

Effect of soil environment on hydrogen embrittlement behavior of X60 steel

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ABSTRACT

A negative disturbance simulation experiment of X60 steel was carried out in different soil environment. The influence of soil environment on the hydrogen embrittlement sensitivity of material was obtained by comparing the area shrinkage and elongation after fracture of pipeline substrate under different soil environment. The results show that the hydrogen embrittlement susceptibility of X60 steel in the soil of Tanglang Mountain increases with the negative shift of cathodic protection potential (the increase of cathodic current density). The hydrogen embrittlement susceptibility of X60 steel in the soil of Tanglang Mountain is less than 5% when the cathodic protection potential is less than -1.07 V vs. CSE (the current

density is less than -0.1 mA/cm^2). and the risk of hydrogen embrittlement is low; When the cathodic protection potential exceeds -1.1 V vs. CSE (current density exceeds -0.3 mA/cm^2), the hydrogen embrittlement sensitivity coefficient exceeds 35%, and there is a certain risk of hydrogen embrittlement. Key words: X60 steel; Cathodic protection; Hydrogen embrittlement; Soil; Potential

INTRODUCTION

With the rapid development of China's economy, energy and transportation industries have developed rapidly, and more and more oil and gas pipelines and urban rail transit have been built and put into use. Urban rail transportation systems, such as subways or light rail, generally use direct current traction and backflow through the rail. Because the track is not completely insulated from the earth, it is inevitable that some electric current will be discharged from the track to the earth to form stray electric current, which will cause interference to the surrounding metal components such as buried oil and gas pipelines. The distribution of stray current varies with the train running time, so the dynamic fluctuation is a typical characteristic of the interference of rail transit to oil and gas pipelines [1]. With the development of urban rail transit and oil and gas pipelines in China, the interference of dynamic DC stray current in buried pipelines is becoming more and more serious [2]. Under AC-DC negative interference conditions and forced discharge measures, the negative potential on the pipeline is far more cathodic than the standard requirements. When the pipeline potential is too negative, large-scale hydrogen evolution reaction occurs on the surface of the pipe, and hydrogen production from the cathode enters the pipe easily causing the risk of hydrogen embrittlement. In particular, in the manufacturing and repair process of pipeline welding joints, elbows, b-type sleeve welding parts and other special positions, it is inevitable to be affected by assembly stress, heat treatment process and other factors, prone to local tissue hardening [3]. In addition, in the process of installation and service, pipelines are prone to local plastic deformation caused by third-party external force damage, or even local remelting of pipeline surface caused by lightning strike, which may lead to increased sensitivity of local hydrogen embrittlement of pipelines, and hydrogen embrittlement failure is more likely to occur under the condition of over-negative potential [4].

At present, both domestic and abroad have formed a relatively consistent understanding of the corrosion problem caused by the dynamic DC interference of urban subway to the buried pipe network and the positive potential mitigation measures and mitigation effects [5-6]. However, the risk of pipeline hydrogen embrittlement and anticorrosive layer peeling caused by dynamic DC negative interference has not been thoroughly studied, and the mitigation limit requirements for on-site negative interference are not clear, so effective mitigation measures and mitigation schemes cannot be specified. Therefore, it is necessary to study the hydrogen embrittlement risk of product oil pipeline under the condition of DC negative interference and forced discharge, and give the safety boundary conditions, which can provide a basis for the formulation of on-site mitigation measures and the safety management of pipeline operation.

In this paper, X60 steel was studied, and the negative interference simulation experiment of X60 steel in soil is carried out. According to the physical and chemical properties of materials and soil, the tensile plastic loss of X60 steel under different negative disturbance conditions was measured and the acceptable critical negative current density of X60 steel was obtained.

EXPERIMENTAL PROCEDURE

Materials

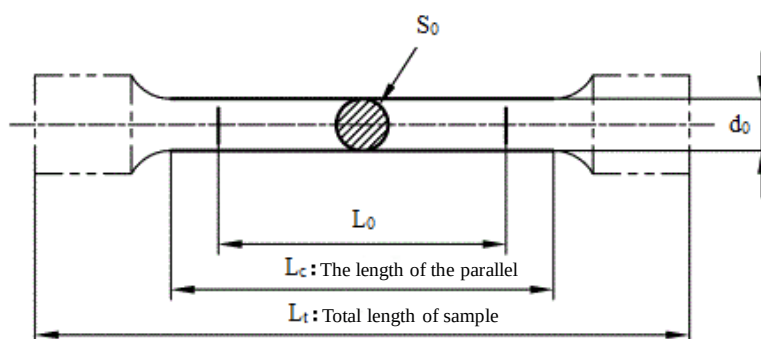
X60 steel base material was selected as the experimental material, and its chemical composition is shown in Table 1. The metallographic structure of X60 steel base metal is shown in Figure 1. According to the results of the figure, it is mainly composed of ferrite and pearlite, with relatively uniform grain size and microstructure distribution.

Table. 1. Chemical composition of X60 base metal (wt%)

Element	C	Mn	P	S	Nb	V	Ti	Fe
wt%	0.16	1.49	0.0152	0.0036	≤0.004	≤0.004	0.0054	Balance

**Figure 1: Microstructure of X60 steel**

Using X60 base material, cathodic protection was simulated by potentiostat or constant current source, and slow strain rate tensile test was carried out. According to GB/T228 "Method for Tensile Test of Metallic Materials at Room Temperature", the tensile test was carried out on the WDWLL50 stress corrosion tester at a rate of $1 \times 10^{-6} \text{ s}^{-1}$. The tensile sampling was carried out in strict accordance with ISO 3183, perpendicular to the rolling direction of the steel plate, that is, transverse sampling. The sample size is shown in Figure 2.

**Figure 2: Test sample processing drawing**

There are obvious differences in the physical and chemical properties of different soils, soil type, ion content, pH value and other parameters will affect the hydrogen evolution process of materials under cathode conditions, and then affect the hydrogen embrittlement sensitivity of materials. Table 2 shows three soil parameters.

Table. 2. Soil parameters

Soil type	Soil properties	Moisture content (%)	Resistivity	Ion content	pH
PM067+300	Sand	21.50	9485	0.084	7.72
Tanglang Mountain	Sand	13.70	28778	0.063	7.52
NJ090	Clay	31.10	1860	0.081	7.46

RESULTS AND DISCUSSIONS

Comparison of hydrogen embrittlement sensitivity in different soil environments

The rate tensile test was based stress- strain curves of X60 base metal under applied current densities of -0.1 mA/cm^2 and -0.3 mA/cm^2 in three different soil environments are shown in Figure 3. As can be seen from the figure, the yield strength of X60 steel base metal does not change significantly with the increase of current density, but the elongation of X60 steel base metal varies greatly in different soil. The base steel X60 exhibits higher elongation during tensile test in air. Compared with the results of tensile test in air, the elongation of the tensile curve of the base steel X60 at the current densities of -0.1 mA/cm^2 and -0.3 mA/cm^2 decreases to varying degree. And the decrease in extension for the case of applied current density of -0.3 mA/cm^2 is more obvious than that for the case of -0.1 mA/cm^2 current density. The results showed that the elongation in the soil of Tanglang Mountain decreased the most, indicating that the plasticity of X60 steel decreased significantly in this kind of soil and serious plastic loss occurred in the material.

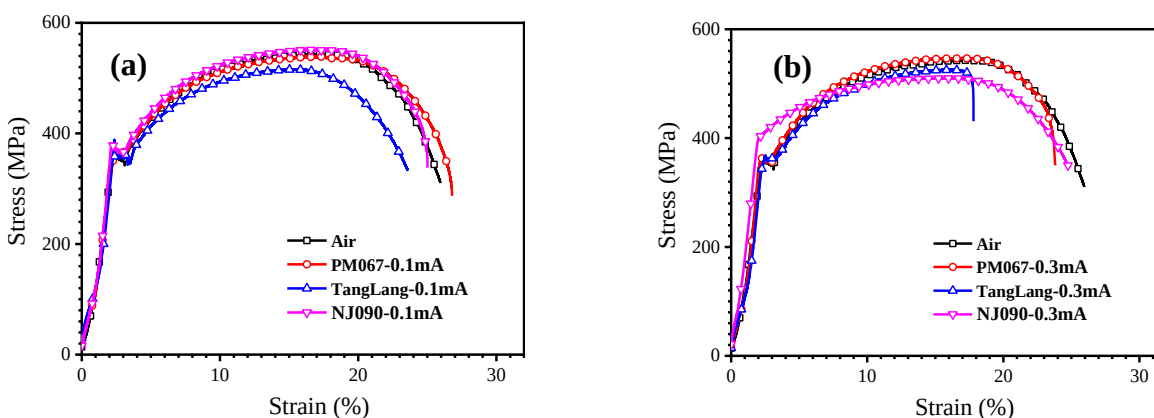


**Figure 3: Tensile curves of different current densities at different times:
(a) -0.1 mA/cm^2 ; (b) -0.3 mA/cm^2**

In order to further clarify the hydrogen embrittlement sensitivity of X60 steel base material under the application of different current densities in the three soils, the fracture morphology of the samples after stretching was analyzed as shown in Figure 4. It can be seen from the figure 4a that obvious necking occurred at the fracture position of the tensile sample in air. Compared with the results of the tensile test in air, the samples in the three soils also have obvious necking when the tensile test is conducted under the condition of -0.1 mA/cm^2 , and the results are not significantly different from those in air (figure 4b, 4c, 4d). When tensile tests were carried out under the condition of -0.3 mA/cm^2 , the fracture morphology of the tensile samples in PM067+300 (figure 4e) and NJ090 (figure 4f) also showed obvious shrinkage, but the fracture morphology of the tensile samples in Tanglang Mountain soil showed obvious