Design and Simulation of Sandwich Pipes for Deepwater Applications

P. Satyanarayana Raju[1,2], AVNL. Sharma[1], A. Gopichand[2]
[1]Department of Mechanical Engineering, GIET University, Gunupur, Odissa, INDIA
[2]Department of Mechanical Engineering, Swarnandhra College of Engineering & Technology, Seetharampuram, Narsapur- 534280, West Godavari (AP), INDIA
Email: psnrgiet@gmail.com

ABSTRACT

The sandwich pipe is a pipeline concept and consists of two concentric steel pipes separated by and affixed to a polymeric annulus, which provides the sufficient structural strength. The designing sandwich pipe is a very complex problem in the current scenario. The usage of sandwich pipes is increased for water depth beyond 1500 m. Modelling of pipes is done using CATIA V5 software. Static analysis is done in ANSYS to determine the deformation by applying pressures on both the inner and outer pipe. In this paper, the static analysis is done in ANSYS to determine the deformation by applying pressures on both the inner and outer pipe. Deformation capacity is one of the essential criteria for a deepwater pipeline. The objective of this paper is to determine the optimum combination of input parameters using Taguchi analysis.

Keywords: sandwich pipe, annulus, deformation, deepwater

1. INTRODUCTION

The sandwich pipe (SP) is made of an insulated inner pipe (IP), protective outer pipe (OP) and separated by core (annulus) materials as shows in figure 1 (Arjomandi and Taheri, 2011). This SP is comprises by two concentrically mounted steel (or metal) pipes with annulus apace filled with either circulating hot water or materials with known thermal insulation properties (Chen et al, 2014). The sandwich pipe is specially designed for the transportation of warmed hydrocarbons or fluids in ultra-deep waters. The external and internal layers are the pipes made of metallic alloys such as carbon steel, stainless steel, aluminum, titanium, etc. with or without longitudinal weld. The outer pipe withstands external pressure. It also protects the insulation materials from mechanical damage and external hydrostatic pressure. The inner pipe conveys hydrocarbons. Therefore, it is exposed to internal pressure and internal temperature. The inner pipe is insulated with thermal insulation materials to attain the required arrival temperature. The annular space or the air gap between the inner and outer pipes is filled with either circulating hot water or materials which achieves high thermal insulation properties. In the literature survey, the design of sandwich pipe under external pressure and bending strength for submarine applications (Estefen et al, 2005; Fabian, 1977; Fabian, 1981; Kyriakides and Shaw, 1982; Kyriakides and Corona, 1988; Kyriakides and Corona, 1991; Netto and Estefen, 1994).

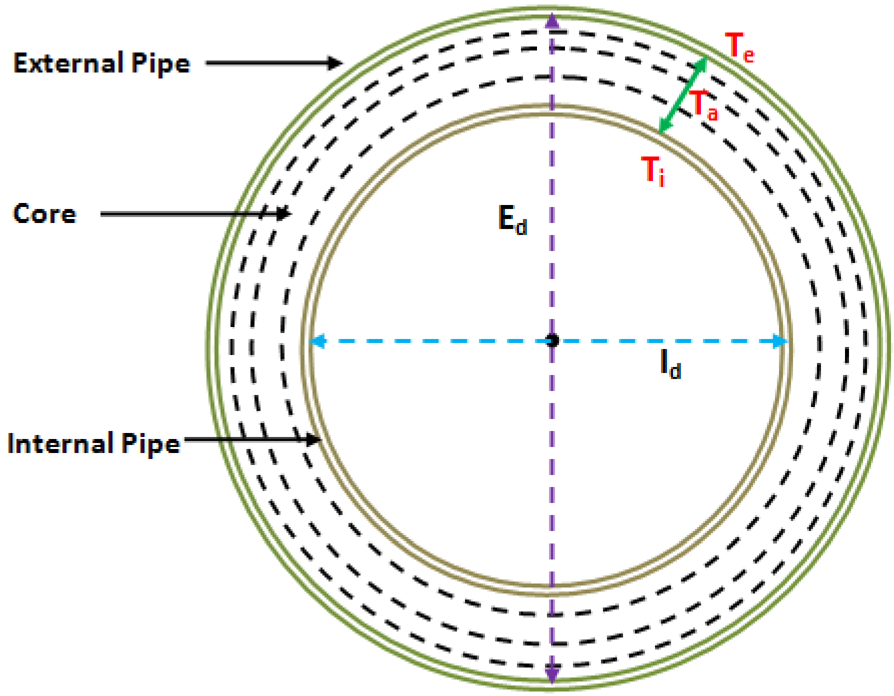

Figure 1. The idealized schematic of a sandwich pipe

Jose Luis et al. (2020) investigated the structural performance of threaded connected sandwich pipes by torque, external pressure and axial load using finite element method (FEM). They have demonstrated the threaded connector was feasible solution for the SP joint which was useful for the watertight condition under various loads. Zhu et al. (2020) presented the design, fabrication and stiffness properties of sandwich pipe by using finite element method (FEM) and developed multistage filament winding technique. They have investigated the structural stability under the confined load of the glass fiber reinforced polymer pipelines and failure map was constructed based on the various numerical parameters. These results generated new structural design and guidance for the optimal pipeline configurations.

Fernandez-Valdes et al. (2020) studied the friction and imperfections effects on sandwich pipes for ultra-deep water applications using FEM method. This numerical result indicates the capacity to with-stand ultra-deep water collapsing pressure up to 3000 m. They reported the collapse pressure inversely proportional to the annular thickness and directly proportional to the decrement of the friction.

In this paper, considering the numerical (CATIA V5 software) methodology employed to study the structural performance of various sandwich pipe for deepwater applications. Section 2 explores the simulation (numerical) parameters and results are discussed in section 3. Finally, the concludes the work in section fourth.

2. DESIGNING APPROACH

Numerical geometry: The characteristic behavior of sandwich pipe systems influenced by the various structural properties of its constituents.

Table 1. The list of various input parameters

S.N.	Types of parameters	Level 1	Level 2	Level 3	Level 4
1	Core Materials	Concrete	Polypropylene (PP)	High-Density Polyethylene (HDPE)	Polycarbonate (PC)
2	IP Material	Steel X-60	Steel X-65	AL 1060	Steel X-56
3	OP Diameter	323.9	355.6	-	-
4	IP Thickness	13.3	15.1	-	-
5	OP Thickness	26.6	27.7	-	-
6	OP Material	Steel X-60	AL 1060	-	-

The three structural layers of inner, outer and core layers have six input parameters with different sandwich pipe levels (Table I) are considered for the structural deformation analysis. These parameters are considered as the primary materials and pipe sizes used for deep water applications such as core materials, inner pipe (IP) material, outer pipe (OP) diameter, outer pipe thickness, inner pipe thickness and outer pipe materials. The primary two parameters are considered with four levels and the last two parameters are two levels. Here, we considered the orthogonal array of L16 for the above. Numerical simulation is performed using Ansys for all 16 combinations for deformation (water depth 1500 m and fluid pressure within the pipe is 12 Mpa). Taguchi analysis is performed using software from Minitab.

Taguchi approach: The Taguchi designing support the L16 orthogonal array for mixed-level combination (conductor & insulator) for the optimum deformation (mm) is as shown in table II. It includes various inner material layers (X60, X65, AL1060 and X56), outer layer (X60 and AL1060) and core material (concrete, polypropylene, HDPE, polycarbonate). The various types of annulus materials have been filled among the sandwich pipes. The selection of the annulus materials must provide better insulation due to their wide availability and low-cost like cement, polypropylene etc (Estefen et al, 2005; Wan et al, 2021).

3. RESULTS AND DISCUSSION

The modeling of the pipe is done using 3D experience (Catia) Software with the following steps. For the preparation of outer/inner/core pipe, the plane, position of the sandwich pipe, two symmetrical circles, diameters and length of the cylinder as shows in figure 2.

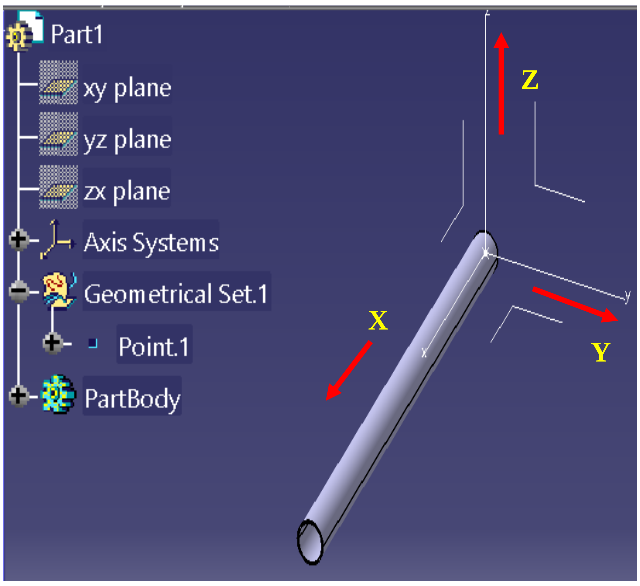

Figure 2. Simulation of outer pipe, core and inner pipe.

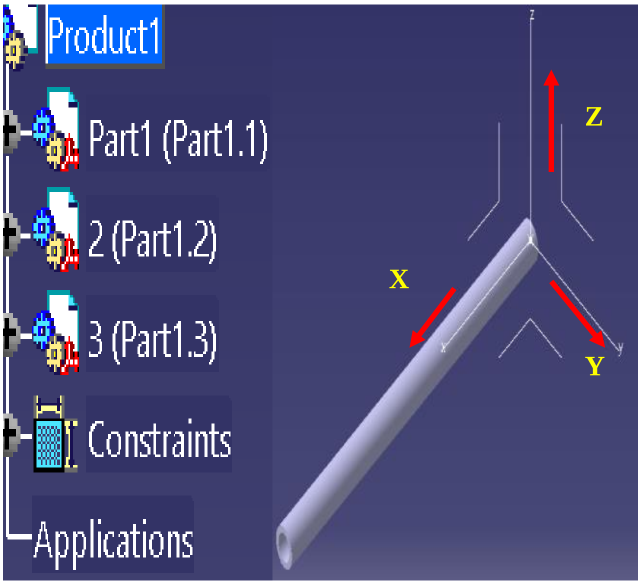

Figure 3. The Assembly of sandwich pipe.

Figure 3 depicts the structural analysis (deformation) was carried out using Taguchi analysis (Ansys). Here, the both ends of the sandwich pipe is fixed as a boundary conditions and applied external pressure 14 Mpa on the sandwich pipe's outer surface area and fluid pressure of the inside the pipe is considered as 12 Mpa by using Hydraulic pressure. Further, the deformation of various combination of sandwich pipe structures are tabulated (Table-III).

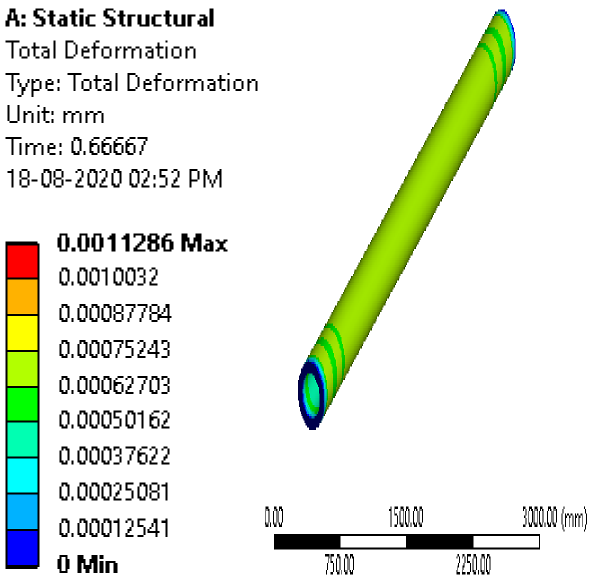

Figure 4. The deformation of sandwich pipes using Ansys.

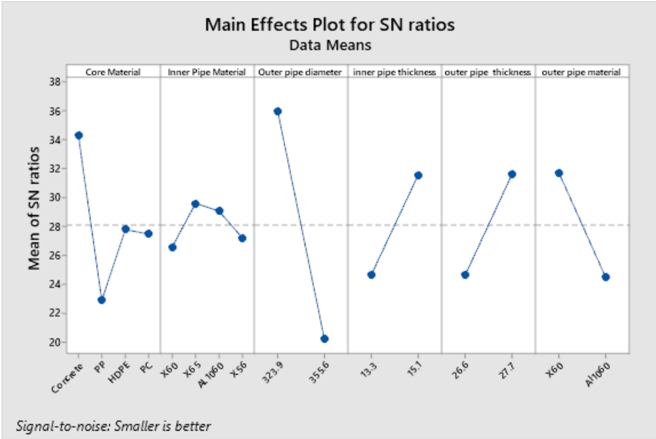

Figure 5. S-N ratio curves of optimum sandwich pipe structures.

Among these pipes, two steel pipes (X60) used as inner/outer pipes and polypropylene (core) as annulus (core) materials showed lowest deformation results. Next, PP core material, steel (X56) and aluminium (AL1060) integrated sandwich pipe structure showed the highest deformation results. The optimum combination of PP core material, steel X-60 as inner pipe material with the thickness 15.1 and the outer pipe materials which was considered as steel X-60 with its diameter 323.9 and thickness 27.7.

Table 2. The list of orthogonal array and various input parameters.

Combination No.	Materials			Thickness (mm)		OP Diameter (mm)	Deformation (mm)
	Core	IP	OP	IP	OP		
PIP. 01	Concrete	X60	X60	13.3	26.6	323.9	0.01729
PIP. 02	Concrete	X65	Al1060	13.3	26.6	323.9	0.01732
PIP. 03	Concrete	AL1060	X60	15.1	27.7	355.6	0.01733
PIP. 04	Concrete	X56	Al1060	15.1	27.7	355.6	0.02667
PIP. 05	PP	X60	X60	15.1	27.7	323.9	0.01018
PIP. 06	PP	X65	Al1060	15.1	27.7	323.9	0.0166

PIP. 07	PP	AL1060	X60	13.3	26.6	355.6	0.13556
PIP. 08	PP	X56	Al1060	13.3	26.6	355.6	1.17035
PIP. 09	HDPE	X60	Al1060	13.3	27.7	355.6	0.16294
PIP. 10	HDPE	X65	X60	13.3	27.7	355.6	0.06339
PIP. 11	HDPE	AL1060	Al1060	15.1	26.6	323.9	0.02534
PIP. 12	HDPE	X56	X60	15.1	26.6	323.9	0.01069
PIP. 13	PC	X60	Al1060	15.1	26.6	355.6	0.17035
PIP. 14	PC	X65	X60	15.1	26.6	355.6	0.06627
PIP. 15	PC	AL1060	Al1060	13.3	27.7	323.9	0.02599
PIP. 16	PC	X56	X60	13.3	27.7	323.9	0.01093

Taguchi analysis is used for the selection of optimum sandwich pipe structures by using Minitab. The lowest value considered as better sandwich pipe. With the addition of optimum combination (or input) parameters are enable to determine the S-N ratio values as shows in figure 5 (Raju et al, 2020).

4. CONCLUSIONS

In this paper, we have presented the numerical investigation for the development of different sandwich pipe structures and studied their structural analysis by using ANSYS (Taguchi) techniques. The optimum combination consists of polypropylene as core material, steel X-60 inner pipe with the thickness of 15.1 mm and the outer pipe material of steel X-60 with diameter 27.7 mm. This optimized sandwich pipe structures are enabled with the lowest deformation (0.01018 mm) results.

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