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Experimental and numerical study on the longitudinal-crack failure of double-shoulder tool joint

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ABSTRACT

In recent years, the failure accidents of double-shoulder tool joint caused by longitudinal-crack occur frequently during drilling with increasing deep and ultra-deep wells, directional wells, extended reach wells and horizontal wells, which not only decreases rate of penetration, but also results in huge economic losses. Although the frictional heat check cracking can cause cracking initiation according to the standard API RP 7G, it has been found heat check cracking is just one of the cracking initiation mechanism rather than crack propagation mechanism; in other words, there are various other causes of crack initiation and propagation. Hence, in order to find out the failure mechanism caused by longitudinal-crack, the failure analysis of one typical double-shoulder joint with longitudinal crack has been investigated in detail from three aspects including its service load, its own structure feature and fracture toughness by combining experimental inspection and finite element simulation. The results from macro-analysis, micro-analysis, chemical component analysis, mechanical properties analysis, stress and deformation analysis, show that this failure mechanism of double-shoulder joint is closely and directly related to overlarge combined load (tensile force, torsion and bending), its own structure feature and difference of fracture toughness between transverse section and longitudinal section. Firstly, the martensite is produced on the thread surface due to severe fraction heat between threads caused by overlarge combined load during jarring releasing of double-shoulder joint, which leads to the inter-granular crack initiation. Secondly, the circumferential stress release is restricted by thread connection. Thirdly, the transverse fracture toughness of material is lower than longitudinal fracture toughness. Finally, the longitudinal-crack failure of this double-shoulder joint occurs under overlarge alternating combined load. It is suggested that if the thread taper of double-shoulder joint is decreased and the area of secondary shoulder is increased under extreme working environment, the bearing capacity of connection can be improved and the failure accident caused by longitudinal-crack can be avoided effectively.

1. Introduction

Drill pipe plays an important role in drilling process, and it is also one of main component in the oil or gas exploration and

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development. With the increasing deep and ultra-deep wells, directional wells year by year, the service environment of drill pipe is worse and worse, which requires the tool joint of drill pipe with higher torsional strength. In order to meet requirement, many tool joints with special structure have been designed, and the main double-shoulder tool joint has been applied widely in oil and gas field [1]. However, it is well-known that the drill pipe bears continuously changeable combined load, such as tension force, bending, torsion, impact load, internal pressure and catastrophic downhole corrosion. Although the standard API RP 7G [2] explains that friction heating and drilling liquid quenching frequently resulted in the cracking through the tool joint box of drill pipe, and controlling hole angle and lateral force is able to minimize or eliminate the longitudinal fracture of the joint box tool, the failure accident of double-shoulder joint still happens frequently in the oil and gas field [3] and the longitudinal-crack or fracture of the tool joint box is also one of main failure mode of drill pipe [4,5].

Hence, it is very important to clarify the failure mechanism of double-shoulder joint caused by longitudinal-crack for optimizing its structure design and improving its using performance. Up to now, some researches have been done about the failure mechanisms of drill pipe body [6,7] and double-shoulder tool joint [5,8,9], and some achievements and good suggestions have been presented. According to those current research results, it is not difficult to find that all the researches on the failure mechanism of tool joint are investigated only by using macro and micro analysis method (such as EDS, XRD, SEM, etc.) in consideration of service condition, material quality, corrosion and stress corrosion, so the structure feature and stress/deformation distribution of tool joint under higher combined load have been neglected during investigation, especially for the double-shoulder joint with special structure. In addition, authors also have identified that heat check cracking [2] is just one of the cracking initiation mechanism rather than crack propagation mechanism [8], and there are various other causes of crack initiation and propagation, such as special structure and stress distribution, etc.

Hence, in order to find the failure mechanism of one double-shoulder joint with longitudinal-crack from one directional well in November 2017, the failure accident is investigated with due consideration of structure feature and stress/deformation distribution of joint by combining experimental inspection with finite element simulation analysis. Based on experimental analysis and simulation results, the failure mechanism has been determined, and the corresponding suggestions and prevention measure have been proposed.

2. Case description

2.1. Well information for the failure tool joint

According to the well information, six accidents of 7″S135 tool joint with longitudinal crack occurred in kick-off section of directional wells in the west of China. In this paper, the investigated box tool joint with longitudinal crack is taken from one directional well, whose planned total depth is 5300 m, and longitudinal depth is < 4000 m, and depth of kickoff point is 3000 m. The drilling fluid is brine mud. The bottom hole assembly in this well consists of 12 1/4″BT, screw, HWDP 5 1/2″and 5 1/2″drill pipe. The sticking accident happened at the depth of 3700 m (where the bit had not reached the horizontal section), and then the drill operation was stopped and the drill pipes were taken out from the well by jarring releasing. The obvious longitudinal crack on one box tool joint near sticking point was found, as shown in Fig. 1.

2.2. Macro-morphology and size of crack

Fig. 2(a) is the macro-morphology of the failed box tool joint with longitudinal crack, and the length of crack is 400 mm. On the surface of outside wall, there are some rusting and tong tooth bite marks caused by making up and breaking out. It can be observed from Fig. 2(b) that the crack extends longitudinally from main sealing surface to surface of secondary shoulder, and the length of longitudinal growth is 170 mm, it has been penetrated radially the whole wall of tool joint. In addition, it can be observed for Fig. 2(c) that the slight extrusion deformation near crack on the main sealing surface of box tool joint has been formed, and there is some trace of slight contact wear between metals on the surface of main shoulder and secondary shoulder, as shown in Fig. 2(d). The further investigation and analysis are conducted as follows.

Fig. 1. Outward appearance of the failure joint of drill pipe in the field.