Journal of Petroleum Science and Engineering ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Journal of Petroleum Science and Engineering

journal homepage: www.elsevier.com/locate/petrol

Numerical and theoretical analysis of burst pressures for casings with eccentric wear

Zhanfeng Chen [a,b], Weiping Zhu [a,*], Qinfeng Di [a,*], Shiqiang Li [a]

[a] Shanghai Institute of Applied Mathematics and Mechanics, Shanghai University, Shanghai 200072, China
[b] Institute of Process Equipment, Zhejiang University, Hangzhou 310027, China

ARTICLE INFO

Article history:
Received 23 February 2016
Received in revised form
18 May 2016
Accepted 20 May 2016

Keywords:
Eccentric casing
Burst strength
Wear
Thickness-to-diameter ratio
Finite element method

ABSTRACT

With the development of multilateral and extended-reach wells, trajectories of wellbores are becoming more complicated, and operating conditions are extending to higher temperatures and higher pressures. For safe down-hole operations, accurate predictions of casing burst strength are crucial. Based on the elastic–plastic theory for large deformations, we propose a three-dimensional finite element model (FEM) for predicting the burst pressure of a pipe having geometric eccentricity. Using the cross-sectional shape, we divide eccentric casings into two types: crescent-shaped and eccentric cylinder; then, we verify the accuracy and reliability of FEM results by comparing them to a series of full-scale experimental data. To estimate burst pressure, we derive a modified theoretical equation for eccentric pipes. Finally, we discuss how burst pressure is affected by wear radius and pipe eccentricity. Our results show that eccentricity has important effects on burst strength, whereas effects of wear radius are small. Our modified theoretical equation provides results that are consistent with experimental data published by others; moreover, the equation is more accurate and extends over a wider range of applications than previous equations. The FEM approach and the modified theoretical equation presented in this study are appropriate for predicting the burst pressures of pipes employed in the oil and gas industries.

1. Introduction

In the oil and gas industry, casings are widely used as protective conduits during all phases of drilling operations and production. As the requirement for deep wells and wider applications of multilateral and extended-reach wells continue to increase, trajectories of wellbores are becoming more complicated and operating conditions are becoming harsher. Consequently, problems due to casing wear are becoming more prominent. For example, the integrity of casings is threatened in wellbores at high temperatures and high pressures. Therefore, in integrity analyses, accurate predictions of burst strength are crucial; burst strength is the minimum internal pressure that can cause burst failure of a steel casing.

The two modes of casing burst failures are ductile instability and brittle fracture, and a simple criterion for distinguishing between them has been proposed by Tallin et al. (1998). Because of improved manufacturing processes and strengthened materials, a ductile burst failure is more likely than a brittle fracture. Brittle fractures rarely occur in practice; however, they can be induced when the environment is filled with active gases such as H_2S. Early work on the burst strength of casings under internal pressure can be traced back to Hill (1998). In recent years, Klever (1992) developed an analytical model based on the von Mises yield criterion and contributed a predictive equation for the burst strength of regular casings. The model was further modified by the Tresca yield criterion by Stewart et al. (1994). Chen et al., (2015a, 2015b) proposed an analytical method for burst pressure of eccentric wore casing. However, it is difficult to accurately predict the casing burst pressure caused by geometric imperfections (eccentricity and ovality) (Huang et al., 2007), which may lower the actual casing burst pressure. Furthermore, a casing burst under excessive internal pressure is an elastic-plastic large-deformation problem and a local three-dimensional process. These complex nonlinear phenomena are difficult to simulate accurately. For this study, a three-dimensional elastic–plastic finite element model was used to simulate these processes, and preburst states were clearly observed. A modified theoretical equation and experimental data were used to explore burst strengths of different casings, with and without eccentricities, and to study the effects of wear radius and eccentricity.

* Corresponding authors.
E-mail addresses: wpzhu@shu.edu.cn (W. Zhu), qinfengd@sina.com (Q. Di).

http://dx.doi.org/10.1016/j.petrol.2016.05.024
0920-4105/

2. Geometrical imperfections

In this study, geometrical imperfections mainly refer to eccentricity. During manufacturing, casings occasionally acquire an initial eccentricity (Huang et al., 2007). During operations, the continuous reciprocating or rotational movement of the drill pipe can cause casings to wear in the radial and axial directions (Johnson and Mellor, 1983). Furthermore, dogleg and horizontal wells can increase wear on casings. Based on cross-sectional shapes, most casings can be divided into two categories: those with uniform-wear cross sections and those with eccentric-wear cross sections. This study focuses on the latter. There are two common models for eccentric-wear casings: the *crescent-shaped* model (Fig. 1(a)), which is formed by drill pipes wearing on one side of the casing, and the *eccentric cylinder* model (Fig. 1(b)), which is primarily formed by irregular wear on the casing inner wall.

In the crescent-shaped model (Fig. 1(a) $R_1 < R$ and $\delta \neq 0$), the eccentricity ratio η can be defined as the ratio of the wall thickness at the point of maximum wear to the original wall thickness,

$$\eta = \frac{R_1 + \delta - R}{t}, \tag{1}$$

where R_1 is the radius of eccentric wear, δ is the distance between the casing centre O and O_1, R is the radius of the inner wall and t is the original wall thickness of the casing.

In the eccentric cylinder model (Fig. 1(b) $R_1 > R$ and $\delta \neq 0$), the eccentricity ratio η can be defined by

$$\eta = \frac{t_{\max} - t_{\min}}{t_{\max} + t_{\min}}, \tag{2}$$

where $t_{\max}$ is the maximum wall thickness and $t_{\min}$ is the minimum wall thickness. Eq. (2) can be simplified to

$$\eta = \frac{\delta}{t}, \tag{3}$$

where $\delta = R_1 - R = (t_{\max} - t_{\min})/2$ denotes the distance between the centre of the casing O and the centre of the worn casing O_1, and $t = (t_{\max} + t_{\min})/2$.

When $R_1 > R$ and $\delta = 0$, the casing has uniform wear and the wall thickness of the casing remains the uniform after wearing. Clearly, when the minimum residual wall thickness is constant, as the wear radius increases, the cross-sectional shape of the casing sequentially progresses from the crescent-shaped model, to the eccentric cylinder model and then to the uniform-wear model.

3. Finite element analysis

3.1. Finite element modelling

An eccentric-wear casing bursts under internal pressure in a three-dimensional elastic-plastic process with a large deformation failure. Concentration of stress first appears in the thinnest area of the eccentric casing. Then, yield occurs on the inner wall and gradually extends to the outer wall. Finally, a yield surface spreads over the entire wall and a burst occurs. The ABAQUS software (6.10) is capable of simulating these nonlinear processes. Therefore, ABAQUS (Gulati et al., 1994) was used to perform finite element analysis to investigate the ultimate burst strength of a finite, three-dimensional walled casing that contained geometrical imperfections. It was assumed that the deformed casing was imperfect under internal pressure and that the cross section remained eccentric. Fig. 2 shows a typical finite element model with geometric imperfections. Ovality has no significant effect (Huang et al., 2007), and therefore, its influence was not considered in this study. The cross section and imperfections are the same along the length of the casing (see in Fig. 2).

3.2. Assumptions and algorithm

Because of the large deformation, a casing burst is a local three-dimensional process in which the material undergoes elastic and plastic stages. Therefore, in modelling the process, three-dimensional materials and geometric nonlinearities need to be considered. To protect casings, many intermediate casings are solidified by cement, although some are used without a surrounding cement ring. The model built in this study was for a casing without the surrounding cement. In practice, casings are not regular tubes and do not have uniform wall thicknesses; geometric imperfections are mainly elliptical or eccentric. Because ellipticity can be automatically corrected by internal pressure and ovality has no significant effect (Huang et al., 2007), the influence of elliptical imperfections is ignored in this study. This study mainly focused

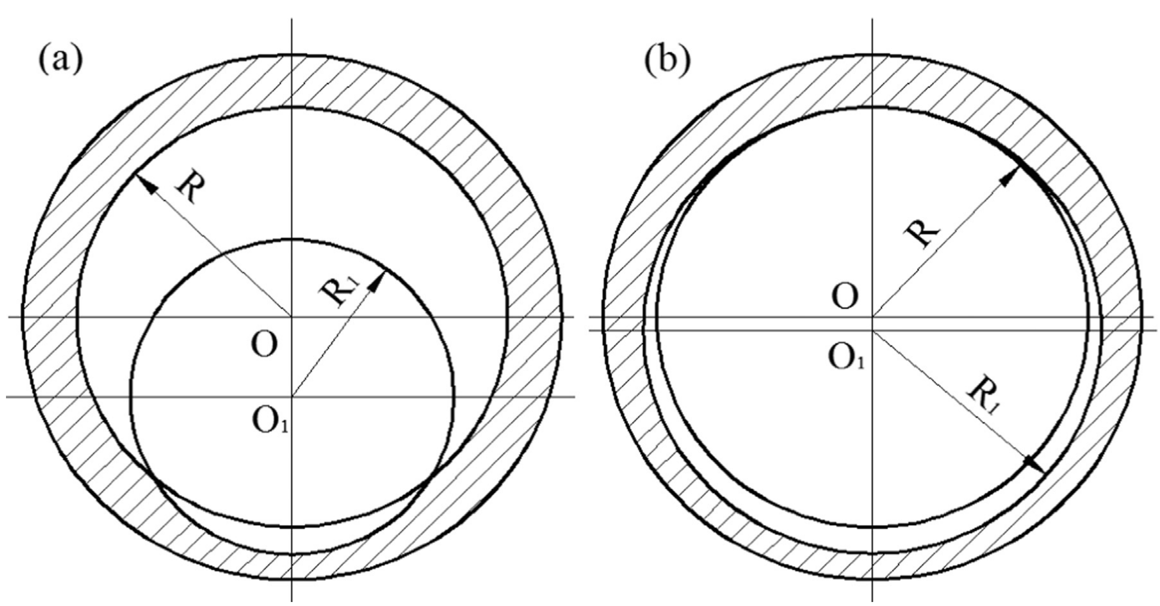

Fig. 1. Models for eccentric wear on casings. (a) Crescent-shaped model and (b) eccentric cylinder model.

Please cite this article as: Chen, Z., et al., Numerical and theoretical analysis of burst pressures for casings with eccentric wear. J. Petrol. Sci. Eng. (2016), http://dx.doi.org/10.1016/j.petrol.2016.05.024