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MODELLING PERFORMANCE OF SANDWICH PIPE JOINTS UNDER INSTALLATION LOADINGS

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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 [1, 2]. 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 [3], and lightweight alternatives will need to be sought.

The significant benefits of the sandwich pipe as an alternative to conventional pipe-in-pipe systems and single wall pipes has been researched and documented over the last decade. The bulk knowledge of this research has focused on the intended benefits of cost savings and increased capacity-to-weight ratio for deepwater pipeline installation and operation with respect to external pressure capacity, internal pressure capacity, pure bending capacity and reel-lay analysis. Developing a suitable method that permits the joining of sandwich pipes in an efficient manner, preserving the integrity of the insulation 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. 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 joint components on the strain concentration at the joint.

2. METHODOLOGY

Strain concentration at the field joint is a result of variation in bending stiffness along the pipe [4]. 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 [5].

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 base three-dimensional axisymmetric model used in this study can be seen in Fig 1. A uniform bending moment was applied at the pipe ends and the variation of the longitudinal strain in the inner pipe was studied; for this paper, we use the term strain concentration factor (SCF) to quantify this variation, defined as: $\varepsilon_{\max\_FJ}/\varepsilon_g$ 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 bending theory for a simple beam. The yield curvature for the inner pipe was defined by the expression: $k_y = \sigma_y/E.r_i$. The mechanical properties for the base model sandwich pipe are shown in Table 1.

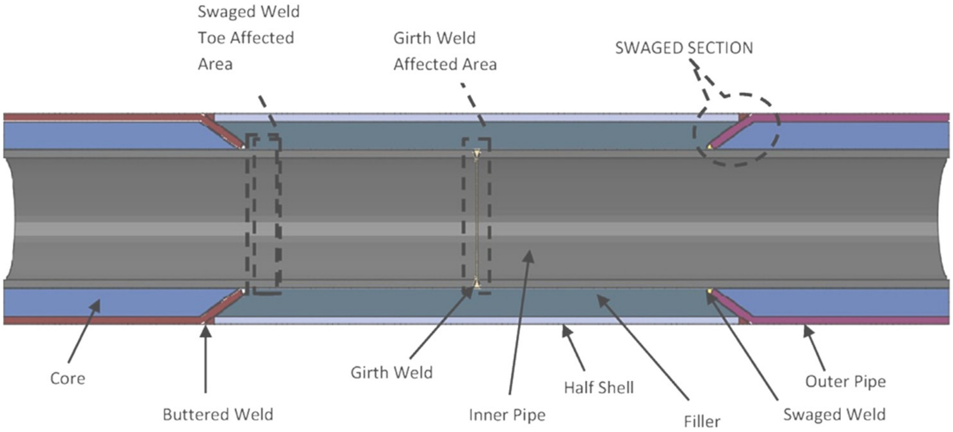

Fig. 1: Sandwich pipe swaged joint.

Table 1: Mechanical properties for the base model sandwich pipe.

Component	Material	Young's Modulus E (GPa)	Yield strength σ_y (MPa)	Ultimate tensile strength σ_{UTS} (MPa)	Poisson's ratio v
Inner Pipe, Outer Pipe, Half Shell	Steel	207	448	603	0.3
Core	Polymer	1.0	Perfectly elastic	Perfectly elastic	0.43
Filler	Polymer	0.9	Perfectly elastic	Perfectly elastic	0.43

The analysis was carried out using the commercial FE software Abaqus, with only a quarter of the field joint modelled due to geometric axial symmetry. The base model was developed as an 8" x 12" sandwich pipe. Mesh convergence studies and model de-featuring were carried out to produce a robust model that closely matched experimental results as carried out by [6]. 52 elements along the circumferential direction proved to be enough when predicting the system instability for convergence (Fig. 2). The mesh for the steel parts was generated using 3D solid elements C3D20R while that for the core polymeric layer was meshed with C3D20H elements. Post yield behaviour for the steel layers was modelled by J2 plasticity theory with isotropic hardening with true stress-strain data evaluated by an elastic response followed by a Ramberg-Osgood plasticity response with strain index fitted from experimental results for API X65 pipes.

3. RESULTS AND DISCUSSION

Longitudinal strain distribution along the length of the inner pipe is shown in Fig. 2 starting from the girth weld interface. As is expected, strain localisation at the girth weld interface due to weld-pipe metal mismatch and hi-lo is observed. Moving further away, the strain appears constant and then elevates signifying the beginning of the stiffening enhanced region due to the presence of the swaged weld. The swaged weld can be characterised as a stiffener ring acting on the surface of the inner pipe thus allowing for higher strain just adjacent to the weld toe as can be seen in Fig. 2.

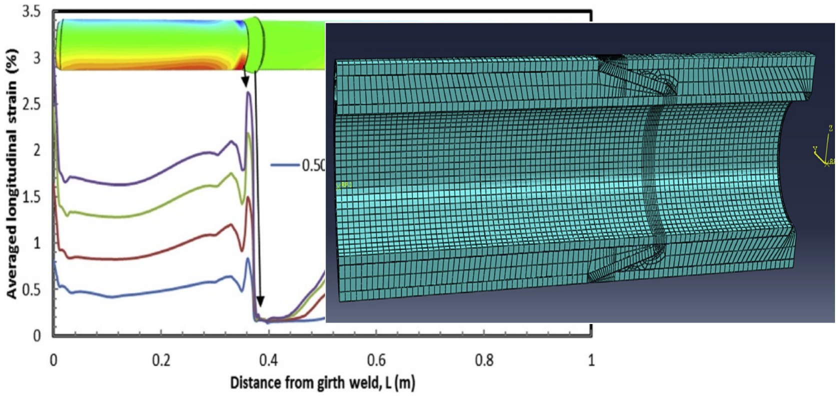

Fig. 2: Strain variation along the pipe for a range of global strain values (left), Finite element mesh of a sandwich pipe swaged joint (right).

The parametric studies [7] involved varying the studied parameter whilst keeping the other parameters as is in the base model. The influence of the inner pipe's diameter-to-thickness ratio on the SCF was studied and showed that reducing the ratio would lead to a decrease in the SCF as the bending stiffness of the pipe would increase. Also, increasing the filler-to-core stiffness ratio was seen to have a decreasing effect on the SCF at the swaged weld region of the inner pipe. This added structural advantage was more pronounced after the yielding of the inner pipe and thus supports the argument for a stiffer field joint region for sandwich pipes during installation by reel-lay or S-lay.

The effect of the cutback length on the strain concentration of a conventional swaged sandwich pipe joint is generally different from that expected for concrete coated pipe or wet insulation pipelines. This is due to the complex geometry and varying sectional profiles of the swaged weld field joint. The ratio of the inner pipe radius to the cutback length $\left(r_i/L_f\right)$ was used as the defining parameter. Increasing the cut-back length would yield significant advantages by reducing the SCF but is not always favourable (a long cut-back length) as that leads to increased offshore time in making a tight connection. Utilising shorter cut-back lengths $r_i/L_f > 0.5$ avails lower SCF to the swaged weld region but greatly increase the SCF at the girth weld region for high reel curvatures. From the sensitivity studies, $r_i/L_f = 0.3 - 0.4$ would be suitable as they produce a good balance between the SCF at the swaged region and girth region. The effect of interlayer adhesion is shown in Fig. 3 where FB: fully bonded layers, FJ-NB: filler not bond, C-NB: core layer not bond and A-NB: no bond between the layers.

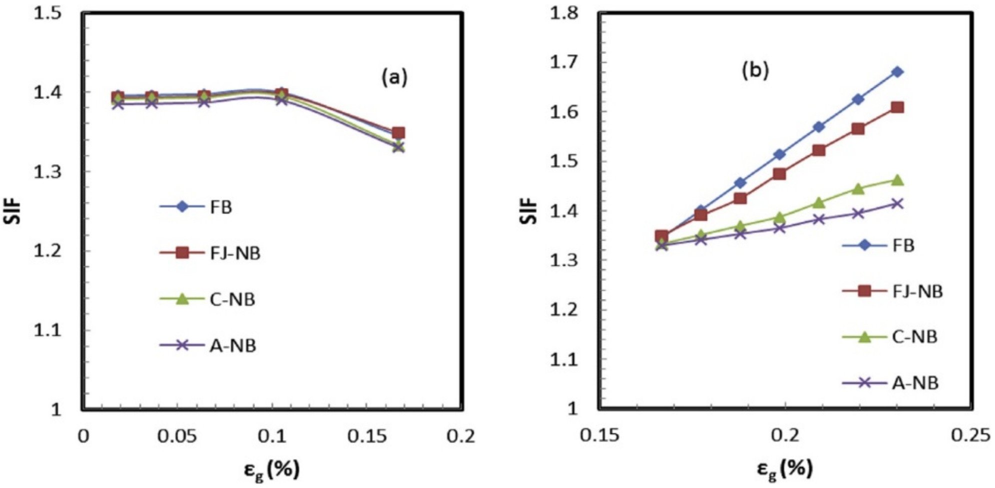

Fig. 3: Effect of interlayer adhesion on SCF at the swaged weld region: Elastic regime (left), Post-yield regime (right).

The choice of weld material and welding procedure will definitely have an impact on the SCF, and as such results showed that utilising a weld metal with a greater yield strength than that of the adjacent pipe would increase the SCF at the swaged weld region but this is only of significance for bending strains below the yield point of the swaged weld. Further research into the effect of the geometry of the swaged weld on the SCF is recommended, looking into dynamic loading (as with the reel installation procedure).

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