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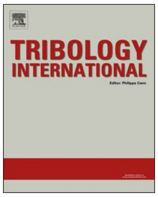

Fretting fatigue on thread root of premium threaded connections

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ABSTRACT

Identification of the fatigue failure mode of the premium threaded connection for Oil Country Tubular Goods pipes was conducted via full-scale fatigue tests. A through-wall crack was found at the imperfect thread root of the male embodiment, but the crack initiation site depended on the stress level. At relatively higher stress amplitude region, the crack originated from the thread rounded corner by stress concentration. At relatively lower stress amplitude region, the crack originated at the middle of the thread root because of fretting fatigue. To investigate the fretting fatigue mechanism in the threaded connection, a fundamental fretting fatigue test was conducted. This test achieved the fretting fatigue failure at the middle of the contact surface under large gross slip condition.

1. Introduction

Oil Country Tubular Goods (OCTG) pipes for the production of crude oil and natural gas are connected by threaded connections. For the threaded connection, sufficient static strength and sealability are required to achieve the stable oil and gas production. A premium threaded connection, which is a non-American Petroleum Institute (API) standard [1] product, is used particularly for a well with a severe environment. The premium threaded connection consists of metal to metal seal, torque shoulder and tapered trapezoidal thread portion as indicated in Fig. 1. The male embodiment of a threaded connection is called PIN, and the female one is called BOX. When the PIN and BOX are in the make-up state, the PIN thread root and the BOX thread crest are in contact with each other by interference.

In the conventional well drilling as indicated in Fig. 2(a), a hole where the casing pipe will be embedded is previously drilled by a drill pipe. Then, the casing pipe is embedded into the underground hole with a certain rotation. After the embedment, only static loading is applied to the threaded connection of the casing pipe. Therefore, only static strength is required in the threaded connection. Recently, as indicated in Fig. 2(b), new drilling technologies such as Drilling with Casing (DwC), which enables a casing pipe to be embedded without using a drill pipe, have been developed [2,3]. In the DwC, a drill bit is attached to the end of the casing pipe to drill a hole. Consequently, the casing pipe is embedded simultaneously with the drilling. This technology can contribute in the reduction of the total time as well as cost for the well completion. However, the threaded connections receive a huge amount of cyclic rotary bending load when they go through the well curvature. Therefore, the evaluation of the fatigue performance of the premium threaded connections becomes increasingly important.

Several studies have been previously performed concerning the fatigue performance of threaded connections. For instance, full-scale fatigue tests were conducted to evaluate the fatigue performance [3–8]. In these studies, Stress Amplification Factor (SAF) was evaluated by the ratio between the S–N curve of the threaded connection obtained by the full-scale fatigue test and DNV-B1 curve [9]. The fatigue performance of the connection is regarded higher, as SAF value became lower. For example, Ong et al. [3,4] reported that the sufficient fatigue performance was achieved for the premium or semi-premium threaded connection which they developed, by considering from the evaluated SAF obtained by the full-scale fatigue tests. Sches et al. [5] reported the results of full-scale fatigue tests of the premium threaded connection. The fatigue performance was improved by applying the larger thread

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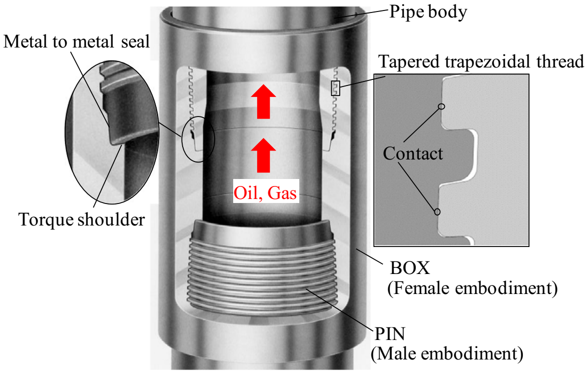

Fig. 1. Schematic of real premium threaded connection.

root radius.

Simulation works were also performed to evaluate the stress concentration of the thread root by a finite element analysis and predict the fatigue life of the threaded connection [10–14]. For example, Cetin et al. [12] focused on the thread root radius and proposed a model based on the principal stress or notch sensitivity methods by Peterson [15] and Neuber [16] to predict the fatigue life of the threaded connection. Lin et al. [14] applied a multi-axial fatigue life prediction method based on the critical plane model to calculate the fatigue life of a standard API drill collar connection.

However, these anterior researches are not focused on the clarification of the fatigue failure mechanism or influential factors for the fatigue performance intrinsic to threaded connections. Without the understanding of the fatigue failure mode, it is difficult to develop the effective methodologies for improving the fatigue performance and to establish a more accurate predictive model of the fatigue life.

In the present study, full-scale fatigue test of the premium threaded connection for the OCTG pipes was performed. Then, a failure analysis was performed to identify the fatigue failure modes of the threaded connection. As the result, it was found that the fretting fatigue failure is one of the major failure modes of the premium threaded connection. Thus, a fundamental fretting fatigue test using a specimen taken out from the OCTG pipes was conducted to clarify the fretting fatigue failure mechanisms of the threaded connection.

2. Full-scale fatigue test of premium threaded connection

2.1. Specimen of premium threaded connection and material

Fig. 3 displays the longitudinal-sectional view of the real premium threaded connections for OCTG pipes used for the full-scale fatigue test. The connection consists of imperfect threads, perfect threads, seal and torque shoulder from the left side of the figure to the right. For the PIN pipe, the outside diameter (OD) was 177.8 mm, and the wall thickness (WT) was 11.5 mm. The threaded portion had 1/16 tapered trapezoidal threads. The thread consists of thread root, thread crest, load flank and stabbing flank. Imperfect threads had less engagement because the thread crest of the male was truncated due to the tapered thread. When an axial load is applied to the connection, the engaged portion of PIN and BOX sustain the axial load. However, at the imperfect thread portion, only the PIN has to sustain a large part of the axial load due to the end of the engaged portion of the PIN and BOX. As the result, the stress at the imperfect thread portion of the PIN should be increased. Therefore, the critical portion for the fatigue strength of the thread connection is the imperfect thread of the PIN.

Machining tolerance is one of the important factors for threaded connections. For the threaded connection used for the full-scale fatigue tests in this study, so-called HH-PNBN configuration was applied. In short, the machining tolerance designated by the HH-PNBN is high for the thread interference (H), high for the seal interference (H), nominal for the thread taper of the PIN (PN) and nominal for the thread taper of the BOX (BN). Surface treatment with manganese phosphate was applied to the BOX thread, whereas the PIN was as machined. It is noted that the diameter of the PIN at the thread root was a little bit larger than that of the BOX at the thread crest. Therefore, the engagement between the thread root of the PIN and thread crest of the BOX was in interference fit. This means that the thread root of the PIN and the thread crest of the BOX were in contact with each other with a certain value of contact pressure. The threaded portions, seal and torque shoulder of the specimens were covered with the lubricant grease specified by API. Then, the specimens were made-up by a hydraulic power tong.

Three types of API standard materials, L80, P110 and Q125, were used for the full-scale fatigue tests. The mechanical properties and the chemical compositions are indicated in Tables 1 and 2. The chemical composition is given by the maximum values specified by the API standard. Fig. 4 displays the microstructures of these materials. The materials exhibited tempered martensitic microstructure with approximately 30 μm of the prior austenite grain size.

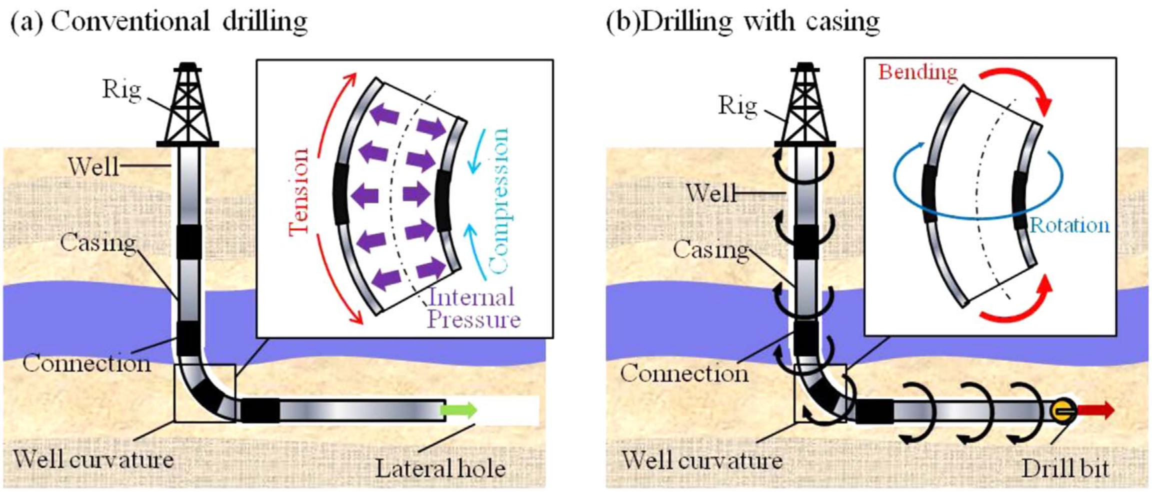

Fig. 2. Applied stress to the threaded connection in conventional drilling (a) and drilling with casing (b).