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On the performance analysis of AHSS with an application to SET technology – FEM simulations and experimental measurements

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ABSTRACT

Solid expandable tubular (SET) is an innovative breakthrough in the petroleum industry that aims to resolve issues associated with deep wells. It consists of in-place plastic deformation of tubular diameter resulting in larger conduit size that allows drilling deeper. However, due to volume constancy, increasing the tubular diameter results in a decrease in its wall-thickness, and hence even an initially thick-walled tubular may convert into thin-walled; especially at high expansion ratios. Extending the frontier of expandable applications require larger expansion percentage and enhanced tubular integrity after expansion, which exceed the capability of current tubular material. Therefore, the current study aims to investigate new alternative materials to be used as tubular for SET technology. Selected AHSS grades including TRIP, TWIP, and DP steels are analyzed numerically using FEM. Experimental validation of the FEM model was carried out using full-scale expandable tubular testing facility available at Sultan Qaboos University (Muscat, Oman). Interesting results in terms of stress, strain, expansion force, burst and collapse pressures, length shortening and wall-thickness reduction were obtained. Bauschinger effect arises at the collapse pressure rating has been considered in the study. It was found that materials with high true uniform elongation (and therefore with large strain hardening capability) are more capable of counteracting strain intensifications caused by plastic deformation, allowing either larger expansion ratio or larger safety margin for the deformation capability of the material at a given expansion ratio.

1. Introduction

As easily and economically recoverable hydrocarbon resources are depleting, the oil and gas industry focuses more on exploring oil and gas from ultra-deep, tight, and scattered pockets of reserves. However, these recoveries are not only difficult and expensive, but also require the development of new materials and technologies that can meet stringent requirements of operations in sub-surface environment [1–3]. Wells are typically built with a telescoping design, where a hole is drilled until it becomes unstable. A steel tubular (casing) is inserted into the hole to keep it stable, and is cemented or anchored in place. Drilling then recommences at the bottom of this hole using a narrower diameter tubular [4]. In this way, tubulars of progressively smaller diameters slide inside each other like a closed telescope. However, this technique results in losses in the diameter of the well, which limits the possibility of reaching target depths with big size leading to weak production and very limited chances to continue drilling to larger depths.

Solid expandable tubular (SET) technology is an innovative breakthrough in the oil and gas industry with the potential of changing the way the wells are drilled and maintained. An effective technique for slimming down of new wells, and for remediation of old and damaged wells, it can facilitate production from deep and difficult-to-access reservoirs with less environmental impact and better cost effectiveness [5]. It consists of in-place mechanical expansion of tubular achieved by pushing or pulling a mandrel through it, which enlarges the diameter of the tubular [6]; Fig. 1. It reduces the tapering effect of conventional wells design by reclaiming the clearances required between tubular strings resulting in an appropriate conduit size that allows drilling deeper. This is very exciting because it potentially means that well design can be much simpler; almost the same tubular size all the way until target depth, rather than starting with a very large diameter to leave a room for telescoping. Hence, wells can be drilled with less energy, steel, mud, and cement; thus reducing the cost, time, and environmental footprint [7]. The percentage change in tubular inner diameter (*ID*) with respect to its original inner diameter is generally termed as expansion ratio, and is commonly

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Nomenclature

σ_{true}	true stress (Pa)
σ_{eng}	engineering stress (Pa)
σ_{uts}	nominal ultimate tensile strength (Pa)
σ_y	yield strength (Pa)
σ_{yo}	initial yield strength (Pa)
σ_{y1}	yield strength after hardening effect (Pa)
σ_{yc}	compressive yield strength (Pa)
ε_{eng}	engineering strain
$\varepsilon_{ln}{}^{Pl}$	logarithmic plastic strain
ε_{ult}	engineering strain corresponding to σ_{uts}
E	modulus of elasticity (Pa)
P_{Br}	burst pressure (Pa)
t	tubular wall thickness (m)
ID	tubular inside diameter (m)
OD	tubular outside diameter (m)
ER	expansion ratio (%)
n	hardening exponent
K	strength coefficient (Pa)

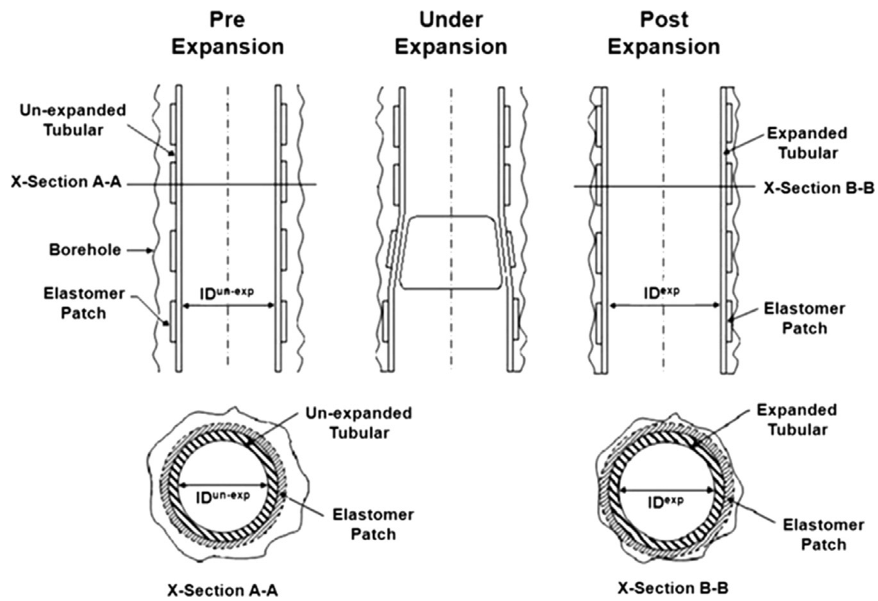

Fig. 1. Schematic representation shows three stages of variation in tubular size as a result of the in-place tubular expansion process performed using a conical mandrel.

expressed as:

$$\text{Expansion Ratio } (ER) = \frac{ID_{desired} - ID_{\text{original}}}{ID_{original}} \times 100 \tag{1}$$

Though SET has gained wide acceptance within the industry for well remediation activities, the technology has not yet achieved the desired level of success to be considered as a primary option for wells design [8]. This is mainly due to issues related to cost, low expandability limit, large force required to achieve certain expansion percentage, and critical variations in mechanical and geometrical characteristics of the tubular due to expansion. For example, to maintain volume-constancy, tubular wall thinning takes place to balance out the increase in diameter, and hence this may convert the tubular from being thick-to-thin walled; especially at high expansion ratios.

In-situ expansion of tubular involves three main elements, tubular material, expansion tools, and techniques or procedures employed for expansion. There are many published papers that address SET concept and its application in drilling and remediation tasks [9]. Also reported is good progress in terms of expansion tools, techniques and procedures [10]. However, there are very few papers that discuss selection and design of materials for expandable tubular applications [11]. The expandable tubular material is a critical element of this technology, and restricts its deployment in many wells due to different formations, sulfur cracking, failure due to reduction in its strength-related properties after expansion, etc. The capacity of the tubular material to achieve higher expansion percentages and the confidence about its performance after expansion are two main factors that prevent larger spectrum of applications [12]. So far, in down-hole condition, tubular can be expanded from 15% to 20% of its original inner diameter without significantly lowering its collapse strength. Experimental investigation [13] showed that tubular wall thinning of about 12% lowers the collapse resistance by one-half, making the tubular inappropriate for deep well applications.

In line with American Petroleum Institute (API) recommendations, tubulars made of steel (N-80, L-80, K-55, and more recently LSX-80) are utilized in SET technology. These steel grades have the superiority of high strength and good toughness, but are coupled with the distinct deficiency in terms of low formability and considerable weight. These necessitate larger expansion force and power, and expensive load-bearing structures for the down-hole tubular expansion. Use of high strength-to-weight ratio with improved formability steels may considerably improve the performance of SET tubulars, contributing to higher reliability and cost reduction in well construction. A series of innovative steel grades such as TRIP (transformation-induced plasticity), TWIP (twinning-induced plasticity) and DP (dual-phase) are being developed in various research laboratories around the world. However, the applications are focused more on automotive industry [14]. Until now, these AHSS grades have never been used as an option for SET applications, even though TRIP and TWIP steels have definite advantages over the conventional steel grades. Hence, the present study focuses on the use of TRIP, TWIP and DP steels for expandable tubular applications, and on a comparison between these steel grades and the conventional expandable steel (LSX-80). Experimental and FEM approaches have been adopted to examine the behavior of these steel grades before, during and after the