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PRELIMINARY STUDY OF TUBULAR EXPANSION USING FINITE ELEMENT METHODS

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ABSTRACT
Recent developments in the oil industry show that downhole tubular expansion is highly attractive due to the fact that the technology contributes to economical savings and exploration efficiency. As the technology is new, however, there still remain many unsolved problems to achieve the optimal design and implementation of the technology. Primarily, there is a need to establish a thorough understanding of the process, both the material mechanics and the complex force interaction during the expansion process as well as after expansion. Among others, the friction between the expansion tool and the tubing, and the response of the material to the force in downhole contribute to the current need for an intensive research. This conference paper attempts to highlight the accompanied challenges with this new technology and presents a preliminary analysis scheme based on Finite Element Methods.
Keywords: Tubular expansion, Finite Element Method (FEM), Stress analysis.

1. INTRODUCTION
Expandable Tubular Technology, ETT (also referred to as Solid Expandable Technology, SET) is a downhole process of expanding the diameter of a pipe by means of pumping or pulling a conical mandrel through it. This technology is relatively new and a number of applications of the technology are rapidly emerging particularly in the area of oil well drilling industry. The main advantage of the technology compared to the conventional means is that it can restore the casing to its original integrity without a significant loss in internal diameter [1].
Though the development of this technology is still at its very infant stage, the implementation has already registered a number of advantages and opportunities. Among others, its use offers the drilling industry the opportunity to access smaller deepwater reservoirs that were previously uneconomical using the high cost traditional well drilling technology. By replacing the conventional telescopic well construction, the technology can offer a single-diameter wellbore that employs one casing size resulting in deep drilling benefits resulting in economical savings and exploration efficiency.
The original vision to this technology can be traced back to the implementation of a single-diameter wellbore that started in Royal Shell's laboratory in the Netherlands around 1993 [2]. In this original expansion concept, a pipe made of special automotive steel with original diameter of 4 in. (ca. 100 mm) was expanded to 22% size. Today, the technology is rapidly expanding and the major market players of this technology at this time are Baker Hughes, Enventure and Weatherford.
Regardless of the fact that the use of ETT sounds beneficial in economic terms, there still exist many outstanding challenges to be solved. Since the inception of the concept, many central issues have been identified in the implementation process. For example, a) supply of suitable tubular materials, b) change of material behavior under and after expansion, such as burst and collapse problems, c) design of the connection and the sealing system, d) provision of anchor point where mechanical reactions are provided while expanding. A limited number of research results have been reported so far that are basically based on analytical and experimental approaches.

This paper describes an alternative approach to the ongoing research to establish a thorough understanding of the tubular expansion process. This alternative approach involves FE modeling of both the tube and the expansion mandrel in a commercial FEA tool and varying parameters of potential interest to the process. It is the author's belief that this approach establishes a significant technological breakthrough and provides cost-effective solutions to several tubular problems that have loomed as obstacles to comprehensively understand the material behavior during tubular expansion as implemented in reservoir exploitations.

2. FUNDAMENTALS OF THE EXPANSION PROCESS AND THE CHALLENGES

Accessing new reservoirs that currently cannot be reached economically and maintaining profitable production from older fields are the dual challenges facing operators of the petroleum industry. The recent advances in tubular technology are expected to play a key role in meeting these challenges.

The ETT concept is, in its simplest form, a cold-working process of steel downhole where a conical mandrel is used to permanently deform the diameter of solid tubulars. The expansion process, in short involves:

1. Running the expandable casing into the wellbore and
2. Hydraulically pushing or pulling a cone of larger diameter than the inside diameter (D_i) of the casing or tubular.

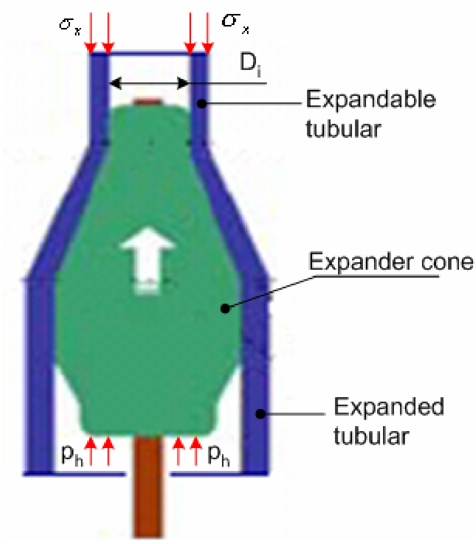

Figure 1: Schematic of expansion model

Pumping the cone through the tubular requires high liquid pressure (p_h). The expansion pressure subjects the casing of the tubular to contact pressure and how this contact pressure and the required expansion pressure vary with the cone angle is the subject of research. Another mechanical issue related with these problems is how the rate of expansion affects or reduces performance properties, such as burst and collapse, of the expanded tubular.

Researches executed so far to find solutions to the problems accompanying the implementation of this technology are presently based on analytical modeling, laboratory tests and large-scale filed tests. Particular focus has been on establishing a thorough understanding of the change of material behavior both while under expansion and after expansion is completed. As it is impossible to experimentally test all parameters that an operator faces in the oil-drilling field, many analytical and experimental tests have resulted to develop a certain level of knowledge about the process that can be applied at field works. For example, an analytical study done by Ruan and Maurer [3] presents the mechanics of expandable casings in oil and gas well and outlines the development of a spreadsheet-based model based on a force and energy balance. Similar studies, both analytical [4] and laboratory experiment [5], have been executed in our university aimed at developing knowledge of the expansion process.

Though the analytical models and laboratory experiments supported by field trials for verification sound viable and reliable, performing validation of new materials or processes is costly and time consuming. As a solution to this bottleneck, the idea of studying the expansion process using numerical methods was initiated by modeling the process in commercial Finite Element Analysis (FEA) tools. An extensive study has been done to compare the results of FEA simulation with laboratory experiments. The following chapter shortly discusses the methodology and results of the study using FEA.

3. FINITE ELEMENT MODELING OF THE EXPANSION PROCESS

The commercial Computer-aided Engineering (CAE) tool ABAQUS was used to simulate the expansion process and to study various field and geometric conditions. In order to have as realistic and minimum model as possible, an axisymmetric model of both the tubular and the conical mandrel were developed. As shown in Figure 2, the expansion process was modeled using two approaches:

a) expanding in compression where the expansion starts from the free end of the tubular and the opposite end is imposed axial and rotational boundary conditions (BCs) and
b) expanding in tension where the opposite end is set free and the expansion starts from the end where the boundary conditions are imposed.

The first essential decision is defining the material model to be used. As the tube is to be expanded well over its elastic limit, the plastic response of the stress (σ) – strain (ε) relation was described using power law from Ramberg-Osgood expression

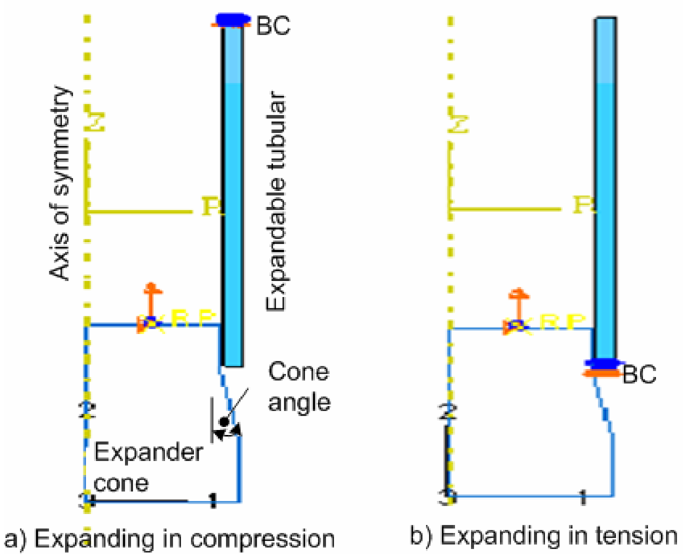

Figure 2

$$\sigma = \sigma_{0.2}\varepsilon^{n} \quad \ldots (1)$$

where $\sigma_{0.2}$ and n are the yield stress and hardening constant of the tubular material.
However, it is not simple to find the values of the hardening constant n for different materials. The results for this paper are based on a stainless steel material of 5.5” (140 mm) diameter having yield strength of 320 MPa. The different rates of expansion i.e., 10%, 15%, …. 35% were obtained by varying the cone angle.

4. ANALYSIS RESULTS AND DISCUSSIONS

The main advantage of FE modeling is that different parameters that can have the potential to influence the expansion process can be varied and studied at a very minimal cost. The typical responses in tubular expansion like stress and strain variations, thickness and length changes, level of contact stress and the drawing/expansion force needed to expand the tubular both in compression and tension were studied. Due to space limitations in this conference article, only few of these results are presented and shortly discussed below.
As expected, both the maximum stress level according to von Mises criteria and the max. nodal reaction force, which is the indication of the level of the necessary drawing force, increase with increasing expansion rate. It can be observed, from Figure 3, that the average value of the nodal reaction force almost triples when the expansion rate changes from 10% to 35%. The results show, however, no significant deference in terms of the location of the imposed boundary conditions.
As shown in Figure 4, a significant difference of displacements is observed when the tubular is expanded in compression and tension. While the axial deformation is higher for expansion in compression, the reverse is observed for radial deformation. These phenomena are to be further investigated for any mechanical or material behaviour related explanation.

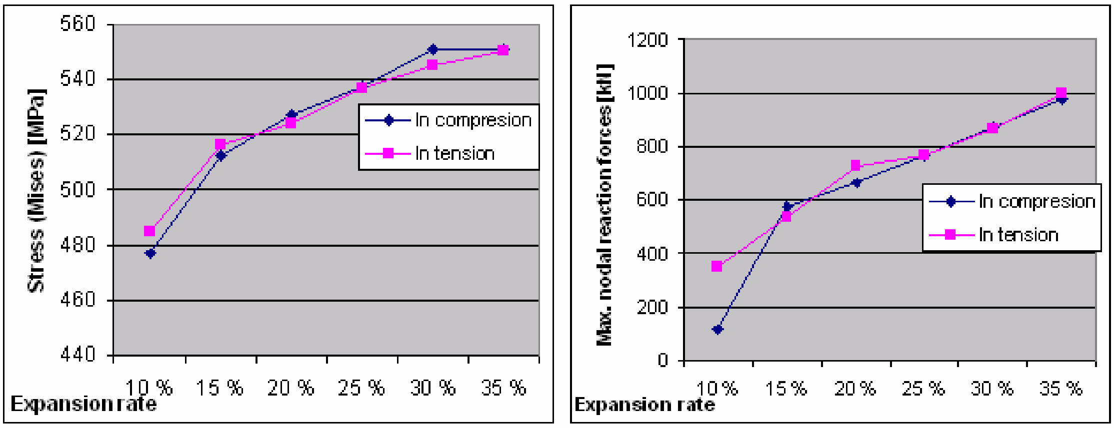

Figure 3 Plot of Mises stress and max. nodal reaction force

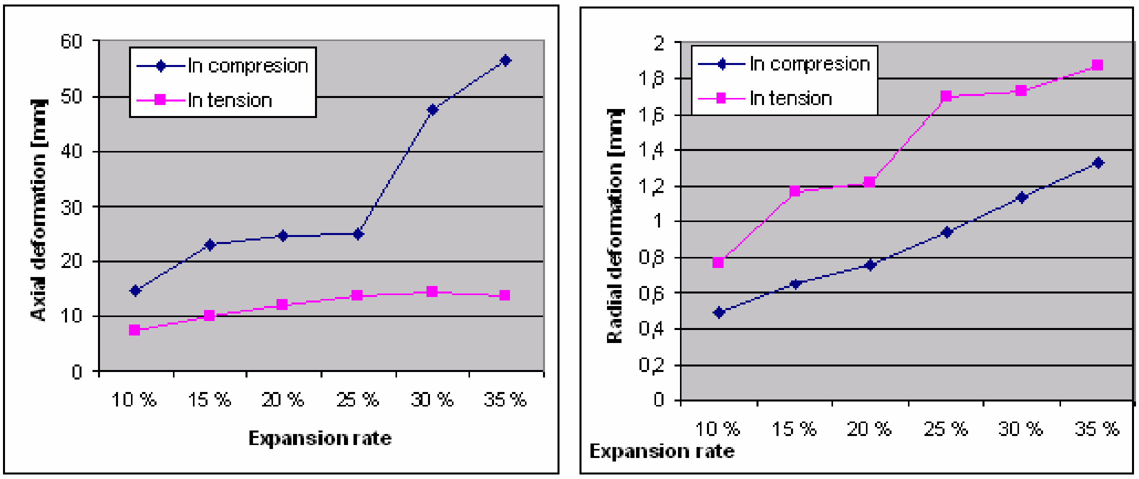

Figure 4 Plot of axial and radial displacements

5. CONCLUSION

This paper has attempted to demonstrate how FE modeling technique is used to analysis of tubular expansion under various loading. In this study the responses due to expansion rate and/or cone angle are studied and briefly discussed above. In its simplest form, the study has demonstrated a cost-effective approach to get better understanding of the process and the knowledge gained can be beneficial to large-scale applications. Proceeding works in this study will investigate the effect of other parameters such as mandrel form and friction coefficient including verification of the approach using either analytical or laboratory results or both.

6. REFERENCES

[1] Ruggier, M., *et al.*, *Advances in Expandable Tubing*. SPE Paper Nr. 67768, presented at SPE/IADC Drilling Conference, 27 Feb. – 1 March, 2001.

[2] Flippov, A., *et al.*, *Expandable Tubular Solutions*, SPE Paper Nr. 56500, presented at SPE Annual Tech. Conf. and Exhibition, Housten, Texas, 3 – 6 Oct. 1999.

[3] Ruan, C.G. and Maurer, W.C., *Analytical Model for Casing Expansion*, SPE Paper Nr. 92281, presented at the SPE/IADC Drilling Conference, Amesterdam, the Netherlands, 23 – 25 Feb. 2005.

[4] Asen, J.A., Belayneh, M. A. And Aadnøy, B. S., *Mechanical Analysis of Expandable Solid Tubulars*, Computational Mechanics, APCOM'04, Springer-Verlag, 2004.

[5] Giskemo, J. T. *Experimental study of Expandable Tubular*, Master thesis, Dept. of Petroleum Engineering, University of Stavanger, Norway, 2005.