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Stress corrosion cracking behavior of high strength casing steel in working fluids

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A B S T R A C T

Aiming at the stress corrosion cracking behavior of a high strength steel, the air working conditions, the annulus protection fluid and the organic salts mud were simulated under the temperature of 60 °C, 100 °C, 150 °C by slow strain rate tests (SSRT). Tensile strength and elongation and stress corrosion cracking susceptibility index and fracture morphology were analyzed by stress–strain curves and SEM. To determine the applicability of high strength steel under different working conditions, the extent of damage were analyzed quantitatively. The results showed that less degree of stress corrosion occurs when temperature below 100 °C or even lower, and severe increase of stress corrosion occurs when temperature is 150 °C. The high strength steel stress corrosion cracking tendency increase as the temperature grows, and so do the stress corrosion cracking susceptibility index F(σ) and F(δ). Besides, the tendency of increase of F(σ) is more significant than that of the F(δ). In the working conditions of the organic salt mud, the changes of mechanical properties of the high strength casing steel are more significant. The corrosion pits on the sample surface contributed to such changes as a mainly factor. The crack nucleation can occur under the action of stress concentration at the bottom of the corrosion pits, and results in crack initiation extension inside the sample along the direction perpendicular to the tensile stress. In addition, the annulus protection fluid protected the strength and toughness of the casing excellently.

1. Introduction

With the increase of the depth of oil and gas wells, bottom temperature and pressure increase. The rigorous service condition and mechanical characteristics put forward new requirements and challenges to the material resistance to stress corrosion performance (Zhong-quan et al., 2014; Shuan-lu et al., 2009; Buzzichelli and Scopesi, 2000). High strength steel is a kind of casing material which is promoted to be used in the domestic and foreign major oil fields in deep wells and ultra-deep wells (Xiaoqing et al., 2011). Now there is no commonly accepted definition of high strength casing steel. The steel whose tensile strength is more than 800 MPa at the room temperature is called the high strength casing steel. The material mentioned in this article is 140ksi high strength casing steel. The 140 ksi high strength casing steel have already been used in big batch in the Tarim Oil field, especially in the Crassus piedmont tectonic belt which is the gas source of the West-East natural gas transmission project.

Field practice shows that with the improvement of strength, the material's ability to resist environment sensitive fracture presents downward trend (Bott et al., 2005; Anderson, 2005). In the harsh working condition of underground, the stress corrosion cracking (SCC) often occurs due to the casing under the comprehensive action of many factors such as temperature, working liquid medium and its own gravity stress. Research shows that when the micro cracks appear in the service time of casing, the macroscopic crack will gradually form. Macroscopic crack then will expand and lead to the fracture damage of casing (Yuanhua et al., 2004). Once the casing suffers quality problems it will then turn the whole well into scrap and cause a great economic loss. Therefore, for the designers of high strength casing, the most concerned issue is whether the casing in the process of service can keep the performance of the ductile fracture as long as possible (Hashemi, 2008). Looking for a reliable evaluation method is one of the ways to effectively guarantee the casing's security and the integrity of the structure in the

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process of service.

There are a lot of research results focusing on the stress corrosion of high strength steel in the aqueous medium at home and abroad. Steigerwald EA and Benjamin WD (Steigerwald and Benjamin, 1971) studied the components' effect on the stress corrosion cracking of five high strength steels. They used the samples with prefabricated crack, and the medium was distilled water. The research showed that component had greater effect on the dynamic stress intensity factor and hardly had effect on the K_{ISCC}. Chu Wuyang, Li Shiqiong and Xiao Jimei et al. (Wuyang et al., 1980) studied stress corrosion of high strength steel in water medium. They used WOL constant displacement specimen, and tested four kinds of high strength steel's crack arrest K_{ISCC} and da/dt. Li G F, Wu R G and Lei T C (Li et al., 1992) studied the effects of tempering temperature and carbon content on the stress corrosion cracking (SCC) behavior of high-strength CrMo steels. They used double-cantilever beam (DCB) specimens, and the medium was 3.5 pct NaCl aqueous solution, tempering temperature were 200 °C, 300 °C, 400 °C, and 500 °C. Experimental results show that the specimens with higher carbon content and tempered at lower temperatures have a higher tendency for intergranular fracture and lower threshold stress intensity K_{ISCC}. Li Huilu, Hui Weijun and Wang Yan et al. (Huilu et al., 2001) studied the threshold stress intensity of stress corrosion cracking (SCC) for five 40CrMo high strength steels. They used WOL constant displacement specimen, and the medium was 3.5 pct NaCl aqueous solution. They deduced the relationship between K_{ISCC} and the yield strength σ_S. But the research results on the stress corrosion of high strength steel in working fluids are seldom published. To this end, the author simulated working conditions in working fluids medium, and studied the stress corrosion properties of high strength steel casing by the slow tensile test method. This study simulated the working condition of air, organic salt mud, annulus protection fluid under the temperature of 60 °C, 100 °C and 150 °C. It analyzed the high strength casing steel tensile strength, break elongation, stress corrosion cracking sensitivity index and the fracture morphology by stress strain curves and SEM in order to evaluate environment sensitive fracture sensitivity of high strength casing material in different service environment. It can evaluate the safety and reliability of the material and provide experimental basis for the prediction technology of fracture failure formation and development.

2. Test

2.1. Test material and specimen

The chemical composition (W%) of experimental high strength casing steel is that C 0.25, Si 0.32, Mn 0.64, P 0.007, S 0.001, Cr 1.00, Mo 0.76, Ni 0.04, Ti 0.006, Nb 0.02, Cu 0.09, V 0.16, Al 0.02, and Fe balance. The reason why this kind of steel has high ductility is partly caused by its high content of Mn and low content of C, P, and S. Metallographic analysis was carried out on the high strength casing material. As shown in Fig. 1. Non-metallic inclusion is silicate C0.5. Annular oxides class is D1. Metallographic organization is tempering sorbite, and grain size is 8.5. The method A of Standard Ø5 was used in this paper. Round bar tensile sample size is shown as Fig. 2. The sample surface was burnished with 1000 # waterproof abrasive paper, washed with acetone ultrasonic, cleaned with alcohol and dry.

2.2. Test method and equipment

As the SCC is not quickly stimulated in the traditional stress corrosion experiment, the SSRT method is utilized to provide a fast experimental way of determining SCC sensitivity of ductile material. It has a series of advantages such as greatly shortening the stress corrosion experiment period, taking the smooth and small sample. Therefore, it is widely used in the different kinds of materials - medium stress corrosion researches (Nishimura and Maeda, 2004; Eriksson and Bernhardsson, 1991; Conde et al., 1998; Braun, 1994; Beavers and Koch, 1992; Schofield et al., 1996; Zhang and Du, 1998; Raman, 2005; Castellote et al., 2007). The LF -100-100-V-304 slow strain rate test machine made by CORTEST is used in this experiment. According to different working condition of medium environment, the stress corrosion cracking performance of oil well pipe material was evaluated by slow strain rate test machine. The appearance of experiment machine is shown in Fig. 3. The slow strain rate test machine mainly includes 50 kN rack, 10,000 pounds load sensor, twin displacement sensor, stepper motor drive, and compound transmission. The test machine is forged integrally by HastelloyC-276. The autoclave' volume is 2.2 L. Its maximum working pressure is 35 MPa, and the maximum working temperature is 350 °C. The loading rate is continuously adjustable in the range of $1 \times 10^{-8} \sim 3 \times 10^{-4}$ mm/s. The micro-morphology inspection of the specimen is analyzed by the scanning electron microscopy (SEM).

2.3. Test evaluating method

The result of slow strain rate stress corrosion experiments is usually compared with the result of tensile experiment of which the specimen is in the inert medium. Materials stress corrosion sensitivity is characterized by comparing the experimental results under those two conditions. Commonly used stress corrosion sensitivity index mainly are break elongation, reduction of area, tensile strength, energy absorption and fracture time. Among them, as the reduction of area is difficult to measure, and the error is large, therefore the break elongation is chosen to be the appropriate parameter. This paper used the same tensile rate, thus fracture time and reduction of area is the same on the characterization of stress corrosion sensitivity index. Energy absorption is calculated by the area under the stress and strain. So the tensile strength, break elongation and the absorption energy are the same on the characterization of stress corrosion sensitivity index. Based on the above analysis, changes of strength and breaking elongation before and after stress corrosion were implemented to evaluate the degree of stress corrosion in this paper.

$$F(\sigma) = \frac{\sigma_0 - \sigma}{\sigma_0} \times 100\% \quad (1)$$

$$F(\delta) = \frac{\delta_0 - \delta}{\delta_0} \times 100\% \quad (2)$$

where, F(σ) is the stress corrosion sensitivity index corresponds to specimen's elongation; F(δ) is the stress corrosion sensitivity index corresponds to specimen's maximum load; σ_0 is the specimen's maximum load before fracture in the inert medium; σ is the specimen's maximum load before fracture in the corrosive medium; δ_0 is the specimen's maximum load after fracture in the inert medium; δ is the specimen's maximum load after fracture in the corrosive medium.

The larger stress corrosion cracking sensitivity index is, the greater orientation of the stress corrosion cracking, and the more significant of the stress corrosion is.

2.4. Test scheme design

In this paper, the experimental is designed to test high strength casing steel's performance on resisting environment sensitive