

Sensitivity Study Of Typical Pipelines And Station Pipes In Hydrogen Environment

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ABSTRACT

This article selects a certain gas pipeline system, the director of the line on material X60 steel and typical process pipeline structure of 20 # steel elbow, yard by the metallurgical structure observation of the typical sampling position and hardness tests, hydrogen permeation test compared the hydrogen and hydrogen content of X60 steel base, girth weld and hydrogen embrittlement sensitivity of 20 # steel elbow position size. The risk of hydrogen embrittlement at sensitive sites in hydrogen environment was studied by notch tensile test. The results show that the hydrogen diffusion coefficient of base metal and weld of X60 steel is higher, and the hydrogen concentration adsorbed on the surface is lower. The hydrogen diffusion coefficient of 20# steel is low, and the concentration of hydrogen adsorbed on the surface is

high, which indicates that the hydrogen trap content in 20# steel is high, and it is easier to capture hydrogen atoms, and the possibility of hydrogen embrittlement exists. The notch tensile test of 20# steel at a sensitive position was carried out in a medium with a total pressure of 6 MPa and a volume fraction of 3% hydrogen. Compared with the similar experimental results in the air, the strength and plasticity of 20# steel have no obvious changes. The results show that the risk of hydrogen embrittlement of 20# steel is low in the mixed hydrogen transportation environment.

Key words: X60 steel; 20 # steel; Hydrogen permeation; Hydrogen content; tension test of notched specimens.

INTRODUCTION

With the increasing global energy demand, the transportation volume of natural gas increases rapidly, and pipeline transportation has become the most commonly used transportation mode of natural gas [1]. Hydrogen is produced as a byproduct of ethylene production from ethane. Hydrogen is flammable and explosive. If it is directly discharged into the atmosphere, there are some safety risks. As a kind of efficient and clean secondary energy, hydrogen can not only avoid energy waste, but also increase economic benefit if it is mixed into natural gas pipeline. However, considering the particularity of hydrogen, hydrogen mixed natural gas will also bring certain risks to the safety of pipeline transmission system and equipment and facilities in the station, so the influence of hydrogen on pipeline steel is attracting more and more attention [2,3]. In the process of transportation, hydrogen molecules can adsorb on the steel surface, decompose into nascent hydrogen atom, diffuse through iron lattice, trapped and concentrated at crystal defects such as dislocations and grain boundaries as well as in stress-concentrated areas, resulting in hydrogen embrittlement[4]. Existing literature shows that the risk of hydrogen embrittlement of grade of X60 steel has been reduced. However, in the manufacturing and repair process of pipeline welding joints at specific positions, the properties of X60 are inevitably affected by assembly stress, heat treatment process and other factors, making material prone to local tissue hardening and formation of various defects [5,6]. At the same time, the position of pipe in the station may be subjected to complex forces which could lead to hydrogen embrittlement failure when transporting natural gas mixed with hydrogen [7]. At present, there is no relevant domestic and internal industry standards for hydrogen mixing proportion of natural gas pipeline for reference. Therefore, in order to have a safe transportation of natural gas mixed with hydrogen through pipelines, it is necessary to conduct a study on hydrogen mixing transportation based on the hydrogen mixing ratio of the existing pipeline transportation system.

In this paper, X60 steel base material, X60 girth weld and 20# steel elbow are studied. By analyzing the physical and chemical properties of the materials, comparing the hydrogen embrittlement sensitivity of different materials with hydrogen permeation test and hydrogen concentration test after hydrogen charging, the more sensitive positions of the X60 pipeline were determined. Notch tensile test under the total pressure of 6 MPa and 3% partial pressure of hydrogen (the balance gas is N_2) was carried out to study the mechanical property degradation of the sensitive positions. The changes of hydrogen embrittlement sensitivity of more sensitive positions in hydrogen-containing environment were obtained.

EXPERIMENTAL PROCEDURE

Materials

The experimental materials are X60 base metal (BM) 、X60 weld metal (WM) and 20# steel, whose chemical composition is shown in Table 1.

Table. 1. Chemical composition of the Chemical composition of X60 and 20# steel (wt%)

element	C	Si	Mn	S	P	Mo	Nb	Ni	Cu	Ti	Fe
X60W	0.057	0.257	1.59	0.002	0.014	0.117	0.017	0.012	0.022	0.017	Bal
M											
X60	0.064	0.194	1.48	0.001	0.012	0.002	0.041	0.034	0.017	0.009	Bal
BM											

Metallographic structure observation

Metallographic test was conducted as per GB/T 13298-2015 "Method for Inspection of Metal Microstructure". Before the microscopic test, the sample was cut into 10×10×10 mm test material, and surface polishing was using Sic paper of 600#, 800#, 1000# and 1200# in sequence. Then 3 μm and 1 μm alumina polishing solution was used for final polishing. The polished sample was cleaned with anhydrous alcohol and dried with an air dryer. Finally, ferric oxide hydrochloric acid solution was used to etch the surface of the sample, and the microstructure of the material was observed by ECLIPSE LV150N optical metallographic microscope.

Hardness testing

The hydrogen embrittlement sensitivity of metallic materials is affected by strength and hardness. In order to better study the influencing mechanism of the hydrogen embrittlement sensitivity of each tissue sample, the Vickers hardness test was performed as per GB/T 4340.1-2009 vickers. Hardness Test for Metallic Materials, Part 1: Test Method [8]. HV10 was carried out on metallographic samples with pressure of 98 N, and holding time of 15 s. The indentation diagonal length d and surface area were measured and determined. Finally, the average pressure on the indentation surface area was calculated, which was the Vickers hardness values were obtained by dividing average pressure by indentation surface area.

Hydrogen permeation test

Hydrogen penetration experiment refers to GB/T 30074-2013 "Method for Measuring Hydrogen permeation (Absorption and Migration) in Metal by Electrochemical Technology" [9]. In this experiment, Devanathan-Stachurski double electrolytic cell was used to study the influence of simulated environmental parameters on the diffusion coefficient, permeation rate, surface concentration and hydrogen infiltration in the hydrogen charging process. The test sample is a small circular disc with a diameter of 35mm. The sample is polished before hydrogen permeation test, The polishing procedure is similar to what for metallographic test. The polished samples were cleaned with deionized water and then nickel-plated with Watts Bath (250 g/L NiSO₄·7H₂O + 45 g/L NiCl₂·6H₂O + 40 g/L H₃BO₄). The nickel-plated current was 10 mA/cm² at 90 s. During the experiment, 500 mL 0.1mol /L NaOH solution was injected into the anode electrolytic cell. The initial potential was set to passivate surface at anode current density of 1 μA/cm². When constant potential of the anode obtained, 0.5 mol/L H₂SO₄ solution + 0.2 g thiourea experimental solution was injected into the cathode electrolytic cell, and the cathode hydrogen charging current was applied and timing was started to test the curve of the anode current and time.

Hydrogen content test after hydrogen charging

Cathodic hydrogen charging was using a potentiostat at a constant current density of -2 mA/cm² in solution of 0.5 mol/L H₂SO₄ + 0.2 g thiourea at the temperature of normal atmospheric temperature for 24 hours. After hydrogen charging, the sample was immediately stored in liquid nitrogen to prevent hydrogen diffuse out of the material. Finally, the hydrogen content is tested

Notch tensile test

The tensile test of notched specimens was conducted according to ASTM G 142-98 (2018) [10]. The specimens were axisymmetric notched specimens, which were sampled along the axial and circumferential directions of the pipeline respectively. The sample sizes were shown in Figure 1. The notched tensile specimens were installed in an autoclave and under the total pressure of 6 MPa and 3% partial pressure of hydrogen (the balance gas is N₂) environment respectively to apply uniaxial tensile stress at a rate of 0.02mm /s until the specimens broke.

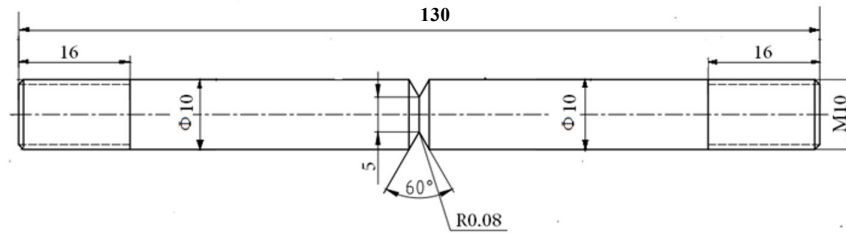


Figure 1: Dimensions of the notched specimens (mm)

RESULTS AND DISCUSSIONS

Microstructure analysis

The metallographic structure of X60 and 20# steel elbows is shown in Figure 2. It can be seen that both X60 base metal and 20# steel elbow present ferrite and pearlite microstructure. Ferrite and pearlite are evenly distributed in X60 base metal. The microstructure of 20 steel elbow has obvious banded structure, and the grain size of ferrite and pearlite is larger than that of X60 base metal. The center of X60 weld is equiaxed grain structure with uneven microstructure distribution. Hydrogen embrittlement sensitivity of the material has close correlation with organization, microstructure. An uniform microstructure with fine ferrite and perlite is low sensitive to hydrogen embrittlement, while a microstructure with bulky and uneven distribution of ferrite and perlite will be more sensitive to hydrogen embrittlement The microstructure with banded structure is most sensitive to hydrogen embrittlement because hydrogen easily gathered at the interface between banded structure, resulting in rapid crack propagation along the banded structure after crack initiation.