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Failure analysis of corrosion at an inhomogeneous welded joint in a natural gas gathering pipeline considering the combined action of multiple factors

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ABSTRACT

A gathering pipeline in a gas field in Northeast China transporting mainly natural gas and also some water and sands was welded using two 20G pipes with different wall thicknesses. The internal corrosion of this pipeline was inhomogeneous. The unequal wall thickness welded joint suffered more serious corrosion damage than did other parts of the pipe and was found to fail during routine maintenance. In this paper, the corrosion damage at this joint was studied based on inhomogeneity. Internal and external factors affecting corrosion, such as the mechanical and electrochemical properties of materials, stress distribution at the joint, and the flow condition in the pipe, and their combined action were investigated. Failure attribution was performed on this basis. Specifically, a hardness test was conducted on different zones of the joint, including the base metal (BM), heat-affected zone (HAZ) and weld metal (WM), to investigate the abrasive wear resistance at the joint. Microstructures of the three zones were characterized by optical microscopy. The morphology and composition of the corrosion film covering the inner surface of the welded joint were characterized by scanning electron microscopy (SEM), energy-dispersive spectroscopy (EDS) and X-ray powder diffraction (XRD). Potentiodynamic polarization experiments and electrochemical impedance spectroscopy (EIS) were conducted on samples from the three zones to investigate their electrochemical performances. Moreover, a computational fluid dynamics (CFD) analysis was performed to obtain the flow condition near the joint, and a finite element method (FEM) was used to calculate the stress distribution at the joint. The results showed that the internal corrosion mechanism of the pipeline was CO_2 corrosion accelerated by detrimental Cl^-. The geometric discontinuity of the welded joint was the main cause of the accelerated corrosion damage at the joint. The change in wall thickness of the welded pipe not only produced gas vortices but also led to stress concentration. Both of these conditions can further accelerate corrosion by destroying the protectiveness of the corrosion film. It is suggested that the corrosion can be prevented by eliminating the inhomogeneities of fluid flow and stress distribution.

1. Introduction

Welding is the most commonly used technology to connect steel natural gas pipelines. By the end of 2013, the total length of natural gas pipeline in China had reached 62,000 km. With the extensive use of natural gas pipelines in China, corrosion failures at welded joints of natural gas pipes have begun to more frequently occur, causing substantial annual economic losses to enterprises and the country. Due

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to metal melting and solidification involved in the welding process, along with the melting and recrystallization of crystals, the material properties of a welded joint, which includes different zones, such as the weld metal (WM), heat-affected zone (HAZ) and base metal (BM), always exhibit inhomogeneities. Moreover, certain joint forms, such as T-joints and unequal wall thickness joints, always lead to geometric discontinuities, and this type of discontinuity can cause stress concentration at the joint and a sudden disturbance of fluid flow in the pipe. The inhomogeneities of material properties, stress distribution discontinuity, and flow disturbance are considered to be a type of generalized "inhomogeneity" in this paper. Inhomogeneous distributions of matter and energy are manifested in different forms, and the inhomogeneity always becomes the driving force behind other natural phenomena. In regard to pipe welded joints, the inhomogeneities of material properties, stress and flow make the joints become the sensitive parts in terms of the internal corrosion of pipelines.

For decades, increasingly more research has focused on corrosion damage at welded joints. L.M. Byvoishchik et al. [1] investigated the influence of the microstructure on the plasticity, impact toughness, and corrosion resistance of welded joints in low-alloy steels, which are widely used in the oil industry. W.Y. Wu et al. [2] studied the microstructure, mechanical properties, and corrosion behavior of dissimilar metal welded joints between carbon steel and ferritic stainless steel. The influence of the fluid flow on the preferential corrosion of welded X65 pipeline steel in brines containing carbon dioxide was studied by K. Alawadhi et al. [3,4] and M.A. Adegbite et al. [5], respectively, and further consideration was given to the influence of sand on preferential weld corrosion in such environments by R. Barker et al. [6]. Moreover, corrosion failures caused by stress, such as stress corrosion cracking, have also been a key concern of many scholars [7,8]. However, for welded joints in natural gas gathering pipelines, relatively little comprehensive analysis considering multiple factors affecting corrosion, such as the material properties, stress and flow, has been conducted. There has also been little research on their combined action. This paper studies a corrosion failure case of a welded joint in a certain natural gas gathering pipeline via experimental analysis and numerical calculation. Multiple sensitive factors affecting corrosion at the joint and their combined action were analyzed. The influence of inhomogeneity on the weld corrosion was discussed. On this basis, the failure mechanisms of weld corrosion were investigated. Two anti-corrosion measures were also provided to prevent similar corrosion failures.

2. Natural gas gathering process and corrosion failure phenomena

In the production of natural gas, gathering pipelines gather gases from different wells and transport them to a purification plant, where dehydration and desulfurization are conducted. Due to the direct contact between gathering pipelines and untreated gases that are highly corrosive, severe pipeline internal corrosion always occurs. Meanwhile, the flammability and high pressure of natural gas can greatly increase losses caused by corrosion failures. Serious corrosion damage at a welded joint of a gathering pipeline was detected in a gas field in Northeast China during routine maintenance. Fig. 1 shows the location of the failed welded joint in the pipe network. An image of the pipe section with the failed welded joint is shown in Fig. 2. It can be observed that internal corrosion occurred along the entire pipe section, with brownish-yellow corrosion products covering the pipe inner surface. However, compared with other parts of the pipe, the welded joint suffered more serious corrosion. The wall thinning at some locations along the circumference of the girth weld was significant, and perforations were about to occur. To ensure the safe production of natural gas, this dangerous pipe section was immediately replaced. This study attempts to determine what type of corrosion occurred on the inner surface of the gathering pipe, why the corrosion damage at the joint was more serious, and what the corrosion failure mechanism was at the joint.

Through a field investigation, information about the pipe material, operating parameters, and components of the transported medium were obtained. The corrosion environment in the gathering pipe can be assessed accordingly. Similar to many pipelines in China, this

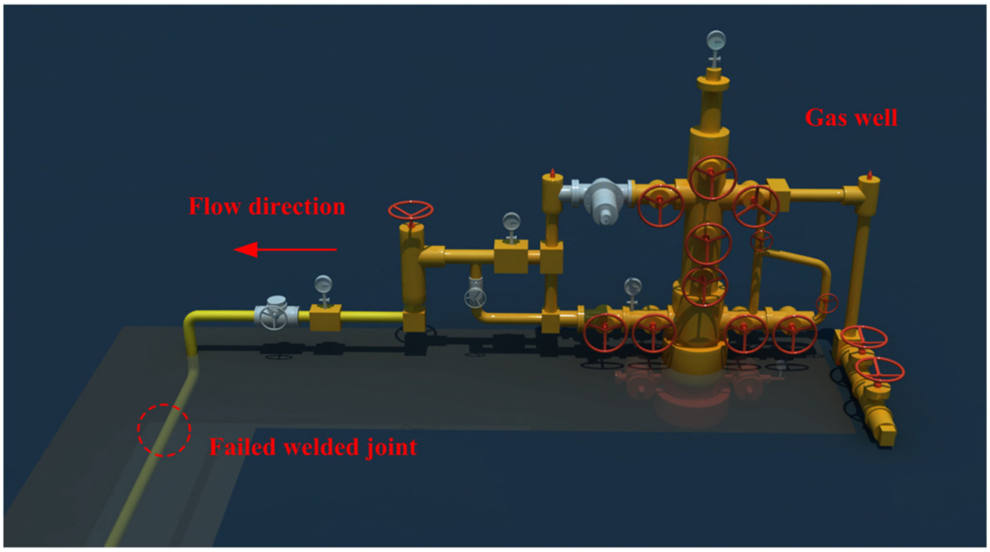

Fig. 1. Location of the failed welded joint in the pipe network.