Numerical and Structural Behavior of Sandwich Pipe Strength Investigations

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Abstract

Sandwich pipes are an effective solution for the use of ultra deepwater applications. It has been developed by researchers to overcome the valuable resolution for ultra deepwater's. In this work, numerically studying the influence of different sandwich structures by using Taguchi analysis and extended the experimental findings with pipe-in-pipe method. Initially, the stress and deformation behavior of the sandwich pipe structures were investigated by the Taguchi analysis. Experimentally fabricated sandwich pipe by the integration of two aluminium pipes (inner/external) by affixed to high density polyethylene (HDPE) annulus materials as core, which provides sufficient structural strength. Further, we have studied the strength behavior of sandwich structure and results produce a new path for ultra deepwater applications.

Keywords: Sandwich pipe; ultra deepwater; aluminium; HDPE; optimization;

1. Introduction

The collapse behavior of pipelines has been investigated systematically due to their significance in offshore oil, gas transportation (hydrocarbon), and ultra-deepwater applications. As an effective resolution for the ultra-deepwater submarine pipelines is enhancing, the combination of two steel tubes with the integration of polymeric or cement-based core structure also known as the sandwich pipe has been fabricated with the capacity to improve their structural resistance (strength), thermal insulation, etc [1-2]. The sandwich pipe also known as the pipe-in-pipe system is suitable for various applications. Oil and gas fields are being developed at water depth (up to 3500 meters) for ultra-deepwater applications. The collapse behavior of the pipelines has been investigating scientifically due to their significant applications in deepwater, oil, and gas transportation [3]. Nowadays, shallow waters are fast depleting, the extraction of deepwater, oil reserves is actively influenced globally. Such an effort is possible and unless efficient oil transportation has been developed. The integrity of current sandwich pipelines must be remarkably improved and higher demands on the deepwater resources. The design and fabrication of sandwich pipe have restrictions when used in deep water applications such as environmental damage from outside, external pressure capacity, thermal conductivity and pipeline buoyancy-related issues that limit the water depth [4]. The composite structures consisting of two steel tubes with a polymeric (cement/ high-density polyethylene) based core have been progressed to maintain utmost structural resistance with thermal insulation properties. The annular space or the air gap between the inner and outer pipes is filled with either circulating hot water or materials which achieve high thermal insulation properties. In ultra-deepwater, well-insulated sandwich pipelines have capable to withstand due to their high internal and external pressures [5].

Arjomandi and Taheri (2011a) investigated the pressure capacity of sandwich pipes using the finite element method. The materials and geometrical nonlinearities were considered and noticed to the real response of the systems. The various parameter influences were analyzed by using a large number of sandwich pipe models. This investigation used for the development of a practical equation to measure the capacity of sandwich pipes. Finally, the low-cost function defined and the minimum algorithm used for the optimized parameters with the water depth range various between 2000 to 10000m [6]. Croll (1997) demonstrated a simple model of upheaval thermal buckling of subsea pipelines. They have extended the work that to make available alternative mechanics for direct upheaval buckling of systems with imperfect geometries. Both simple and closed-form were the solutions with initial lift-off for the maximum upheaval buckling loads [7]. Castello and Estefen (2007) numerically investigated the strength of sandwich pipes that were filled with polypropylene. The influence of the inter-layer adhesion between steel and polymers along with that the vital strength under external pressure and longitudinal bending also investigated. By simulation parameters, the highest shear stress noticed among the metal and polymer interfaces using experimental tests. Finally, the ultimate strength of the sandwich pipe was strongly dependent on the shear stress among their interfaces [8]. Arjomandi and Taheri (2011b) studied the performance of intra-layer adhesion configurated sandwich pipes using the finite element (FE) method. By employing this work, observed the potential thermal insulation properties of core material (sandwich pipes) and structural integrity by the sandwich mechanics. Further, the pressure capacity of sandwich pipe, structural parameters, and various adhesion properties were investigated. The FE method showed ~12000 non-linear models and developed three practical equations. These equations were evaluating the pressure capacity of sandwich pipe with different intra-layer mechanisms and material configurations for optimal structural configurations [9]. Quispe et al. (2019) carried out numerically employed to study the threaded connections, make-up torque, external pressure, and axial load of sandwich pipe using non-linear finite element models. These demonstrations showed the ability to maintain water tightness, structural integrity with all load combinations and suggested the bending behaviour might be studied during installation [10].

In this paper, the bending strength of the various combinations of sandwich pipes is fabricated and investigated. The sandwich pipe strength conceptions fulfill concomitantly both the selection of materials and mechanical strength. These selected materials generate good insulation with enhanced compressive strength, wide availability, and low cost. The structural strength depends on the three layers such as inner, outer and core of the sandwich pipes.

2. Numerical and experimental method

2.1 Simulation

The pipeline is a system of pipes integrated by using various material elements. This sandwich pipe consists of a different combination of the materials and some of the materials with thicknesses are tabulated (Table 1).

Table 1. The different materials diameter and thicknesses.

S.N.	Core Material	IP Material	OP Diameter	IP Thickness	OP Thickness	OP Material
1	Concrete	X60	323.9	13.3	26.6	X60
2	Concrete	X65	323.9	13.3	26.6	Aluminium (AA1060)
3	Concrete	AA1060	355.6	15.1	27.7	X60
4	Concrete	X56	355.6	15.1	27.7	AA1060
5	Poly Propylene (PP)	AA1060	355.6	13.3	26.6	X60
6	Poly Carbonate (PC)	X60	323.9	15.1	27.7	X60
7	PP	X56	355.6	13.3	26.6	AA1060
8	PP	X65	323.9	15.1	27.7	AA1060
9	High Density Poly Ethylene (HDPE)	X60	355.6	13.3	27.7	AA1060
10	HDPE	X65	355.6	13.3	27.7	X60
11	HDPE	X56	323.9	15.1	26.6	X60
12	HDPE	AA1060	323.9	15.1	26.6	AA1060
13	PC	X65	355.6	15.1	26.6	X60
14	PC	AA1060	323.9	13.3	27.7	AA1060
15	PC	AL1060	323.9	13.3	27.7	AA1060
16	pc	X60	355.6	15.1	26.6	AA1060

Sandwich pipes may be responsible for low-intensity, low-thermal conductivity, inferior mechanical strength which is useful for the transportation of hydrocarbon, subsea field development, fluids, and ultra-deepwater applications. This configuration of sandwich pipes system includes different types of pipes such as connecting elements of pipes, seal packing connecting two detachable sections of pipeline, etc [11]. The geometry of the sandwich pipe is shown in Figure 1 which is composed of three different layers where the internal diameter of the internal pipe, the internal pipe (IP) thickness, the outer pipe (OP) diameter, outer pipe (OP) thickness and the annulus (core) layer thickness. The intermediate layer generates the thermal insulation and avoids sliding in between adjacent layers. Therefore, three different materials are selected to evaluate, the different geometries and feasibility of sandwich pipes using the Taguchi analysis. The selection of materials and pipe (internal/external) sizes are tabulated below. The sandwich pipe includes six parameters that play a crucial role for the strength analysis such as core materials, external diameter, external and inner pipe materials (diameter and thickness). In addition, a systematic parametric study was performed by optimization of outer, core, and inner materials selection, thickness, and diameters [12].

2.2 Experimental approach

The selection of the sandwich structure materials was depends on the property of low Vonmises stress (MPa) [13]. Figure 1(a)-(c) shows the numerically simulated and selected materials used as inner, outer, and core of sandwich structures by the pipe-in-pipe method. The hydraulic machine played a pivotal role in the preparation of sandwich pipes as shown in Figure 1. This sandwich structure incorporated by two concentric steel pipes in which the annulus filled with insulating materials like polypropylene, HDPE, concrete, etc. These annulus materials (core) are decreasing the thermal insulation, well-suited among inner and outer pipes, enough strength against either burst/collapse during installation and working loads [14]. Further, it is withstanding by various factors like tension, bending loads, internal and external pressure. The two different materials (X56, AA1060) selected for the fabrication of different sandwich pipes with core are shown in Table 1.

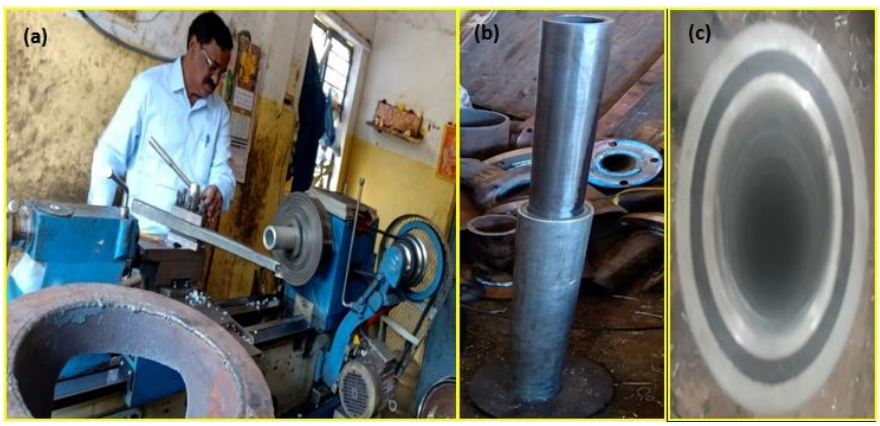

Fig. 1. The preparation steps of sandwich pipe using hydraulic machine.

3. Results and discussion

3.1 Deformation and stress investigation

The sandwich pipe has been various parameters and exploring their significance in ultra-deepwater applications. The research considers various mechanical properties for example friction, collapsing pressure, geometric variation, bending strength, and initial imperfections [15]. Initially, the high- strength steel is useful in both internal and external layers. Consequently, cement, polypropylene, and high-density polyethylene (HDPE) considered for the annulus materials [16, 8]. With the addition of that prepared sandwich pipe, total deformation and stress (MPa) are tabulated. At first, the concrete cement was selected as a core material among the steel X56 and Aluminium alloy (AA or AA1060) as shown in Figure 2(a). These core materials have different merits like low-cost and easy manufacturing, high compressive strength, and low thermal conducting properties. However, cement is a fragile material and favorable to their nucleation of imperfection and breaks the propagation due to tension loads. Overall, the deformation (0.04mm) and stress (51.22Mpa) of the sandwich pipes decreased significantly as compared to other structures, named as ‘C-1’ in table 2. Next, polypropylene used as core material in the sandwich pipes which is a hyperelastic (300%) material and less thermal conductivity. Figure 2(b) shows the core material integrated among the steel-X56 and aluminum alloy materials named ‘C-2’. This demonstrated sandwich structure shown maximum mechanical properties of deformation (0.14811mm) and stress (106.32Mpa). Next, HDPE used as core materials by combining the inner and outer pipes of aluminium alloy and calculated the corresponding deformation (0.07795mm), and stress (66.31Mpa). Furthermore, the bending strength performance employed for the various fabricated sandwich pipe structures by using a Universal testing machine (Micro control systems, UTN 40). Similarly, *Liu et al. (2019)* demonstrated the low-strain integrity test and investigated sandwich pipe defects by optimization of various parameters [17].

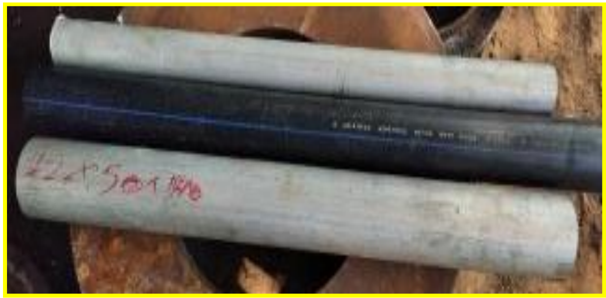

Fig. 2. The sandwich pipe of aluminium, HDPE, and aluminium materials.

Figure 3(a)-(b) shows the bending testing equipment, inner/outer, and core materials. The bending strength test results of various fabricated sandwich pipe structures (C-3) parameters are tabulated (Table 3) and calculated such as span distance, outer radius, inner radius, bending load, bending strength, outer pipe, and inner pipe diameters.

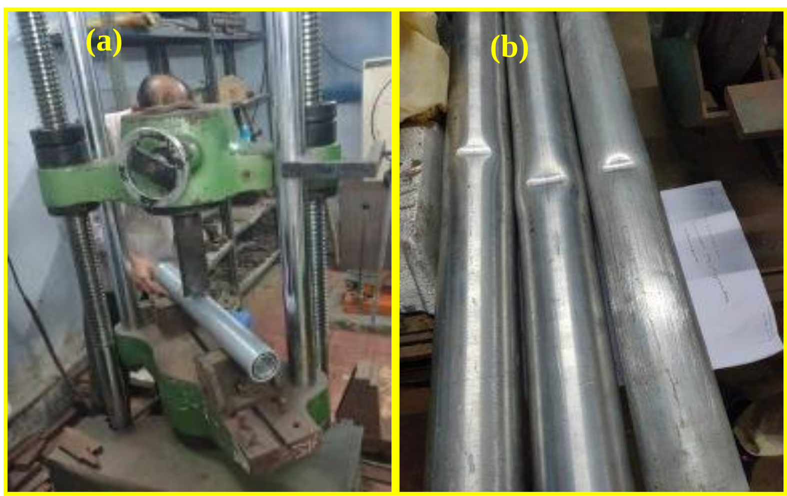

Fig. 3. The testing equipment (a) and bending strength materials (b).

Table 2: The different combinations of sandwich pipe mechanical properties.

Combination No.	Core Material	Inner Pipe Material	Outer pipe material	Deformation (mm)	Stress (MPa)
C-3	HDPE	Aluminum (AA1060)	Aluminum (AA1060)	0.07795	66.31

Table-3 The sandwich pipe structures bending strengths

Bending Strength Test	Sandwich Pipes
Span distance (mm)	300
Outer radius, R1 (mm)	36
Inner radius, R2 (mm)	22

Bending load, (F, N)	40620
Bending Strength (N/mm^2)	107.72
Outer Pipe, OD (mm)	72
Inner Pipe, ID (mm)	44


Fig. 4. The sandwich pipe structures AA-AA-HDPE.

Overall, remarkable performance noticed from the cement annulus combined sandwich pipes such as bending load (86460 F, N) and bending strength (229.29 N/mm^2). Finally, the fabricated three different sandwich pipes are depicted in Figure 4. Consequently, the characteristic of different sandwich pipe system bending capacity, geometrical, and selection of the materials investigated as reported by Arjomandi and Taheri (2012) and Xia et al. (2002) [18-19].

4. Conclusions

In this work, we have investigated the three various combinations of sandwich pipes using Taguchi analysis and pipe-in-pipe methods. The combination of inner and outer sandwich pipes (X56, X65, X60, and AA1060) was explored by integrating annulus materials (HDPE, concrete, and polypropylene). Numerically optimized parameters used in the experimental investigations systematically and studied the bending strength performance. Overall, the improved bending strength of 107.72 N/mm^2 noticed from the combination of HDPE material with the aluminium (inner pipe) and aluminium (outer pipe). This enhancement is useful in the employment of potential sandwich pipe systems for the transportation of ultra-deepwater applications. Further, the optimization process and mechanical (thermal) properties will be carried out for better performance.

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