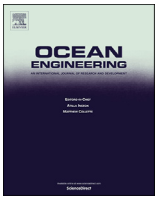
Ocean Engineering 146 (2017) 363–374

Contents lists available at ScienceDirect

Ocean Engineering

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



Finite element analysis of a sandwich pipe joint

Ikechukwu Onyegiri, Maria Kashtalyan *

Centre for Micro- and Nanomechanics (CEMINACS), School of Engineering, University of Aberdeen, Fraser Noble Building, Aberdeen AB24 3UE, Scotland, UK

ARTICLE INFO

Keywords:
Sandwich pipe
Field joint
Strain concentration
Finite element modelling

ABSTRACT

Sandwich pipes in which the core material performs both thermal insulation and structural function are viewed as a lightweight alternative to conventional pipe-in-pipe systems in which insulation material carries no loading. Developing a suitable method that permits the joining of sandwich pipes in an efficient manner is essential for their successful application. In this paper, the mechanical response of a swaged field joint between sandwich pipes subjected to bending is investigated using a series of finite element models. In order to gain a thorough understanding of the response of the joint components to installation based loadings, parametric studies are carried out to establish the effect of the inner pipe thickness, cutback length, and stiffness of the field joint filler on the strain concentration at the joint, with particular focus on the swaged weld region and the girth weld region. The influence of interface adhesion properties and weld metal yield strength on the variation of strain intensity is also evaluated. Numerical studies show that increasing filler stiffness and maintaining a cutback length less than 2.5 times the radius of the inner pipe could produce lower strain intensity at the two regions of interest.

1. Introduction

As oil and gas production moves to deep- and ultra-deep waters, new pipeline configurations are required to meet simultaneous demands for thermal insulation and structural integrity to ensure safe and reliable transportation of hydrocarbons. Over the past two decades pipe-in-pipe systems have been developed for fields with flow assurance challenges (Bai and Bai, 2014; Sriskandarajah et al., 2016). However, with increasing water depths and associated increasing demands on structural performance, the pipe wall thickness in pipe-in-pipe systems will have to increase, with pipe-in-pipe systems becoming exceedingly heavy and uneconomical (Bruschi et al., 2015), and lightweight alternatives will need to be sought.

In the pipe-in-pipe concept, the annular space between the inner pipe and outer pipe is not used to its full structural potential because the insulation material does not perform any structural function. In contrast, a sandwich pipe combines thermal insulation and structural performance in its design and attempts to realise the full structural potential of the annular space.

A sandwich pipe typically consists of two thin-walled pipes – an inner pipe and an outer pipe – and a core layer that completely fills the annular space between the pipes and is bonded to them. The concept of sandwich pipelines has been studied for over a decade now. Estefen, Netto and Pasqualino (2005) and Castello and Estefen (2008) performed small-scale tests and strength analysis of sandwich pipes under combined external pressure and longitudinal bending. They showed that sandwich pipe systems with either cement or polypropylene cores are feasible options for ultra deepwater applications. Buckling capacity of sandwich pipes with various structural configurations and core materials, subject to external hydrostatic pressure was studied by Arjomandi and Taheri (2010) using an analytical approach. Arjomandi and Taheri (2011a-c) also performed extensive finite element modelling of sandwich pipes to analyse different bonding scenarios at the interfaces between the core layer and the pipe layers and examined the effect of material and geometrical nonlinearities on the pipe buckling and post-buckling behaviour. Behaviour of sandwich pipe systems under pure bending was examined by Arjomandi and Taheri (2012) while reeling effects was studied by (Castello and Estefen, 2007; Paz et al., 2015). Collapse behaviour of sandwich pipes with strain hardening cementitious composite reinforced with polyvinylalcohol (PVA) fibers as a core material was investigated experimentally and numerically by (An et al., 2014). A parametric study examined the effects of ovality, thickness and outer/inner radius ratio on the collapse pressure of these sandwich pipes. Post-buckling responses and pressure capacity of sandwich pipes with the solid polypropylene core was investigated by (He et al., 2015) using finite element modelling.

Developing a suitable method that permits the joining of sandwich pipes in an efficient manner, preserving the integrity of the insulation

---

* Corresponding author.
E-mail address: m.kashtalyan@abdn.ac.uk (M. Kashtalyan).

https://doi.org/10.1016/j.oceaneng.2017.09.042
Received 7 February 2017; Received in revised form 31 July 2017; Accepted 24 September 2017

0029-8018/© 2017 Elsevier Ltd. All rights reserved.

and the mechanical properties, is essential for successful application of sandwich pipes, however joining of sandwich pipes has received considerably less attention in the literature.

Offshore pipeline joints (referred to as field joints) that link two adjoining pipe sections represent a critical design area during installation and operation analysis. The design of a joint usually follows set guidance criteria established wholly by the loadings the field joint would undergo from fabrication and throughout operation (Thielhelm, 1968). For pipe-in-pipe systems, several joint configurations were proposed (Hausner and Dixon, 2002; Hausner and Dixon, 2004). In sliding pipe-in-pipe systems, field joints require welding of both the inner and outer pipes. Fixed pipe-in-pipe systems utilise either swaged connector, forged bulkheads or forged tulips that are welded to both the inner and the outer pipe (Hooper et al., 2004). In a swaged joint configuration developed by InTerPipe, the ends of the outer pipe are swaged down and welded unto the outer surface of the inner pipe at the ends of pipe segments; this is carried out onshore. Segments of the pipe are transported to the offshore lay vessel where the ends of the inner pipes are joined together by a girth weld. To make a complete connection, a sleeve is placed over the girth weld and the swaged section of the pipe, and fast-curing resin is injected into the cavity. This joining method is considerably faster than welding both inner and outer pipes and is suitable for J-lay and S-lay methods (Janton, 2006). More recently, a reelable bulkhead pipe-in-pipe technology (Boi et al., 2012) and a swaged joint with flush welded half shells for reel lay (Jones et al., 2013) have been developed. Design aspects of pipe-in-pipe systems for high pressure/high temperature (HP/HT) applications are discussed by Sriskandarajah et al. (2016).

The swaged joint configuration with flush half shells arguably represents the most effective way for providing continuity of bending stiffness (Hooper et al., 2004). Bending is one of the primary loading conditions experienced by pipeline during installation and in-service. Bending loads are inevitable when laying offshore pipelines and the response of field joints to high levels of curvature requires comprehensive study of all joint components (Dixon et al., 2003).

Sandwich pipe joints are expected to behave in a manner similar to pipe-in-pipe joints, with the main difference being the effect of the extra stiffness added by the core material. This makes the swage and half shells weld even more critical due to the enhanced transfer of bending loads across the field joint region. In sandwich pipes, bending will lead to stress and strain concentrations at the field joint similar to those experienced by field joints in pipe-in-pipes, however the effect of the structural core on the mechanical response of the field joint has not been quantified yet.

The aim of this study is to analyse, by means of finite element method, performance of a swaged joint between sandwich pipes and establish the effect of both geometrical and mechanical properties of field joint components on the strain concentration at the joint.

2. Design considerations

Strain concentration at the field joint is a result of variation in bending stiffness along the pipe (Roberts et al., 2009). On the application of a bending moment, longitudinal strains in tension and compression are experienced and can be analysed starting from the girth weld connecting two adjacent inner pipe ends to some distance along the inner pipe where the swaged weld toe is encountered. The magnitude of strain especially in the girth weld is dependent on weld shape, wall thickness variation, pipe ovality and weld metal mismatch (Dixon et al., 2003).

Strain concentration is an important design input for field joint design. The severity of strain concentration in the field joint area is represented by the strain intensity factor (SIF), which is sometimes also called strain concentration factor. It is simply defined as

$$SIF = \frac{\varepsilon_{\max\_FJ}}{\varepsilon_g} \tag{1}$$

where $\varepsilon_{\max\_FJ}$ is the maximum longitudinal strain at the field joint and ε_g is the global bending strain calculated by the Euler beam theory:

$$\varepsilon_g = \frac{kD}{2} \tag{2}$$

where k is the applied curvature and D is the outer diameter of the pipe. The curvature can be written in terms of pipe length L and the rotational displacement of the pipe θ in radians as

$$k = \frac{\theta}{L} \tag{3}$$

Comparative models employed to verify the accuracy of Eq. (2) confirmed the plausibility of using the Euler beam theory to calculate global strain for materials undergoing plastic deformation. The results revealed that up until the point of yield, Eq. (2) captured the global strain accurately. Post yield results showed an undervaluing of the global strain results by Eq. (2). A correction polynomial function was thus used to accurately define the global bending strain after yield (ε_g^{corr}) by post yield data obtained by Eq. (2) and results obtained from the comparative FEA model:

$$\varepsilon_g^{corr} = 159.57\varepsilon_g^3 - 2.4444\varepsilon_g^2 + 1.0493\varepsilon_g - 0.00009 \tag{4}$$

The yield curvature k_y at which the inner pipe outer fibre begins to yield is defined by the empirical expression:

$$k_y = \frac{\sigma_y}{E \cdot r_i} \tag{5}$$

Using the formulation above, a radius of curvature (R_{curv}) at yield of 50.6 m is calculated; showing close alignment with the R_{curv} at yield of 49.8 m obtained from a comparative FEA model of the inner pipe undergoing pure bending.

The reference value for SIF as quoted by DNV (DNV, 2013; Bai and Bai, 2014) is 1.2 for conceptual design in the absence of detailed engineering, a value that analysis by Nourpanah and Taheri (2012) showed only to be precise for pipelines with light insulation and exposed to relatively low bending strain. For curvatures representing reeling (plastic deformation), SIF values would be larger as represented in work done by Crome (1999) who studied the reeling of pipelines with thick insulation. The same conclusion was reached by Sriskandarajah et al. (2003) who showed that due to non-uniformity of material properties and adjacent geometries, the effect of strain concentrations will arise which will yield higher strain levels than the normal design strains due to the reel drum radius.

The geometry of the swaged joint is shown in Fig. 1, together with several areas of interest. First is the inner pipe region between the girth weld and the swaged weld (cutback length), which can be analysed as a single pipe bordered at two ends by greater stiffness cross sections. The next is the fusion area between the inner pipe and the swaged weld which is a full penetration weld. Another region of interest would be the inner pipe length just after the swaged weld. In the outer region, the critical zones include: the fillet interface (extrados) with the buttered weld and the half shell region. The structural integrity of the welds is also of paramount importance as it to a large extent controls the mechanical response of the field joint but is outside the scope of this paper.

Due to the presence of a relatively stiff core in the assembly adjacent to the field joint and weld locations, one would expect the distribution of bending strains to differ from that in a conventional pipe-in-pipe system. One could review the sandwich pipe geometry as a single wall pipe with layered coating of the core and outer pipe, picking some similarities to work that has been done on bending of field joints used for subsea operations.

Geometric tolerances remain the most difficult hurdle to overcome in understanding the swaged field joint connections for pipe-in-pipe systems (Mallik et al., 2013). For this reason, this study would be investigating numerically, by means of finite element method, the response of

Download English Version:

https://daneshyari.com/en/article/5474076

Download Persian Version:

https://daneshyari.com/article/5474076

Daneshyari.com