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Study of the effect of the expansion cone on the expansion process in solid expandable tubulars with thread joints

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ABSTRACT

As the core technology of petroleum extraction engineering in the 21st century, Solid Expandable Tubular (SET) technology is applied to drilling, well completion, and cementing. However, the expansion process for tubulars in site operation may well lead to stress concentration, leakage, or even fracture failure in thread joints of the tubular assembly due to the irregular deformation of thread teeth. With the aim of studying the issue with regard to the thread joint of J55 steel expandable tubulars, this study extended a series of finite element models using the commercial software ABAQUS to investigate the structural response of tubulars during the expansion process. The simulation results include the stress evolution, deformation of the thread joint of the tubular assembly, and the effect of expansion cone geometry on the expansion consequences. A laboratory experiment was performed to validate the validity of the simulated solution. It was found from results that both the axial and hoop compressive stress concentrations were generated in the thread teeth edges near the contact surfaces of threads during the expansion process due to the mutual squeezing of box and pin thread teeth. An increase of the tubular diameter led to a reduction of wall thickness and axial length due to the law of volume-constancy. The expansion process resulted in a deterioration of the contact condition between the thread teeth. A cone angle of 9° and sizing section length of 65–75 mm were the optimal choice of the geometric size of the expansion cone according to their superior analytical results.

1. Introduction

With petroleum exploration development in fields of ultra-deep layer reservoirs and complex formations, the presence of difficult conditions, such as different pressure layers, oil-gas-water layers, salt-gypsum layers, leakage zones, and collapsed layers, have caused increasing difficulties for oil drilling in recent years (Grant and Bullock, 2005; Innes et al., 2003; Chan et al., 2000). Both drill bits and tubes with different diameters of telescoping design are utilized to cement leakage zones in present drilling technology when drilling operations reach deeper layers, which are characterized by high pressure, collapse, or leakage. However, this would give the structure of the well a tapered shape and lead to the diameter loss of the well, which limits the possibility of obtaining the desired well size at target depths. Solid expandable tubular technology is a breakthrough in the field of oil and gas well development. It is utilized to expand the diameter of well holes by means of radially expanding the tubular to the required diameter. It reduces the taper effect of traditional drilling technology and increases the possibility of ultra-deep layer reservoir drilling. It can cut down the drilling cost, simplify the structure of the well, and improve the drilling speed. Solid expandable tubular technology has been applied into many fields including drilling, well completion, sealing of the expandable liner hanger, cementing complex well sections, and remediation of damaged wells (Wang et al., 2007; Yang et al., 2007). Because of the characteristic of the same size of the tubular diameter, solid expandable tubular technology can significantly simply the well design, reach the target of deeper well drilling, and extended-reach well drilling.

A review of the research on solid expandable tubular technology showed that this technology has made enormous progress in recent years due to the efforts of researchers and engineers. A series of studies was developed and applied to practical engineering, such as the effect of the expansion process on mechanical properties (Pervez et al., 2012; Butterfield et al., 2007; Al-Abri et al., 2015), the microstructural variation (Al-Abri et al., 2016a), the Bauschinger effect (Klever, 2010; Al-Abri et al., 2016b), and corrosion resistance (Gao et al., 2015). Agata et al. (2013) extended the experimental and numerical models to investigate the effect of material factors on the collapse resistance of solid expandable tubulars, and a formula was determined based on the results. It was

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found that the formula can accurately predict the collapse resistance of radially expanded tubulars by modifying mechanical properties of the material. In order to reduce friction and enhance the wear resistance property of the expansion cone, the application of the bionic non-smooth theory on the expansion cone achieved a satisfactory result in which the expansion pressure decreased by at least 15% in a ground test (Shi et al., 2013). Engineering researchers, Li et al. (2013) and Wilson (2013), developed innovative designs of solid expandable tubulars to successfully perform casing patch in difficult conditions, and the designs proved to be cost effective. Al-Abri and Pervez (2013) established analytical, numerical, and experimental models of solid expandable tubulars to investigate the effect of the four main factors on the stress distribution, the expansion force and collapse pressure rating, as well as the length and thickness shrinkage induced by the expansion process. The results showed that a good agreement was attained from different models. A comparative study between hydraulic and mechanical expansion was conducted by Seibi et al. (2007) aimed at investigating the tubular fluid response in solid expandable tubulars, and the results showed that the mechanical expansion caused limited damage to the structural integrity of the tube. Much research has been done to study various aspects of solid expandable tubulars, including the effect of technological parameters on the tubular expansion process (Pervez et al., 2005), research on aluminum as a material of expandable tubulars (Pervez et al., 2008), irregularly shaped boreholes investigations (Pervez et al., 2011), and oil well ovality analysis (Pervez and Qamar, 2011), provided the theoretical foundation for the application of solid expandable tubular technology.

For convenience of transportation, solid expandable tubulars are generally processed into short tubes of several meters, and the tubes are installed in series at the construction site with thread connections. Therefore, the assembled tubes in series, similar to a pressure vessel, are in service under internal and external pressure, which means that the thread joints have to be of superior quality for the strength and sealing properties. The expansion process may well lead to stress concentration, leakage, or even the fracture failure in thread joints due to irregular distortion of the threads, so it is imperative to investigate the effect of the expansion process on thread connections. Some researches with respect to thread joints were mentioned in the literature (Zhang et al., 2011; Liu et al., 2014), but the existing knowledge is relatively insufficient about the structure and properties of the thread joint after it undergoes the expansion process. Engineers lack the available data about post-expandable tubular thread joints. Engineers also lack confidence in the performance of tubular thread joints under down-hole conditions. All these limiting factors partly influenced the development of solid expandable tubular technology. Therefore, this limited knowledge is the major reason behind the current predicament that the application of solid expandable tubulars cannot be completely implemented in practice (Al-Abri et al., 2016a). On one hand, laboratory experiments on solid expandable tubulars are expensive and are a complex operation. On the other hand, the tubular behaviors after undergoing radial plastic expansion cannot be directly measured due to the limitation of detection technology involved in residual stress distribution, strain, and plastic deformation. Therefore, the finite element method (FEM) was introduced into thread joint investigation because of its accuracy and conciseness.

In this study the experimental method and FEM were employed. First, a 2-D axisymmetric finite element model of the expandable tubular with the thread joint was developed using the commercial finite element software ABAQUS. In the second step, an expandable tubular experiment was carried out in the laboratory to verify the validity of FEM (Xu et al., 2017). In the third step, after validation this finite element model was used to investigate the effect of the expansion cone geometry on the property of the post-expansion thread joint, and then an optimal design of the expansion cone geometry was attained. The flow chart of the study is shown in Fig. 1.

2. Finite element analysis

2.1. Geometry and the finite element model

The tubular model in this study consisted of the pin thread section and box thread section. It has a total length of 200 mm with an outer diameter of 139.7 mm and a wall thickness of 7.72 mm. The negative angle trapezoidal thread tooth was selected as the thread joint between tubulars. The thread taper is 1:16. The length of thread section is 84 mm. The thread pitch is 5.08 mm, and the pin thread has a tooth depth of 1.575 mm and a tooth width of 2.605 mm. The box thread has a tooth depth of 1.775 mm and a tooth width of 2.505 mm. There is a small amount of interference between the box thread and pin thread. For the thread teeth, the angle of the guide surface is 9° and the angle of the bearing surface is 3°, as shown in Fig. 2. The geometry of the expansion cone is shown in Fig. 3. The expansion cone consists of the entrance section, transition section, and the sizing section. The diameter of the entrance section is 120 mm, and the length is 90 mm. The angle of transition section is 10°. The sizing section has an outer diameter of 137 mm and a length of 65 mm. For sake of preventing stress concentration in the simulation, the expansion cone has a filleted radius of 10 mm at the edges.

The tubular expansion process was modeled using the finite element software ABAQUS. The finite element analysis of solid expandable tubulars with thread connections is a multiple nonlinear problem, including a nonlinear structure problem with large deformation, and a nonlinear material problem with elastic-plastic behavior. Therefore, a simplified two-dimensional axisymmetric model was established with the standard finite element method for convenience of calculation. The tubular was set as the deformable material using a 4-node bilinear

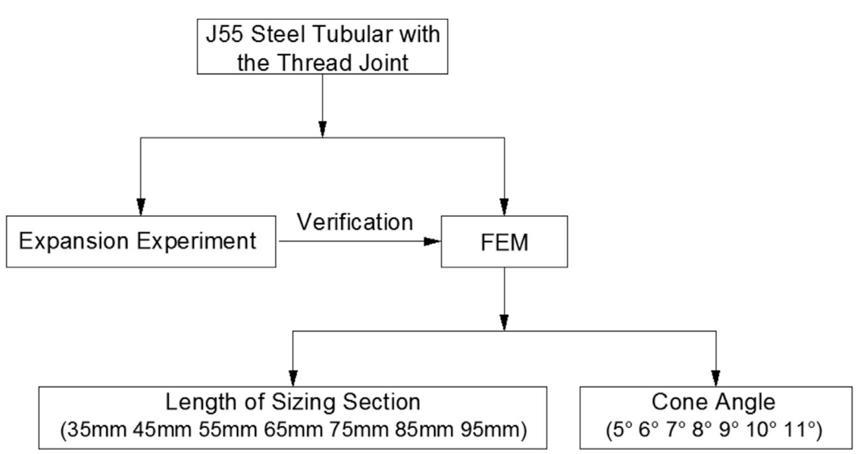

Fig. 1. Flowchart of the investigation.