Engineering Failure Analysis 59 (2016) 410–418

Contents lists available at ScienceDirect

Engineering Failure Analysis

journal homepage: www.elsevier.com/locate/efa

Short-term electrochemical corrosion behavior of pipeline steel in saline sandy environments

Bin He [a,c], Chun-hui Lu [c,d], Peng-ju Han [a,b], Xiao-hong Bai [a,*]

[a] College of Architecture and Civil Engineering, Taiyuan University of Technology, Taiyuan 030024, P. R. China
[b] College of Materials Science and Engineering, Taiyuan University of Technology, Taiyuan 030024, P. R. China
[c] Department of Civil Engineering, Monash University, Clayton, Victoria 3800, Australia
[d] State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, Hohai University, Nanjing 210098, P. R. China

ARTICLE INFO

Article history:
Received 12 May 2015
Received in revised form 29 October 2015
Accepted 2 November 2015
Available online 6 November 2015

Keywords:
Soil corrosion
X70 pipeline steel
Salinized sandy soil
Discontinuous gradation
Electrochemical impedance spectroscopy (EIS)

ABSTRACT

In this study, we investigate the short-term electrochemical corrosion behavior of X70 pipeline steel in salinized sandy soil using the electrochemical impedance spectroscopy (EIS). The results show that the corrosion behavior of X70 steel in sandy soils with a relatively high water content (~18%) is mainly dominated by pitting or localized corrosion, which is controlled by charge-transfer processes. The reason can be attributed to the loose corrosion products (unable to produce an effective protective layer) and discontinuous gradation in sand particles. EIS plots of X70 steel consist of two capacitive loops at the initial stage of corrosion, while a capacitive arc at high-, medium-, and low-frequency is developed after 12 h of corrosion. The capacitive loop formed at the high frequency indicates the resistance and capacitance generated by the penetration of ions into the metal surface through the sand pores and the defects of the corrosion product film.

1. Introduction

The West–East Gas Pipeline Project operated in 2004 was developed to transmit natural gas from the western part of China to the east, and the majority of the pipelines in Northwest China are buried in sandy soil. With the increase of the service life of underground gas pipelines, the corrosion of pipeline steels in soils becomes a more and more important issue, as it can affect the normal operation of the pipelines and result in safety and economic impacts [1–4]. Corrosion of buried metals can be affected by a variety of factors, including soil water content, chemical constituents, the pH of the corrosion environment, electrical resistivity, soil types, salinity, porosity, and others, which have been investigated extensively in previous studies [5–11].

The majority of the pipelines in Northwest China are buried in sandy soils formed by frequent land desertification [12,13]. Compared to dense and clay soils, sandy soils have a better aerated property and a higher permeability [14]. Due to the complexity in the mechanisms of soils as special capillary-porous solid electrolytes [5,15], the corrosion mechanisms of the pipelines buried in sandy soils are not well known. Moreover, soil salinization is a ubiquitous problem in arid and semiarid regions. It is reported that the area of salinized soils in Northwest China accounts for more than 60% of the total land with soil salinization issues in the country, and importantly, the pipelines in Northwest China are buried mainly by salinized soils. Limited studies have been reported to explore the corrosion of pipeline steels in salinized sandy soils under highly aerated and permeable conditions [16–18]. In the region of sandy soils, steel corrosion is negligible if there is no rainfall or snow, while water could percolate into the underground and accelerate the processes of steel corrosion once rainfall or snow occurs. As such, it is important to

* Corresponding author at: College of Architecture and Civil Engineering, Taiyuan University of Technology, Yingze Street 79, Taiyuan 030024, P. R. China.
E-mail address: bxhong@tyut.edu.cn (X. Bai).

http://dx.doi.org/10.1016/j.engfailanal.2015.11.007
1350-6307/

understand the short-term steel corrosion behavior in moist salinized sandy soils. Furthermore, most of previous studies are based on the soils with continuous gradation particles, and hence, it is of practical interest to know the effects of discontinuous gradation on the steel corrosion behavior.

Soil (especially sandy soil) is a high-impedance multiphase system, and therefore, appropriate methods are required to measure the corrosion process. There are a number of methods available to investigate the corrosion processes of buried pipeline steels. Electrochemical impedance spectroscopy (EIS), among others, has been successfully applied to the study of corrosion problems in the past decades and proved to be a powerful and accurate method for characterizing corrosion processes of pipeline steels [19–22]. This method is also adopted in the current study [23], as the disturbance of the EIS method on the target system (i.e., the system to be tested) is small and not affected by the IR drop.

In this study, we use electrochemical methods to explore the short-term (24 h) corrosion behavior and mechanism of X70 steel (used in the No.1 West–East Gas Pipeline) [13,17,24–25] under the water content of 18%, a critical value that could result in the maximum corrosion rate [16].To mimic soil salinization and to generate accelerated corrosion, 1.5 wt% sodium chloride (NaCl) solution is added to the soil. The study is expected to reveal the effects of discontinuous gradation of salinized sandy soils on the corrosion processes and hence to provide insight into the understanding of the corrosion behavior and mechanism of X70 steel in the soil environments in the Northwest China.

2. Materials and experiment

2.1. Materials

Soil samples for laboratory experiments were collected at the depth of 1 m below the ground surface from Liuyuan (Town), Gansu Province in the Northwest China, where the No.1 West–East Gas Pipeline is located (see Fig. 1). The soil samples were naturally dried and their chemical compositions were tested and summarized in Table 1. The particle gradation analysis was conducted to determine the coefficients of nonuniformity and curvature. The values of the coefficients of nonuniformity (5.93)

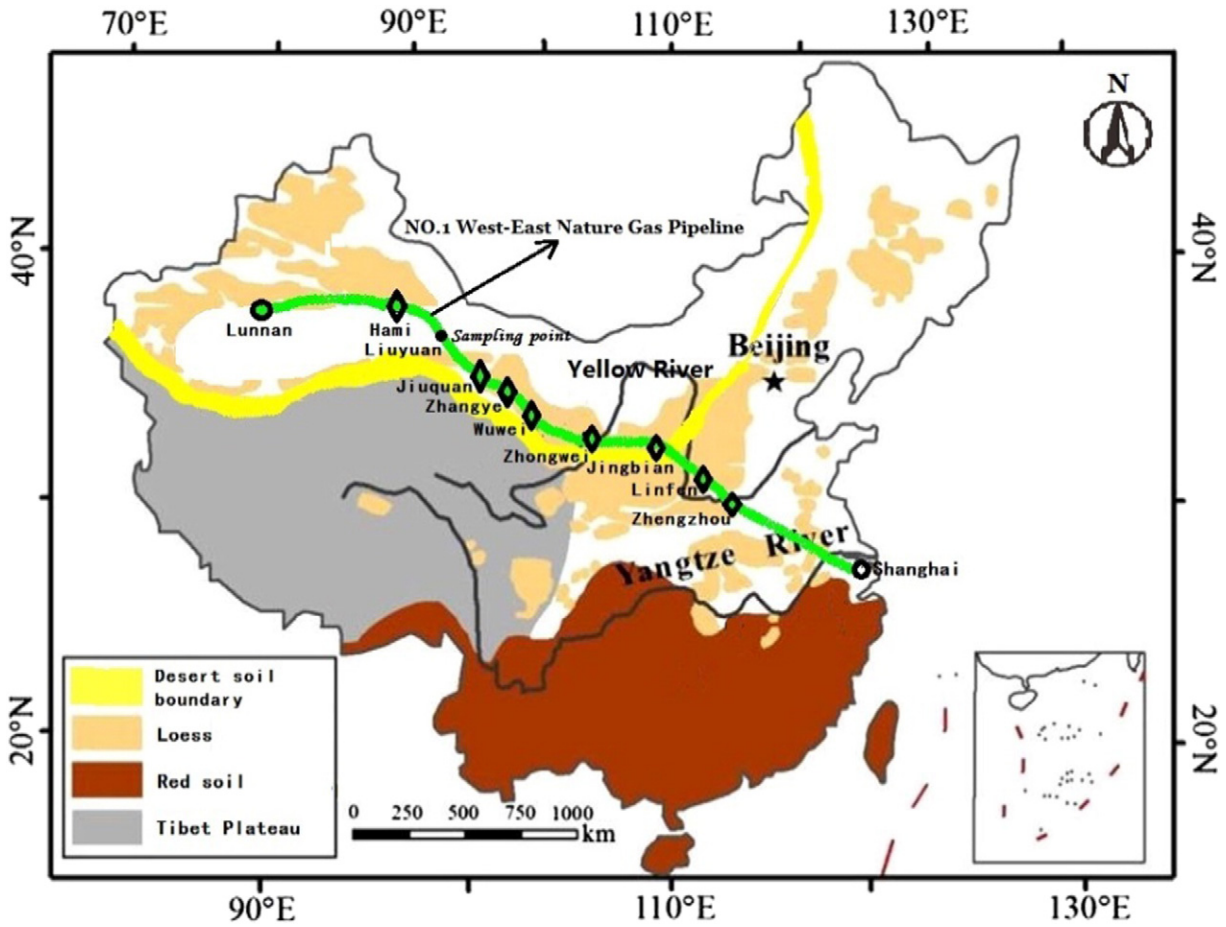

Fig. 1. The distribution of two-thirds of No.1 West–East Gas Pipeline in the desert regions of China (north of the yellow line). The sandy soil samples used for laboratory experiments were collected from Liuyuan town of Gansu Province in Northwest China. The map is modified after [26].