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Field experiment of stress corrosion cracking behavior of high strength pipeline steels in typical soil environments

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HIGHLIGHTS

- The SCC behavior and mechanism of four kinds of high strength pipeline steels in five soil environments have been investigated via one year field test.
- All steels are susceptive to SCC under various typical soil environments, which in acidic soil is more serious than those in other environments.
- The susceptibility to SCC under the five tested soil environments is generally proportional to steel strength but inversely proportional to environment pH value.

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ABSTRACT

In this study, the corrosion behaviors of four pipeline steels, i.e., X70, X80, X100, and X120, in acidic soil (Yingtan and Xishuangbanna), alkaline soil (Korla and Dagang), and dry sandy soil (Lhasa) in China were investigated using U-bend samples and notch crevice specimens by exposure testing. The morphologies and compositions of the corrosion products were analyzed by digital photography, scanning electron microscopy, and X-ray diffraction. The results indicated that all the tested pipeline steels exhibited stress corrosion cracking (SCC) susceptibility in the abovementioned three typical soils. The SCC susceptibility increased as the strength of the pipeline steels increased and as the soil pH decreased. In acidic soil, no relationship existed between the locations of SCC crack initiation and pitting occurrences. In alkaline soil, SCC cracks were mainly initiated at the bottoms of pits.

1. Introduction

Stress corrosion cracking (SCC) is one of the vital threats to the safety of pipeline operations, and has caused significant economic losses throughout the world [1–3]. Until now, similar accidents have occurred in many countries [4,5]. It is widely acknowledged that there are two main types of SCC, i.e., high-pH SCC [2,6,7] and near-neutral-pH SCC [8–10]. Both cases are strongly related to open coating failures, cathodic protection conditions, and soil environments. Sometimes SCC can occur directly in soil without coating [4]. Recently, the development of high-strength pipeline steels, such as API X70, X80, X100, and X120, has accelerated; these are used as high-pressure and long-distance oil and gas transmission pipelines to meet increasing energy demands. However, it is widely acknowledged that the increasing of steel strength may heighten the risk of SCC. Long-distance oil and gas transmission pipelines in China are constructed across complex soil environments. In South China, the red clay soils are extremely aggressive and acidic with low soluble ion contents and high resistivities (such as Yingtan and Xishuangbanna soil). In northwestern China, alkaline-saline soils possess high porosities, high pH values, and very low moisture contents; moreover, inshore saline soils exhibit high moisture contents, high electrical conductivities, and concentrated aggressive ions (such as Dagang and Korla soil, respectively).

So far, much work has been done in laboratory environments to reveal the mechanisms of SCC in pipeline steels. Liu et al. [11–16] extensively studied the SCC mechanism of pipeline steels in acidic soil environments. They demonstrated that high-strength pipeline steels were highly susceptible to SCC in simulated classical soil environments of China. The microstructure [15], pH value [13], and cathodic conditions [11,16] of the steel all played important roles in SCC occurrence. Liang [17] investigated the SCC behavior of X80 steel in a simulated alkaline solution and reported that

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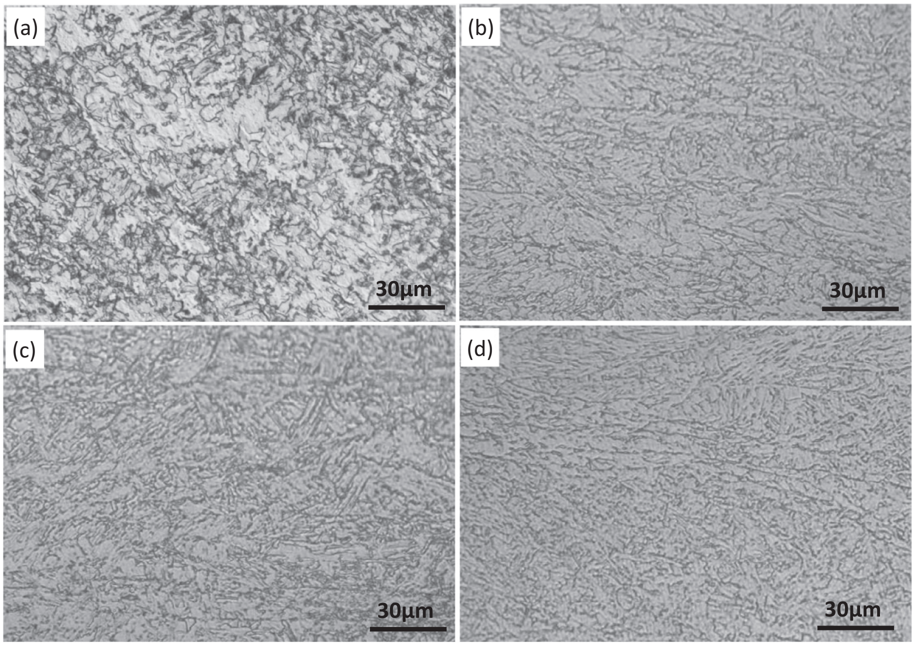

Fig. 1. Microstructure of X70 (a), X80 (b), X100 (c) and X120 (d) pipeline steels.

Table 1
Chemical composition of X70, X80, X100 and X120 pipeline steels (in wt%).

	C	Si	Mn	S	P	Ni	Mo	Nb	Cu	Al	Ca	Ti	Fe
X70	0.045	0.26	1.48	0.001	0.017	0.16	0.23	0.033	0.21	0.035	0.004	–	Bal.
X80	0.041	0.196	1.67	0.001	0.01	0.246	–	0.095	0.26	0.042	0.002	–	Bal.
X100	0.039	0.23	1.75	0.007	0.014	0.32	0.26	0.043	0.27	–	–	0.023	Bal.
X120	0.038	0.24	1.79	0.005	0.016	0.33	0.22	0.062	0.22	0.045	0.002	0.025	Bal.

Table 2
Mechanical properties of X70, X80, X100 and X120 pipeline steels.

	Impact energy at −20 °C	Yield Strength (σ_{ys}, (Mpa)	Ultimate tensile strength (UTS, (Mpa)	Yield ratio	Elongation (σ_o, %)
X70	187	520	615	0.83	17.4
X80	215	612	694	0.88	15.2
X100	242	690	790	0.89	16.2
X120	245	895	961	0.93	8.5

X80 steel encountered environment-assisted cracking, with pitting found to correlate with the occurrence of SCC. However, all of the abovementioned results were obtained in laboratory conditions, rather than under field exposure environments. To the best of our knowledge, no field study has been performed on SCC failures in long-distance oil and gas pipelines. This is because the SCC phenomenon in actual soil is far more complex than that in simulated environments. Moreover, SCC typically develops over long periods, causing detection difficulties. Thus, it is important to determine whether SCC occurs in field conditions; this knowledge will permit a full understanding of the problem and the design of appropriate protection systems in advance.

In this work, therefore, four kinds of high-strength pipeline steels were exposed to real soil environments in China. The SCC behaviors and mechanisms acting in these high-strength pipeline steels were analyzed and the effects of the strengths of the steels and pH values of the soils were discussed.

2. Materials and experimental

2.1. Materials

The test materials were API X70, X80, X100, and X120 pipeline steels, with the microstructures exhibited in Fig. 1. The chemical compositions and mechanical properties of the four pipeline steels are given in Table 1 and Table 2.

U-bend samples were banded in accordance with ASTM G36-2000 [18]. Two types of U-bend samples, including single U-bend samples (Fig. 2a) and double U-bend samples (Fig. 2b), were used in this work. The dimensions of the U-bend samples are given in Fig. 2c. The U-bend specimens were polished with abrasive papers sequentially from 60 to 1500 grit emery papers, before being strained to a fixed level by applying loads to the screw-fixed samples. The single U-bend sample was intended to simulate buried pipeline steels with disbonded coatings in direct contact with the local soil, while the double U-bend sample was tested to simulate the behaviors of crack tips. The U-bend samples were buried underground at the test sites of Xishuangbanna, Yingtan, Dagang, Korla, and Lhasa after their non-working surfaces and fixture surfaces were covered with asphalt paint.

2.2. Long-term exposure tests

Five typical soils in China were selected to conduct the exposure test, including those at Yingtan, Xishuangbanna, Korla, Dagang, and Lhasa; these five soil environments are also representative of the main types of corrosive soil environments found worldwide. Yingtan and Xishuangbanna soils, which are examples of red clay soil that comprise almost 29% and 25% of Australian and African soils, respectively, have similar pH values and moisture contents, but the latter has a higher local temperature. Korla soil is desert soil, which occupies about 11.7% of global land area; Dagang soil is saline soil, which comprises 37.42% of Australian, 22.17% of East and Central Asian, and 13.53% of South American soils, respectively. Both Korla and Dagang soils have similar pH values and salt contents, but the former has lower moisture content. In addition, Lhasa soil, which is ranked as an alpine meadow soil that also appears in Europe, the Americas, and Oceania, has a similar pH value to Korla and Dagang soils, but the temperature in Lhasa is slightly lower than that in Korla, and the soil moisture content is lower than that in Dagang. Clearly, the differences among these five soils are important in characterizing the SCC behaviors of