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Erosion-Corrosion Control in steel pipelines of Reacted alumina Transport

M. A. Doheim[a], S. M. Ahmed[b], Y. M. Abdelrahman[c]

[a] *professor, Min.& Metal. Eng. Dept. Faculty of Eng. Assiut Univt., Egypt.*

[b] *professor, Mech. Eng. Dept. Faculty of Eng. Assiut Univt., Egypt.*

c Engineer , Aluminium company of Egypt, Egypt.

Abstract

Field tests are specifically designed to monitor the deterioration behaviour of the Soderberg pipeline, to evaluate alternative materials of construction, to determine the effect of process conditions, and determining the most useful means for reducing the deteriorating rate. It was found that the change in steel composition affects both erosion and corrosion resistances. The results showed that increasing corrosion resistance is beneficial to decreasing synergistic mass loss rate. Steel with 1%Cr, 0.3%Si, and 1,35Mn was the most resistant. The corrosion rate of C-steels increases with C-content. The horizontal parts of pipelines are more deteriorated than the vertical parts.

Keywords: erosion-corrosion, Steel pipelines, reacted alumina

Corresponding author: mohdoheim@yahoo.com

Tel.: ++2-01007041155

Fax: ++2-0882326134 - ++2-0882332553

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1. Introduction

The erosion-corrosion problem may result in serious deterioration of transport pipelines in various industries [1]. The synergistic effect of erosion-corrosion could cause more damage than the sum of both effects [2,3]. The system under consideration [4] involves recycling the enriched reacted alumina to the self-baked cells in Al-production plant. The system was analyzed and discussed in all its aspects [5]. It is known that the transport lines for fresh alumina or in the pre baked cell system suffer very little damage compared to the self-baked (Soderberg) cell system [5]. Such problems in industry are very annoying and are a threat to the production plant. It needs a good and expert effort for good design and material selection to control such deteriorating effect.

The carbon content of the steel play an important role in the corrosion process, especially in the acidic solutions. The mechanism involved in this effect is not clear [6]. Low carbon steel materials showed high corrosion rates in NaCl 4.5%. The corrosion rates were found to be quite low for the low carbon steels but with higher corrosion rates for the medium and high carbon content steels in NaCl and CO_2 gas. For the third aqueous solution which consists of sodium chloride, sulphuric acid and purged CO_2 gas, the highest corrosion rates were obtained from high carbon content specimen [6].

This paper studies and discusses the erosion- corrosion control problem through field tests on pipeline material of construction under different conditions.

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2. The Problem:

The aluminum cell of the Hall-Heroult process produces environment unfriendly secondary products composed of tar, dust, vapors and gases. These cell emissions (duct gases) include O_2, N_2, CO_2, CO, H_2O, SO_2, HF, and tar [7]. The most important constituents of cell gases are given in Table1. The most aggressive duct gases are: HF, CO_x, and SO_x. The fluoride emissions are gaseous and particulate. Fluoride particulates are solid at a low temperature and are removed with CO_2 gases. The gaseous HF is chemisorped on smelter–grade alumina in the dry gas cleaning system. HF adsorption on alumina occurs in preference to adsorption of SO_2 and may prevent COS adsorption [7]. The CO present due to the back-reaction of the re-oxidation of dissolved aluminum to alumina can form, presence of moisture and Sulphur compounds, toxic metal carbonyls and can cause stress corrosion cracking in carbon steels at elevated pressures [8]. Thus, we have HF, SO_2 and CO in the emitted cell gases which are aggressive enough to attack severely the constructional material of the pipeline. The carbon steel is usually the most economic material used. In such environment, the C-steel can be severely corroded [9]. This is the problem in the transport pipeline of recycled active alumina in Misr Aluminum Co. in Nagaa Hammady, Egypt, and the similar systems.

3. The Experimental work :

Field tests are specifically designed to monitor the corrosion behaviour of the Soderberg pipeline, to evaluate alternative materials of construction, to determine the effect of process conditions that cannot be reproduced in laboratory , and to determine the most useful means of reducing corrosive rate.

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Mass loss experiments have been done to determine the effect of carbon content of carbon steel, the effect of orientation (horizontal- vertical), and the effect of alloying elements (Cr- Mo- Ni- Mn- Nb) on the erosion-corrosion rate.

3.1. Test Materials:

The chemical composition of the existing pipeline material in use is shown in Table 2. Four specimens of this material are fixed in the vertical part of the enriched alumina pipeline of Soderberg cell and other four specimens are fixed in the horizontal part, to study the effect of the orientation (horizontal-vertical) on the erosion-corrosion rate. Four specimens of different carbon content steels are fixed in the horizontal pipeline with its chemical composition given in Table 3, to study the effect of carbon content on the erosion-corrosion rate. Five specimens of different steels with compositions shown in Table 4 are selected to study the effect of alloying elements. To increase the reliability of the tests, the specimens were chosen from rolled sheets.

3.2. Equipment and Procedure:

Small connections were prepared from the pipeline material each one is 40 cm long, two flanges were welded to install the connection in the pipeline. Fig.1 shows the small connection in the pipeline. Square test specimens with dimensions of 20*20*2mm and a hole of 5mm diameter in the center were utilized in the experimental work. Fig. 2 shows the specimens fixation. There is fiber textolite insulation between the specimens and the wall pipe. The specimens were finished by 120 grit belt. The specimens are de-greased by washing in acetone, dried, and weighed on analytical balance ($\pm$0.1mg). After the experiment, the specimen is cleaned and weighed again and the corrosion rate is calculated from the mass loss. The above

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procedure is according to ASTM G1-81 (preparing, and evaluating corrosion test specimens) [10]. The tests were carried out under the same operating conditions of the pipeline with velocity of 31m/s, average temperature of 35^{o}C, inside gas pressure of 3-4 bar, mass solid to gas mass ratio of 8.37 and alumina mass flow rate of 5 kg/s. The analyses of fresh and eriched alumina are given in Table 5,

mass loss per test specimen ,due to the exposure for a specified period of time, is calculated by:

$$\Delta W = W_o - W_i , \tag{1}$$

Where W_o is the original weight of specimen before exposure, and W_i is the weight after exposure.

Corrosion rate was calculated using the equation:

$$CR = \frac{M * 24 * 365 * 10}{\rho * A} , \tag{2}$$

where CR = Corrosion rate in mm/yr , M= rate of mass loss in g/hr, ρ= Density of the test specimen in g/cm^3, and A = Area in cm^2 of the test specimen.

The CR is considered as an average value.

4. Results of Test Conditions:

All steel specimens were found to corrode. This was evidenced by the decrease in the original mass of the specimens. Tables 6 and 7 show the mass loss of specimens after 45 days for the horizontal and vertical pipelines respectively. From these Tables, it can be seen that the average mass loss of specimens of horizontal orientation is greater than that for the vertical orientation. The erosion-corrosion rate of the horizontal orientation is greater than the erosion – corrosion rate of the vertical orientation by a factor of about 2.25.

Table 8 shows the mass loss of specimens with different carbon content after 45 day exposure. The results show that the mass loss is affected by the content of carbon. As the carbon content increases the mass loss increases. Kim et al [11] found that the corrosion rate increases with carbon content within the range of about 0.06% to more than 0.15%C.

The mass loss and erosion- corrosion rate of different alloy steels are shown in Table 9after 45days. It is clear from Table 9 that the mass loss is dependent on the alloying element. Steel No. 5 has the least mass loss.

5. Discussion:

5.1. Effect of orientation (horizontal-vertical)

From Tables 6&7 the erosion-corrosion of horizontal part of the enriched alumina pipeline of Soderberg system is more than the vertical part by a factor of about 2.25.This may be attributed to the gravity effect, since the horizontal part is subjected to the saltation effect which makes the surface subjected to the corrosive agents and the erosive effect of the alumina particles. The saltation effect reduces the cross section of area of the pipeline and thus increasing the gas velocity. The marked increase of the deteriorating erosion-corrosion effect in the horizontal part was verified by the field observation that the replacement of the horizontal part is frequently occurring than the vertical part. Thus, there is compatibility between the field tests and field observation.

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5.2. Effect of carbon content

Table 8 indicates that the erosion-corrosion rate increases with increasing the carbon content. In spite of the hardness increase with increasing the carbon content, consequently enhancing erosion resistance; in our case the erosion- corrosion increases, this may be because the corrosion is the dominant. In the work of Kim et al [11] the CR decreases rapidly as the C-content increases to about 0.06%, then decreases gradually as C-content increases up to about 0.1%. A further increase in C-content up to about 0.15% increases the CR and then substantially increases with further carbon increases (>0.15%). The proper C-content for low corrosion rates is from 0.05% to less than 0.1%.

5.3. Effect of chemical composition

From Table 9 which shows the erosion-corrosion rate of five steels with different alloying elements after 45 days, Steel 1 which did not contain any alloying element is the more deteriorated. Fig 3 shows the erosion –corrosion rate of the five steels after 45days. Steels 2, 3, 4 which contain little amounts of molybdenum and niobium, are more resistant than steel 1. Steel 3 is more resistant than steels 2, 4, which may be attributed to the higher Mn-content. Steel 5, which contains 1% Cr and relatively high percentage of Si and Mn, is the more resistant. The positive effect of low chromium addition is proposed since chromium-enriched surface films are formed and they cause a reduction of the corrosion rate [12]. This information is being used to obtain steels with better corrosion performance than the carbon steel [13].

Conclusions:

1. The orientation of the pipeline affects clearly its deterioration, the horizontal sections are more effected than the vertical ones.

2. The corrosion control is clearly influenced by the C-content of steel and the presence of minor alloying elements. The deterioration increas with C-content,within the investigated range.

3. The pipeline system design and materials selection need to be improved so that the erosion-corrosion problem can be controlled, e.g., the stagnant period, the cleaning of pipeline from the enriched alumina, the versatile change of air velocity, and pipeline orientation.

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Table 1;Analysis showing the effecting species in cell gases

constituents	Value, mg/m3
HF	250
SO_2	400
Tar	100
Dust	2000
Water vapour	10000
CO_2	4600
CO	3500

Table 2: Chemical composition of the pipeline material in use

Element	C	Mn	P	Si	Cu	Mo
Wt.%	0.08	0.55	0.007	0.018	0.019	0.008

Table 3: Chemical composition of different carbon content samples

Sample	Composition wt. %			
	C	Si	Mn	P
1	0.07	0.15	0.48	0.028
2	0.1	0.18	0.58	0.037
3	0.18	0.34	0.73	0.027
4	0.2	0.24	0.69	0.025

Table 4: Chemical composition of low alloy steel specimens

Sample	Chemical composition (wt. %)								
	C	Mn	P	S	Si	Ni	Cr	Mo	Nb
1	0.05	1.18	0.006	0.017	0.08	-	-	-	-
2	0.08	0.8	0.01	0.01	0.15	-	-	0.05	0.05
3	0.19	1.8	0.02	0.015	0.26	-	-	0.035	0.06
4	0.18	1.1	0.018	0.018	0.26	-	-	0.08	0.06
5	0.21	1.3	0.03	0.03	0.3	0.06	1	-	-

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Table 5 Analyses of enriched and fresh alumina

Specification	enriched	Fresh
F,wt%	1.07	---
S,wt%	0.17	---
C,wt%	0.2	---
SiO_2,wt%	0.005	0.008
Fe_2O_3,wt%	0.018	0.008
Na_2O,wt%	0.55	0.4
CaO,wt%	0.05	0.32
Moisture(at 300 C°)	0.69	0.40
L.O.I(at 1000 C°)	2.2	0.87
Bulk density ,g/ m^3	0.98	0.95
Angle of repose degree	30	33
Sieve Analysis		
+ 150 micron,%	1.61	5
- 45 micron,%	4.23	6

Table 6: mass loss of specimen installed in a horizontal position

Specimen (Fig.1)	1	2	3	4	Average	Loss rate, mm/year
Mass loss, mg	360	330	320	360	342.5	0.89

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Table 7: mass loss of specimens installed in a vertical position.

Specimen	1	2	3	4	Average	Loss rate, mm/year
Mass loss, mg	140	150	170	160	155	0.4

Table 8: mass loss of different carbon content specimens

Specimen	1	2	3	4
Carbon content	0.05	0.1	0.18	0.2
Mass loss, mg	150	170	580	1024

Table 9: mass loss and loss rate for different steels after 45 day

Steel	mass loss, mg	loss rate, mm/year
1	1090	2.81
2	641	1.65
3	342	0.88
4	720	1.85
5	88	0.23

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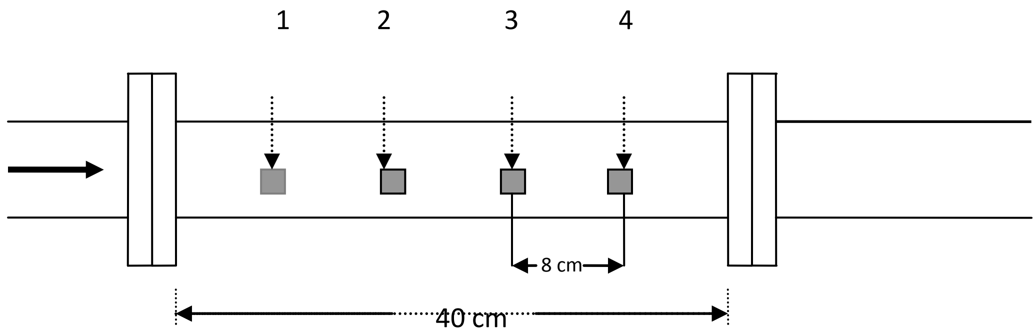

Fig.1: Test section

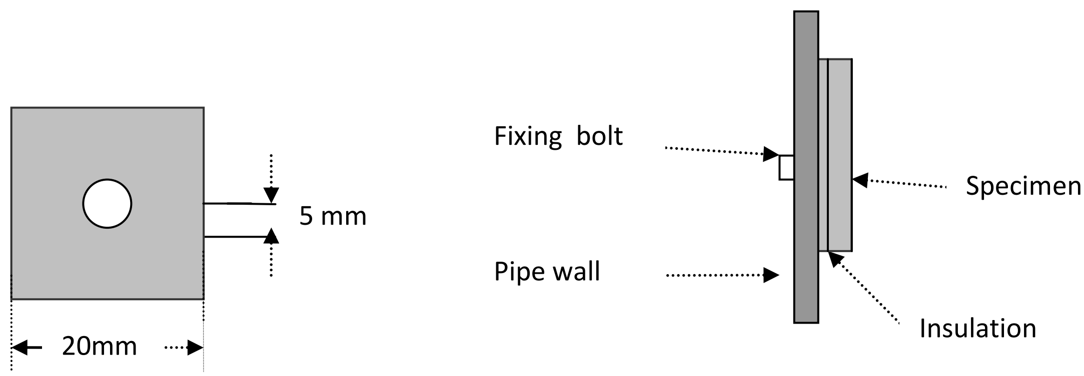

Fig.2: The specimen fixation

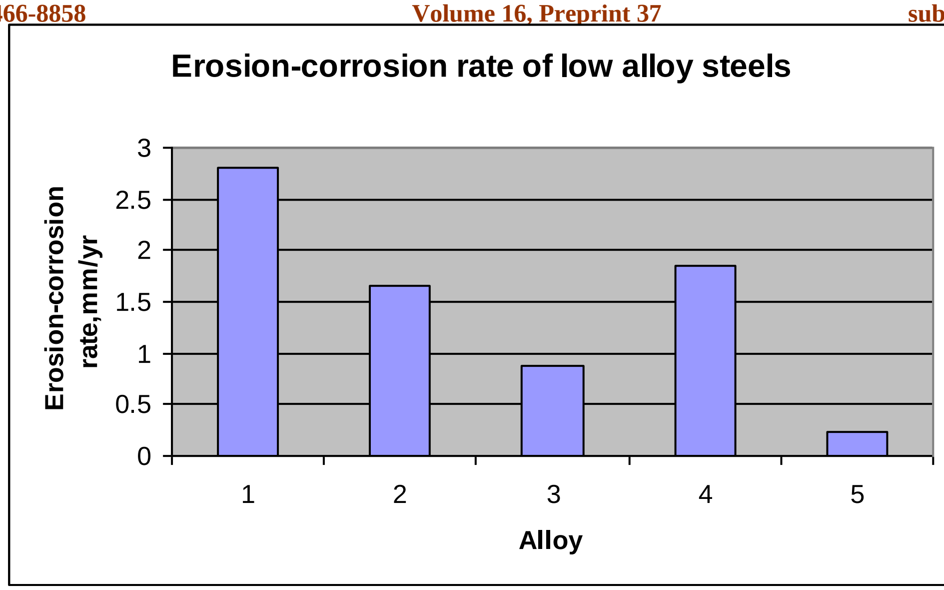

Fig.3: Erosion –corrosion rate of different low-alloy steels after 45 days