ISSN: 2319-5967
ISO 9001:2008 Certified
International Journal of Engineering Science and Innovative Technology (IJESIT)
Volume 3, Issue 5, September 2014

Erosion Mechanisms of API X42 and AISI 1018 Steel Materials at Normal Impact Angle

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Abstract— Sand particles contained in transporting petroleum products can cause severe erosion wear on the steel surfaces along the flow path. The erosion can result in reduction in the operational life of the steel material and subsequent failure of the pipeline system. This paper presents the results of erosion tests of API X42 and AISI 1018 carbon steel materials used in the pipeline transportation. The erosion test was carried out using sand blaster erosion machine at flow velocities from 20 to 80m/s and the impinging angle of 90°. The erosion results revealed that erosion mechanism of API X42 and AISI 1018 steel was velocity and material dependent, showing different erosion mechanisms as the particle velocity was increased from 20m/s to 80m/s. Understanding the transition in the erosion behavior for different steel materials used in transportation of petroleum products will aid in the erosion models employed in the petroleum industry.

***Keywords* —About Erosion, API X42, AISI 1018, Mechanism.**

I. INTRODUCTION

Carbon steel pipeline has been one of the effective means of transporting petroleum products from one region to another due to its ability to withstand pressure [1]. Failure of the transporting steel material is often caused by erosion of the pipeline surface [2-4]. It is believed that the erosion is caused by impingement of solid sand particles suspended in the petroleum products on the steel surface which results in material removal. The erosion mechanism of some of the steel materials has been reported in literature [5-10]. It was shown that mechanism of the steel material removal can vary depending on the pipeline material [11-13]. However, the erosion mechanism is a complex phenomenon and is not yet understood. Studies have shown that cold welding of the asperities and plastic work of the asperities occur when solid particles impinge on another steel surface [14-16]. Al-Bukhaiti et al. [6] identified different mechanisms at different angles for the test conducted with AISI 1017 and white case iron materials. Isam et al. [14] also observed heavy ploughing, fracture and metal cutting mechanisms during erosion of API X42 pipeline steel materials impinged with solid aluminum oxide particle. Although the erosion mechanism of different carbon steel materials has been widely studied [17-20], no significant breakthrough has been made on the comparison of erosion mechanism of different carbon steel materials by which material is removed from the targeted steel surface. Furthermore, studies to explain the erosion mechanisms of different steel materials under similar test conditions at different impinging particle velocities based on microscopic observation of the impinged surfaces are limited in literature. Understanding the erosion mechanisms of different carbon steel materials under similar test condition is important for proper application of corrective measure in reducing erosion rate in petroleum industry. The knowledge gained from the erosion mechanism investigation can be applied in the pipeline material selection and increase of pipeline material life. The present study aims to explore the erosion mechanisms of API X42 and AISI 1018 steel materials in which material is removed from the impinged targeted steel surface at normal impingement angle.

II. EXPERIMENTAL METHOD

A. *Test equipment and materials*

The erosion tests were performed using a dry sand blaster erosion tester shown in Fig. 1. The test rig was designed to control the impact velocity, feed rate, orientation of the specimen relative to the impinging solid particle and the relative specimen distance.

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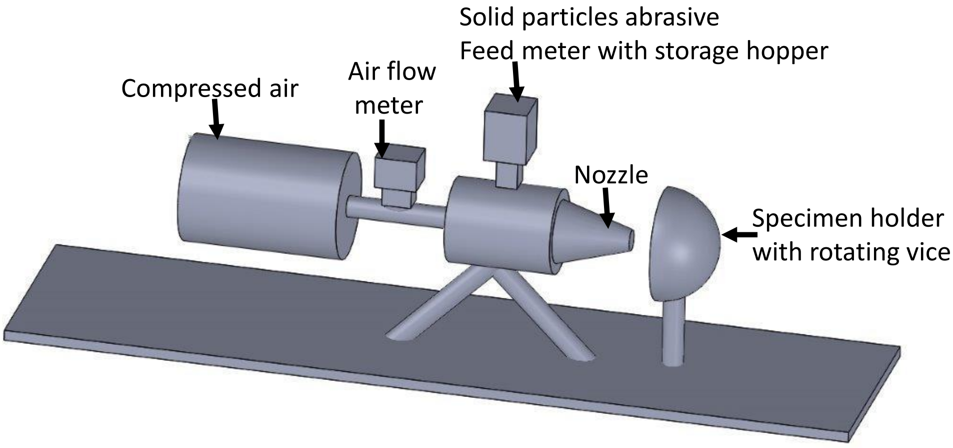

Fig.1. Schematic diagram of the sand blaster erosion machine

The designed apparatus is also equipped with abrasive feed meter which acts as the reservoir tank and controls the solid particles feed rate. Pressure gauge, air flow meter and specimen chamber are also incorporated in the design of the erosion tester. In the tests, aluminum oxide was used as the solid particle eroding materials while API X42 and AISI 1018 steel materials were used as the target steel materials. The chemical compositions of the API X42 and AISI 1018 steel materials used in this investigation are shown in Table 1.

Table 1: Chemical composition of target steel materials and the impinging solid particles

Material	Specimen	Chemical composition
API X42 steel	Target material	Fe C Mn P S Si Bal 0.28 1.30 0.04 0.13 0.15
AISI 1018 steel	Target material	Fe C Mn P S Si 98.98 0.18 0.60 0.04 0.05 0.15
Aluminum oxide	Impinging solid particles	AlO_2 TiO SiO_2 Fe MgO Alkali 99.5 0.099 0.05 0.08 0.02 0.30

The target steel materials used in these erosion tests were cylindrical in shapes of 15.5mm diameter and 4.7mm height. The API X42 and AISI 1018 steel materials were gound using 180, 340,600 and 1200 grits and finally polished using 1 µm and 0.05 µm prior to each test. Scanning electron microscope (SEM) was used to characterize the initial surfaces of the API X42, AISI 1018 and the aluminum oxide particle used in this test, as shown in Fig. 2.

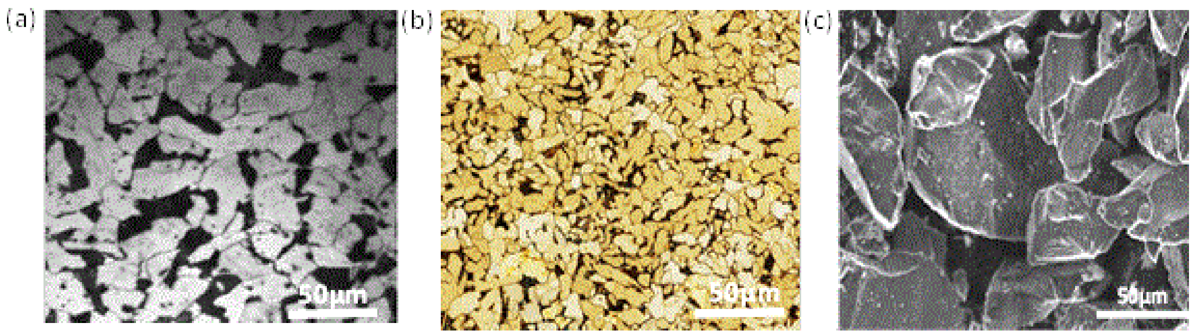

Fig.2. Microstructures of: (a) AISI 1018, (b) API X42 and (c) aluminum oxide particle size distribution.

B. Test procedure

The The erosion test investiagtion was carried out using a sand blaster erosion tester according to STM standard G76 [21]. Adjusting the pressure of the abrasive feed meter was used to control the particle velocity. The particle

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velocity was determined as a fucntion of pressure using double disc method [22]. The solid particle feed rate was determined by measuring the weight of the abrasive solid particles coming through the nozzle per unit time [4]. The solid particles were fed from the tank into the flow channel which exists in a vacuum chamber. The target material is set at a working distance of 3 mm away from the novel, with the solid particle impinging the target material at pre-set 90° angle through the ais of compressed air. The target material was mounted on the specimen holder facing the nozel as shown in Fig. 1. During each test, the specimen was exposed to the solid particle flow for a specified period of time. The tests were run at 10, 300 and 600seconds. Each specimen was weighed before and after each test using a digital electronic balance which has an accurency of 0.0001g to observe any possible diference in the weight loss.

III. RESULT AND DISCUSSION

The wear results of API X42 and AISI 1018 steel specimen subjected to solid aluminum oxide particles impingement carried out at four different particle velocities of 20m/s, 40m/s, 60m/s and 80m/s are presented in this section The wear mechansims of the targeted specimens charaterised using an SEM are also discussed.

A. Erosion rate

Fig. 3 shows the particle velocity versus erosion rate for the two different steel materials impinged at 90° impact angle. The average weight loss of the three tests perfomed at 10 seconds, 300 seconds and 600 seconds was used for calculation of erosion rate. The erosion wear curves for the two steel materials show similar trends. The overall result also revealed that increasing the particle velocity resulted in increased erosion rate. This may be attributed to plastic deformation of the target surface due to multiple particle impacts. However, there is slight deflection in the curve for AISI 1018 steel material at 40m/s test before increasing from 60m/s to 80m/s (Fig.3b).

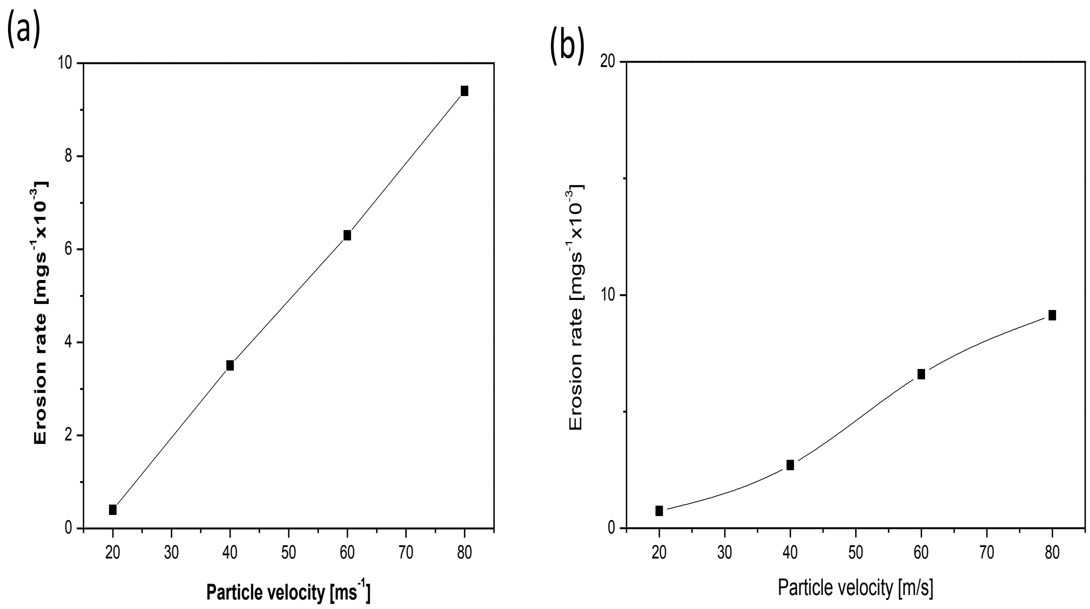

Fig.3. Erosion rate Versus Particle velocity for: (a) API X42 and (b) AISI 1018 steel materials

B. Erosion mechanism at low magnification

Fig. 4 shows low magnification images of eroded API X42 and AISI 1018 steel materials after at 80m/s for 600 seconds test duration. The objective is to show the entire eroded steel surfaces after tests. It could be seen that the impact of the impinging solid aluminum oxide particles on the target steel surfaces resulted in the formation of circular deformed shapes on the steel specimens (Fig.4).

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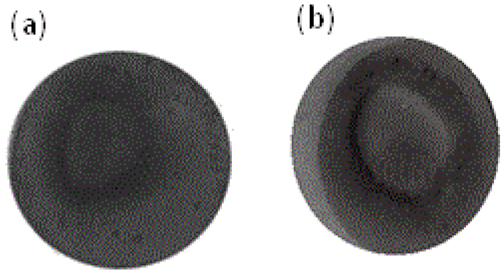

Fig.4. Typical representation of eroded: (a) API X42 steel and (b) AISI 1018 steel specimen after 600 second tests at 80m/s.

C. Erosion mechanism of API X42 steel

Fig. 5 shows the results of the test conducted with API X42 steel material at 600 seconds for diferent velocities. Embedment of the eroding aluminum oxide particles on the targeted API X42 steel surfaces is evident when the test was carried out at 20m/s (Fig. 5a). When the test velocity was increased to 40m/s, deformation of the embedded aluminum oxide particles which was accompanied with ploughing was observed on the eroded API x42 specimen, as shown in Fig. 5b. Fig. 5c shows the increasing severity in the ploughing mechanism as the particle velocity was increased to 60m/s. When the velocity was further increased to 80m/s, cracks and ploughing of the steel specimen were observed (Fig. 5d).

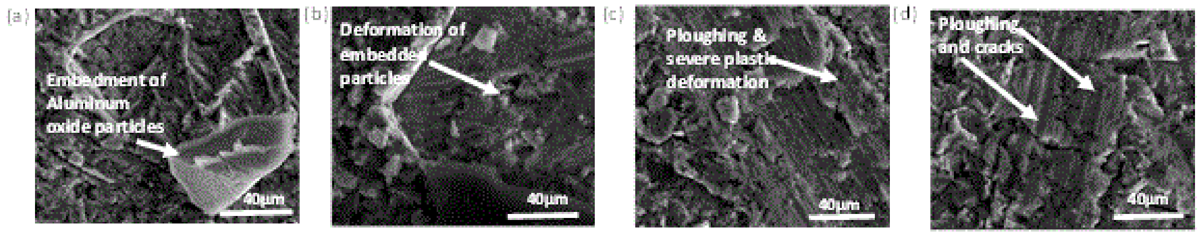

Fig.5. API X42 samples at (a) 20m/s, (b) 40m/s, (c) 60m/s, (d) 80m/s

Embedment of impinging aluminum oxide particles on the API X 42 surface at lower velocities of 20m/s and 40m/s and subsequent deformation of the embedded materials are features of repetitive material removal mechanisms. This mechanism might be associated with the property of both the eroded and eroding materials as reported by other authors [19, 23]. At higher impact velocity, it is believed that the impinging aluminum oxide particles have acquired high kinetic energy resulting in ploughing of the targeted steel surface due to repetitive increased impact particle velocity. It is likely the observed crack is associated with high solid particle impact velocity [24].

D. Erosion mechanism of AISI 1018 steel

Fig. 6 shows the erosion mechanim of AISI 1018 steel material at 20m/s for 600 seconds. It could be seen that plastic deformation of the eroded steel specimen is evident. Fig. 6b shows ploughing mechanism for higher particle velocity impinging the target AISI 1018 steel material at 90° impact angle. Fig. 6c revealed the experimental result that was obtained when the impinging aluminum oxide solid particles velocity was increased to 60m/s. It is interesting to notice the initiation of multiple ploughings at this test condition (Fig. 6c).

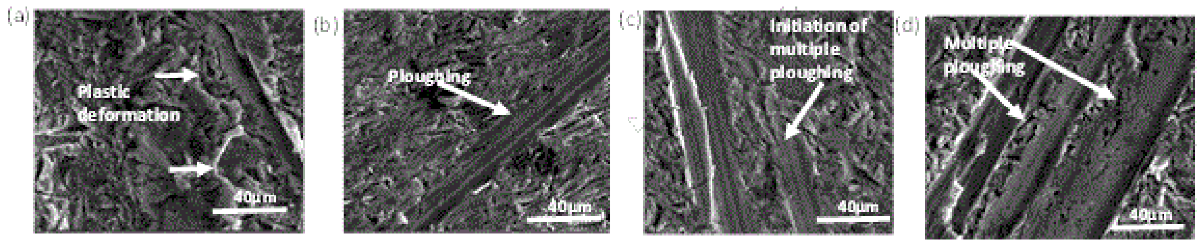

Fig.6. AISI 1018 samples at (a) 20m/s, (b) 40m/s, (c) 60m/s, (d) 80m/s

Further increase in the particles velocity shows the mechanism of multiple ploughings on the eroded AISI 1018 steel surface at this test condition (Fig. 6d). Evidence of ploughings observed at 40m/s, 60m/s and 80m/s show that ploughing is the prevailing erosion mechanism at these test conditions. Increasing the particle velocity resulted in increased number of ploughings as seen in Figs. (6b, c, and d). It is believed that at higher impact velocity, the

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elastic strain energy of the impinging particle is higher than that of the targeted material [25, 26]. At this condition, the impinging solid particles penetrate the target steel material matrix resulting in more material removal. This process can cause some of the reflecting solid particles to collide with some in-coming particles at this normal impact angle. Under this condition, the direction of the solid particle might change and plastic deformation, followed by ploughing of the targeted materials might occurs as observed in this investigation (Fig.6). [27]. Similar observation was reported by Al-Bukhaiti et al. [6], where ploughing mechanism of AISI 1017 steel material was seen on eroded steel surface between impinging angle of 15° and 75°.This observation is in close correlation with that seen in this study. It could then be imply that ploughing mechanisms observed at 90° impact angle and the increasing number of ploughings as the particle velocity was increased is influenced by material property.

IV. CONCLUSION

The experimental investigation described in this study confirms that the erosion rate on carbon steel surfaces subjected to impinging aluminum oxide particles varies with the impinging particle velocity. At low impact velocity, embedment of impinging particle materials on the target steel surfaces followed by plastic deformation occurred. At higher particle velocity, ploughing of the targeted steel surfaces becomes the prevailing erosion mechanisms. Material property play significant role in the erosion mechanisms of the carbon steel material. This was evident in the erosion mechanisms of the two carbon steel materials used in this investigation. It was observed that most of these erosion mechanisms may occur simultaneously in the metal removal process, but in each case, one of the mechanisms plays a dominant role.

ACKNOWLEDGEMENT

This publication was made possible by NPRP Grant 6-027-2-010 from the Qatar National Research Fund (a Member of The Qatar Foundation). The statements made herein are solely the responsibility of the authors.

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