinging surfaces were characterized using a scanning electron microscope (SEM), 2D surface profilometry and energy dispersive x-ray (EDX) to identify and classify the different erosion mechanisms that occurred.

2. Experimental method

2.1. Test equipment and materials

The erosion studies were carried out using a dry sand blaster erosion tester shown in Fig. 1. In this test, the erosion tester was designed to control the impact velocity, feed rate, relative specimen distance, and orientation relative to the impinging solid particles.

The erosion tester is also equipped with an abrasive feed meter which functions as the reservoir tank and controls the feed rate of solid particles. Air flow meter, pressure gauge and specimen chamber are incorporated in the design shown in Fig. 1. The chemical composition and properties of materials used in this study are given in Table 1. For comparison with material used in oil and gas transportation, API X42 steel was used as the eroding surface materials while aluminum oxide was used as the solid eroding material [6].

The aluminum oxide particle was utilized in the as-received condition and the API X42 steel material was ground using 240, 400, and 600-grit silicon carbide papers, and subsequently polished using 1 and 0.3 μm to achieve the final specimen roughness of 0.04 ± 001 μm. The API X42 steel used in the tests was cylindrical in shape of 15.8 mm in diameter and 4.7 mm in thickness. The erodent aluminum oxide particle is displayed in Fig. 2a, while the microstructure of API X42 steel used in this study is shown in Fig. 2b.

2.2. Test procedure

Erosion tests were carried out using an in-house sand-blast type erosion tester based on specification of ASTM standard G76 [30]. The particle velocity was controlled by adjusting the pressure of the abrasive feed meter. Particle velocity was determined as a function of pressure using double disk method [31]. The feed rate of solid particles was determined by measuring the weight of the abrasive particles coming through the nozzle per unit time [32]. The erosion test machine is pre-run for 30 min before each test to enhance free flow of erodent particles through the nozzle to the steel surface. For the actual test, specified test time is assigned to the machine and the test is completed at the end of the test time. Through this process, stability and free of the solid particle is achieved. All tests were carried out with the particle flow impacting the surface at incident angle of 90°. The working distance between the nozzle outlet and the surface of the specimen was kept constant at 3 mm for uniform distribution of the particle stream [33]. The API X42 specimens are mounted on the specimen holder facing the nozzle, as shown in Fig. 1. In order to verify and stabilize the feed rate before each test, the sand-blast unit was turned on for several minutes. During each test, the specimen was exposed to the particle flow for a precise period of time. The erosion test machine was mounted on a concrete support for firmness during each test. The dry erosion tests were carried out for 10, 300 and 600 s for each particle velocity to investigate the effect of particle velocity on the erosion mechanism of API X42 steel. Before and after the tests, each specimen was weighed using a digital balance with an accuracy of 0.0001 g to observe the difference in weight loss for each test.